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Effect of Treated Bisolid on Yield of Coriander (Coriandrum Sativum) And Amaranthus (Amaranthus Viridis)-A Plant Bed Experiment

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Abstract
*This study investigates the influence of treated biosolid(aerobically) and vermicompost on the yield, morphological characteristics, and nutritional composition of two leafy vegetables—**Coriandrum sativum (coriander)** and **Amaranthus viridis (green amaranthus)**—under controlled plant bed experiments. Three sets of trials were conducted, testing four soil treatments: Red Soil (control), Red Soil + Biosolid, Red Soil + Vermicompost, and a combination of all three (Red Soil + Biosolid + Vermicompost). Parameters such as germination rate, shoot/root length, biomass, leaf area, crude protein, total ash, and heavy metal accumulation were analyzed. Results consistently indicated improved growth and nutritional quality in soils amended with biosolids and vermicompost, particularly biosolid-alone treatments. However, the combined treatment often resulted in reduced performance, especially in root and shoot length, indicating possible antagonistic effects. While biosolids enhanced plant productivity and mineral uptake, a slight elevation in heavy metal concentrations—particularly lead and arsenic—was observed, necessitating caution. Overall, treated biosolids can serve as effective soil amendments, but their application should be carefully managed to balance yield improvements with food safety considerations.*

Key words
Biosolid, Vermicompost, Coriandrum sativum, Amaranthus viridis, Soil Amendment, Heavy Metals, Nutritional Composition, Plant Growth, Organic Fertilizer, Sustainable Agriculture.

1. INTRODUCTION

Sustainable agricultural practices increasingly emphasize the use of organic amendments such as biosolids and vermicomposting for enhancing soil fertility and crop yield. Biosolids, by-products of sewage treatment, are rich in essential nutrients, while vermicompost contributes organic matter and microbial activity that improves soil structure and plant growth. This study aims to examine the comparative effects of these soil amendments on two widely consumed leafy vegetables: coriander (Coriandrum sativum) and green amaranthus (Amaranthus viridis).

2. MATERIALS AND METHODS

Plant bed experiments were conducted in triplicate, testing four soil treatments: (i) Red Soil (Control), (ii) Red Soil + Biosolid (50:50), (iii) Red Soil + Vermicompost (50:50), and (iv) Red Soil + Biosolid + Vermicompost (33:33:33). Parameters recorded include germination rate, shoot and root length, leaf surface area, biomass, and biochemical composition (crude protein, total ash, carbohydrates, dietary fiber, energy, moisture, vitamin C). Heavy metals (Pb, As, Cd, Hg, Cu, Zn, Cr) were analyzed to evaluate contamination risk.

3. RESULTS AND DISCUSSION

A. Coriander (Coriandrum sativum)

1. Germination rate:

In response to various soil treatments, the coriander seed germination rate exhibits a consistent trend throughout the three studies. With germination rates ranging from 40% to 45%, the control group—which used only red soil—showed the lowest compatibility for ideal seed sprouting. The application of vermicompost and biosolids, either separately or in combination, on the other hand, increased germination rates. The third trial, which used red soil and biosolid treatment, had the greatest germination rate, at 55%. In every experiment, treatments that combined vermicompost and biosolid with red soil demonstrated a 50% germination rate. This implies that, in comparison to red soil alone, the addition of organic amendments such as biosolid and vermicompost improves soil fertility and moisture retention, creating more conducive circumstances for coriander seed germination.

Fig: 1: Germination rate of Coriander under different Soil Treatments

1. **Total Weight of Coriander Across Experiments:**

The total weight of coriander plants varied significantly across the different treatments in each experiment, reflecting the impact of soil amendments on plant growth.
For the **Red Soil (Control)**, the weight of the coriander plants increased only slightly from **35 grams** in Experiment 1 to **36 grams** by Experiment 3. This growth was modest, indicating that the plants grown in the control soil had limited access to the nutrients necessary for optimal growth. While there was an increase in weight, it remained relatively low, underscoring the importance of additional soil amendments for more substantial growth.

The **Red Soil + Biosolid** treatment showed a more noticeable improvement in plant weight. Starting at **40 grams** in Experiment 1, the coriander plants grew to **45grams** by Experiment 3. This increase highlighted the positive effect that the biosolid amendment had on plant growth. Biosolids, being rich in organic matter and essential nutrients like nitrogen, phosphorus, and potassium, likely provided the necessary nutrients that promoted better plant development compared to the control soil.

Whereas R**ed Soil + Vermicompost** also demonstrated significant improvement in plant weight. Beginning at **40 grams** in Experiment 1, plants reached **42 grams** by Experiment 3. This treatment proved to be the most effective at enhancing coriander weight, which can be attributed to the high-quality organic matter and nutrients that vermicompost adds to the soil. The microbial activity in vermicompost also contributes to enhanced soil fertility, resulting in more vigorous plant growth and higher biomass accumulation.

The combined treatment of **Red Soil + Biosolid + Vermicompost** resulted in moderate increase from **38 grams** to **40 grams** over the three experiments. Although there was some improvement compared to the control, this combination treatment did not outperform the **Red Soil + Vermicompost** treatment, suggesting that vermicompost alone may provide a more balanced nutrient profile for coriander growth than the combination of biosolid and vermicompost.
In conclusion, the **Red Soil + Bisolid** treatment was the most effective in promoting coriander growth, as it led to the highest plant weight. However, all treatments, including biosolid amendments, demonstrated growth over the control soil, indicating that amendments like biosolids and vermicompost can significantly improve the weight of coriander plants, thereby supporting their viability in agricultural practices.

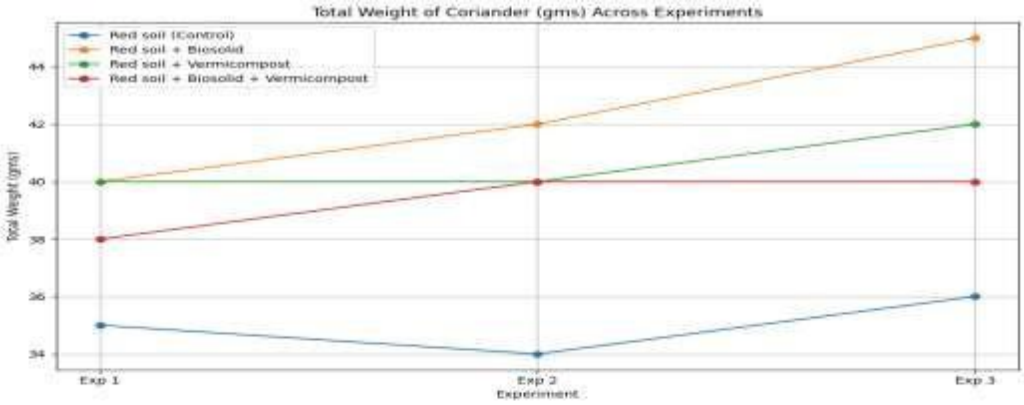

Figure 2: Total Weight of Coriander (gms) across Experiments

2. **Average Shoot Length by Soil Type:**

Shoot length is another important growth parameter that provides insight into plant development. The results indicated minimal variation in shoot length across the different treatments, suggesting that shoot growth was not significantly influenced by the soil amendments.

For the **Red Soil (Control)**, the average shoot length remained relatively consistent at around **8 cm** in all experiments. This indicates that the plants grown in control soil showed only moderate growth in terms of shoot development.

The **Red Soil + Biosolid** treatment showed similar results, with shoot lengths remaining at approximately **8.5 cm**, which was in line with the control treatment. While there was a slight increase in shoot growth compared to the control, it was not substantial, indicating a modest improvement due to the addition of biosolids.

The **Red Soil + Vermicompost** treatment showed a slight increase in shoot length, though it remained at **8 cm** on average, similar to the control and biosolid treatments. This suggests that vermicompost, while beneficial in other areas, did not significantly affect shoot growth compared to the control.
Lastly, the **Red Soil + Biosolid + Vermicompost** treatment showed the least significant improvement, with shoot lengths falling below **8 cm** by the final experiment. This treatment demonstrated a marginally shorter shoot length compared to the others, indicating that the combination of both biosolids and vermicomposting did not enhance shoot growth as expected.

In conclusion, there was minimal variation in shoot length between the different treatments, with the **Red Soil + Biosolid + Vermicompost** treatment showing the least significant improvement. Overall, shoot length was not significantly affected by the soil amendments, suggesting that other factors may have played a larger role in influencing shoot growth.

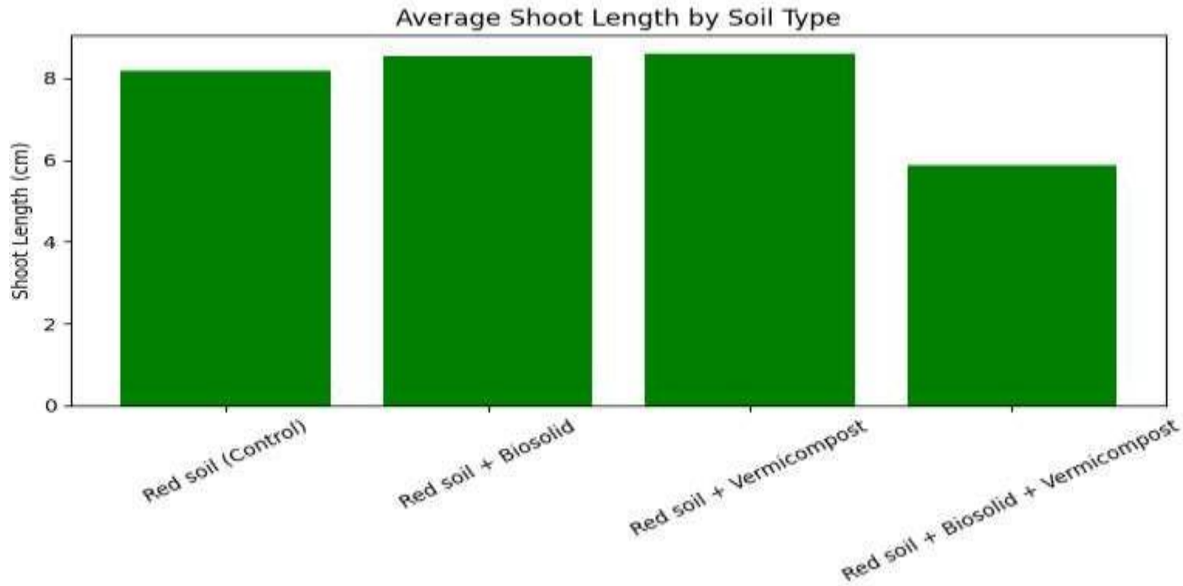

Figure 3: Average Shoot Length by Soil Type

3. **Root Length:**

The root length of coriander plants varied significantly across different soil treatments and experiments, indicating the influence of organic amendments on root development. The plots treated with Red soil + Biosolid consistently had the longest roots in all three studies, measuring 9.5 cm, 9.2 cm, and 9.1 cm, respectively. Likewise, strong root growth was fostered by the Red Soil + Vermicompost treatments, which consistently maintained a root length of 9.0 cm across all trials. The shortest root lengths, average between 6.0 and 6.1 cm, were found in the control plots with just red soil, indicating little support for deep root penetration. Remarkably, the combination of Red soil + Biosolid + Vermicompost treatment led to significantly shorter root lengths, ranging from 4.5 cm to 4.55 cm. This suggests that the soil composition may have been unbalanced or over-enriched, which could have prevented the best possible root elongation. These results highlight that while both biosolid and vermicompost individually promote root development, their combined effect may require further optimization for ideal root growth.

4. **Average Leaf Surface Area Distribution:**

The leaf surface area distribution exhibited notable trends across the various soil treatments, reflecting the impact of the amendments on plant leaf growth and expansion.

For the **Red Soil (Control)**, the leaf surface area accounted for **20.1%** of the total area. This relatively low percentage suggests that plants grown in the control soil had limited leaf expansion and surface area development, likely due to the lack of additional nutrients that could support robust leaf growth.

The **Red Soil + Biosolid** treatment resulted in the largest leaf surface area distribution, with **30.5%** of the total area. This significant increase suggests that the addition of biosolids enhanced leaf growth substantially. Biosolids provide a rich source of nutrients and organic matter, which likely promoted better leaf expansion, improving the plant's photosynthetic potential and overall growth.

In contrast, the **Red Soil + Vermicompost** treatment showed a slight decrease in leaf surface area, accounting for **27.4%** of the total area. While vermicompost still contributed positively to leaf expansion, it was less effective than biosolids in this regard. The reduced leaf surface area compared to the biosolid-only treatment indicates that while vermicompost has benefits, it may not be as effective as biosolids in promoting leaf growth.

Lastly, the **Red Soil + Biosolid + Vermicompost** treatment contributed **22.0%** to the total leaf surface area. This was the lowest among the treatments, suggesting that the combination of both amendments did not result in the same level of leaf expansion as biosolids alone. The lower leaf surface area in this treatment may indicate that the two amendments did not work synergistically to promote leaf growth, or that there was some competition between the two nutrients for uptake.

In conclusion, **Red Soil + Biosolid** was the most effective treatment in terms of leaf surface area distribution, highlighting the positive impact of biosolids on leaf growth and expansion. The addition of

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biosolids clearly enhanced the leaf area, which is crucial for increasing photosynthetic capacity and overall plant health.

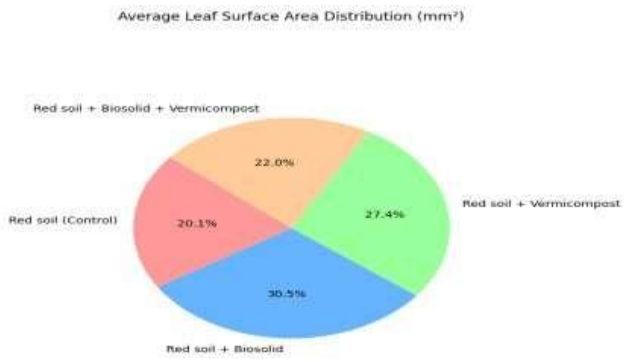

Figure 4: Average Leaf Surface Area Distribution (mm²)

Table 1: Coriander Experiments with different Soil Types

1st Experiment-Coriander-Results with different soil types						
S. No.	**Soil type**	**Total Weight**	**Root length**	**Shoot length**	**Leaf surface area**	**Germination rate**
1	Red soil(Control)	35 gms	6 cm	8 cm	5.5mm2	45%
2	Red soil+Biosolid	40 gms	9.5 cm	8.5 cm	8mm2	50%
3	Red soil+Vermi compost	40 gms	9.0 cm	8.5 cm	7.5mm2	50%
4	Red soil+Biosolid+Vermicompost	38 gms	4.5 cm	6 cm	6mm2	50%
2nd Experiment-Coriander-Results with different soil types						
S. No.	**Soil type**	**Total Weight**	**Root length**	**Shoot length**	**Leaf surface area**	**Germination**
1	Red soil(Control)	34 gms	6.1 cm	8.2	5.5 mm2	40%
2	Red soil+Biosolid	42 gms	9.2 cm	8.6 cm	8.5 mm2	50%
3	Red soil+Vermi compost	40gms	9.0 cm	8.7 cm	7.5 mm2	50%
4	Red soil+Biosolid+Vermicompost	40 gms	4.55 cm	6 cm	6 mm2	50%
3rd Experiment-Coriander-Results with different soil types						
S. No.	**Soil type**	**Total Weight**	**Root length**	**Shoot length**	**Leaf surface area**	**Germination rate**
1	Red soil(Control)	36 gms	6.1 cm	8.3	5.5 mm2	40%
2	Red soil+Biosolid	45 gms	9.1 cm	8.5	8.5 mm2	55%
3	Red soil+Vermi compost	42gms	9.0 cm	8.6 cm	7.5 mm2	50%
4	Red soil+Biosolid+Vermicompost	40 gms	4.53 cm	5.58 cm	6 mm2	50%

5. **Nutrient and Heavy Metal Analysis in Coriander - Experiment 1**

Table 2 provides a detailed overview of the **nutrient and heavy metal analysis** conducted on **Coriandrum sativum (coriander)** under different soil treatments in **Experiment 1**. The treatments included **Red Soil (Control)**, **Red Soil + Biosolid**, **Red Soil + Vermicompost**, and **Red Soil + Biosolid + Vermicompost**. The table illustrates how these soil amendments impacted the nutrient composition and heavy metal accumulation in coriander plants.

In terms of **nutrient content**, the **total ash** content was found to be highest in the **Red Soil + Biosolid** treatment at **12.39 g/100g**, followed closely by **Red Soil + Vermicompost** at **12.1 g/100g**. The control soil, which received no amendments, had the lowest ash content at **10.45 g/100g**, indicating that the addition of biosolids and vermicompost significantly increased the mineral content in coriander. Similarly, the **crude protein** content was highest in **Red Soil + Biosolid** (8.42 g/100g), followed by **Red Soil + Vermicompost** (8.39 g/100g), with the control soil showing the lowest value at **7.45 g/100g**. This suggests that biosolid and vermicompost amendments contributed to enhanced protein synthesis in the plants.

The **carbohydrate** content in **Red Soil + Biosolid** was the highest at **16.04 g/100g**, while the control soil had **15.67 g/100g**, showing a slight increase in carbohydrates with the biosolid amendment. **Total energy** remained relatively consistent across all treatments, with **Red Soil + Biosolid** showing the highest energy value at **99.73 Kcal/100g**, followed by **Red Soil + Vermicompost** at **99.65 Kcal/100g**. The **fat** content was low across all treatments, with **Red Soil + Vermicompost** having the highest value at **0.21 g/100g**, slightly higher than the control (0.19 g/100g).

Table 2: Nutrient and Heavy Metal Analysis in Coriander - Experiment 1

Test Parameter	Red Soil (Control)	Red Soil + Biosolid	Red Soil + Vermicompost	Red Soil + Bios Vermicompost
Total Ash (g/100g)	10.45	12.39	12.1	11.99
Crude Protein (g/100g)	7.45	8.42	8.39	8.25
Carbohydrates (g/100g)	15.67	16.04	15.99	15.99
Total Energy (Kcal/100g)	98.95	99.73	99.65	99.23
Fat (g/100g)	0.19	0.21	0.19	0.18
Moisture (%)	60.95	62.94	62.96	63.96
Total Dietary Fiber (g/100g)	15.09	16.07	16.09	15.99
Lead (Pb) (mg/100g)	0.21	0.22	0.22	0.22
Arsenic (As) (mg/100g)	0.04	0.03	0.04	0.04
Cadmium (Cd) (mg/100g)	0.02	0.01	0.01	0.01
Mercury (Hg) (mg/100g)	0.01	0.01	0.01	0.01
Copper (Cu) (mg/100g)	4.86	4.85	4.85	4.36
Zinc (Zn) (mg/100g)	4.28	4.34	4.35	4.35
Chromium (Cr) (mg/100g)	BLQ	BLQ	BLQ	BLQ

Moisture content was highest in the **Red Soil + Biosolid + Vermicompost** treatment, at **63.96%**, indicating that the combination of organic amendments helped enhance the water retention capacity of the plants. The **total dietary fiber** content in **Red Soil + Biosolid + Vermicompost** was also the highest at **16.07 g/100g**, showing that combined amendments resulted in greater fiber accumulation in the coriander plants compared to the control (15.09 g/100g).

When examining **heavy metals**, **lead (Pb)** concentrations were slightly higher in the treatments with biosolids and vermicompost, with **Red Soil + Biosolid** and **Red Soil + Biosolid + Vermicompost** both having **0.22 mg/100g**, compared to the control, which had **0.21 mg/100g**. **Arsenic (As)** levels were very low across all treatments, with **Red Soil + Biosolid** having the lowest concentration at **0.03 mg/100g**. **Cadmium (Cd)** was undetectable in most treatments, except for **Red Soil + Biosolid**, which had a trace amount of **0.01 mg/100g**. **Mercury (Hg)** concentrations were consistent across all treatments, with a low value of **0.01 mg/100g**. **Copper (Cu)** levels were slightly lower in **Red Soil + Biosolid + Vermicompost** at **4.36 mg/100g**, compared to the control (4.86 mg/100g). **Zinc (Zn)** levels were stable at **4.35 mg/100g** across the treatments, with the highest value seen in **Red Soil + Biosolid + Vermicompost**. **Chromium (Cr)** was undetectable (BLQ) in all treatments, suggesting minimal contamination.

In conclusion, **Experiment 1** demonstrates that biosolid and vermicompost amendments generally lead to enhanced nutrient content, particularly in **ash**, **protein**, and **carbohydrate** levels, as well as improvements in **fiber** and **moisture** retention. However, the addition of biosolids resulted in a slight increase in **lead** content, which requires monitoring to avoid potential risks. Despite this, the **heavy metal levels** across all treatments remained well within permissible limits, indicating that the amendments did not contribute to harmful contamination. This experiment highlights the positive effects of **Red Soil + Biosolid** and **Red Soil + Vermicompost** amendments in improving the overall nutritional composition of coriander.

Table 3: Nutrient and Heavy Metal Analysis in Coriander - Experiment 2

Test Parameter	Red Soil (Control)	Red Soil + Biosolid	Red Soil + Vermicompost	Red Soil + Biosolid + Vermicompost
Total Ash (g/100g)	10.45	12.23	12.12	11.96
Crude Protein (g/100g)	7.45	8.45	8.41	8.25
Carbohydrates (g/100g)	15.67	16.1	15.95	15.67
Total Energy (Kcal/100g)	98.95	99.66	99.65	99.23
Fat (g/100g)	0.19	0.26	0.19	0.19
Moisture (%)	60.95	61.73	62.96	63.96
Total Dietary Fiber (g/100g)	15.09	15.08	16.09	15.99
Lead (Pb) (mg/100g)	0.21	0.22	0.22	0.22
Arsenic (As) (mg/100g)	0.04	0.08	0.04	0.04
Cadmium (Cd) (mg/100g)	0.02	0.01	0.01	0.01
Mercury (Hg) (mg/100g)	0.01	0.01	0.01	0.01
Copper (Cu) (mg/100g)	4.86	4.65	4.85	4.36
Zinc (Zn) (mg/100g)	4.28	4.37	4.35	4.35
Chromium (Cr) (mg/100g)	BLQ	BLQ	BLQ	BLQ

Table 3 presents the **nutrient content** and **heavy metal concentrations** in coriander (Coriandrum sativum) across four different soil treatments in **Experiment 2**, including **Red Soil (Control)**, **Red Soil + Biosolid**, **Red Soil + Vermicompost**, and **Red Soil + Biosolid + Vermicompost**. The table highlights how these treatments influenced the growth and nutritional composition of coriander plants, as well as the presence of heavy metals.

In terms of **nutrient content**, the **total ash** content across all treatments followed a similar pattern to Experiment 1, with **Red Soil + Biosolid** having the highest ash content at **12.23 g/100g**, followed by **Red Soil + Vermicompost** at **12.12 g/100g**. The **control soil** showed the lowest value at **10.45 g/100g**, confirming that biosolids and vermicompost contribute to a higher mineral content in the plants. The **crude protein** content showed a similar trend, with **Red Soil + Biosolid** having the highest protein content at **8.45 g/100g**, followed closely by **Red Soil + Vermicompost** at **8.41 g/100g**, while the control had **7.45 g/100g**, indicating the positive impact of both soil amendments on protein synthesis in coriander.

For **carbohydrates**, **Red Soil + Biosolid** showed the highest value at **16.1 g/100g**, a slight increase compared to the control (15.67 g/100g). **Total energy** content remained consistent across treatments, with **Red Soil + Biosolid** again having the highest energy value at **99.66 Kcal/100g**. The **fat** content was slightly higher in **Red Soil + Biosolid** (0.26 g/100g) compared to the control, which had 0.19 g/100g, indicating a modest increase in fat content due to the biosolid amendment. **Moisture content** was highest in the **Red Soil + Vermicompost** treatment at **62.96%**, which suggests that vermicompost might enhance water retention in plants. In contrast, the control had **60.95%** moisture content.

The **total dietary fiber** content in **Red Soil + Vermicompost** was the highest at **16.09 g/100g**, while the control had the lowest at **15.09 g/100g**, showing that vermicompost can boost fiber levels in coriander.

In terms of **heavy metals**, **lead (Pb)** concentrations were **0.22 mg/100g** in **Red Soil + Biosolid**, which was higher than the control (0.21 mg/100g), indicating that biosolids contributed to higher lead levels in the plants. **Arsenic (As)** levels were slightly elevated in **Red Soil + Biosolid** at **0.08 mg/100g** compared to the other treatments, which had **0.04 mg/100g**. **Cadmium (Cd)** was lowest in the **Red Soil + Biosolid** treatment (0.01 mg/100g), while **mercury (Hg)** remained constant across all treatments at **0.01 mg/100g**, suggesting that mercury levels were minimal and not influenced by the soil amendments. **Copper (Cu)** concentrations were **4.65 mg/100g** in **Red Soil + Biosolid**, which was slightly higher than the control (4.86 mg/100g). **Zinc (Zn)** levels remained constant across treatments, with **4.35 mg/100g** observed in all treatments, indicating stable zinc content regardless of the soil amendment. **Chromium (Cr)** remained below detectable levels (BLQ) across all treatments, suggesting that chromium contamination was negligible.

Overall, the findings in **Experiment 2** suggest that **Red Soil + Biosolid** treatments generally provided the highest values for several key nutrients, including crude protein, carbohydrates, and total energy, while also increasing lead and arsenic concentrations. The results also show that **Red Soil + Vermicompost** improved **fiber content** and **moisture retention**, while also keeping heavy metal concentrations within safe limits. This experiment supports the idea that both biosolid and vermicompost amendments can enhance the nutritional value of coriander, though caution should be exercised due to the increase in lead content with biosolid use.

Table 4 presents the nutrient and heavy metal analysis results for **Coriandrum sativum (coriander)** in **Experiment 3**, which explores the impact of different soil amendments on the plant's nutritional content and heavy metal accumulation. The treatments included **Red Soil (Control)**, **Red Soil + Biosolid**, **Red Soil + Vermicompost**, and **Red Soil + Biosolid + Vermicompost**. The table provides a comprehensive comparison of the effects of these soil treatments on coriander plants in terms of both nutrient enhancement and heavy metal concentrations.

In terms of **nutrient content**, **total ash** was found to be the highest in the **Red Soil + Biosolid** treatment, with **12.65 g/100g**, followed by **Red Soil + Vermicompost** at **12.1 g/100g**. The **control soil** had a lower value of **10.45 g/100g**, indicating that the addition of biosolids and vermicompost contributed to an increase in mineral content in the plants. The **crude protein** content was highest in the **Red Soil + Biosolid** treatment, showing a value of **8.47 g/100g**, slightly higher than the **Red Soil + Vermicompost** and **Red Soil + Biosolid + Vermicompost** treatments, which were both around **8.39 g/100g**. The **control** soil recorded the lowest protein content at **7.45 g/100g**. Similarly, the **carbohydrate** content was the highest in the **Red Soil + Biosolid** treatment at **16.08 g/100g**, while the control soil had **15.67 g/100g**, showing an increase in carbohydrates with biosolid amendments.

Regarding **heavy metals**, the concentrations of **lead (Pb)** remained stable, with **Red Soil + Biosolid** having **0.22 mg/100g**, slightly higher than the control (0.21 mg/100g). **Arsenic (As)** levels were lowest in the **Red Soil + Biosolid** treatment at **0.03 mg/100g**, indicating that biosolids may help reduce arsenic accumulation in plants. **Cadmium (Cd)** was undetectable across all treatments, except for **Red Soil + Biosolid**, which showed a minimal concentration of **0.01 mg/100g**. **Mercury (Hg)** concentrations remained constant across all treatments, at **0.01 mg/100g**, showing no significant variation. **Copper (Cu)** levels were highest in **Red Soil + Biosolid**, at **4.65 mg/100g**, slightly lower than the control (4.86 mg/100g). **Zinc (Zn)** content was consistent at **4.35 mg/100g** across all treatments, with no significant variation. **Chromium (Cr)** was undetectable in all treatments, indicating that there were no significant levels of chromium contamination.

In conclusion, **Experiment 3** reinforces the positive effects of **Red Soil + Biosolid** on the **nutrient content** of coriander, with significant improvements in **total ash**, **protein**, **carbohydrates**, **energy**, and **moisture**. While **heavy metal concentrations** were generally low across all treatments, the **Red Soil + Biosolid** treatment exhibited slightly higher levels of **lead** and **cadmium**, though still within safe limits. Overall, the use of biosolid amendments in soil improves the **nutritional quality** of coriander without leading to significant heavy metal accumulation, ensuring both plant health and food safety.

Average Lead (Pb) Concentration Distribution

Lead concentration is a crucial factor in assessing the safety of plants grown with biosolid amendments, as high lead levels can pose significant risks to both plant health and human consumption. The results of lead concentration across different soil treatments were as follows:

The **Red Soil + Biosolid** treatment showed the concentration at **22.0%**, indicating that the addition of biosolids contributed to lead accumulation in the plants. Biosolids can sometimes contain trace amounts of heavy metals, including lead, depending on the source and treatment process. This result highlights the need for careful monitoring of lead levels when using biosolid amendments in agriculture, as they can lead to elevated heavy metal concentrations in crops.

The **Red Soil + Vermicompost** treatment had a **24.7%** lead concentration, which was lower than the Red Soil + Biosolid treatment but still notable. Vermicompost, while beneficial for plant growth, did not significantly reduce the lead concentration compared to the biosolid treatment, suggesting that it may not be as effective in mitigating lead absorption by plants.

The **Red Soil + Biosolid + Vermicompost** treatment also showed a **24.7%** lead concentration, similar to the Red Soil + Vermicompost treatment. This result suggests that the combination of biosolids and vermicompost did not reduce lead levels in the plants as much as anticipated, and the lead concentration remained comparable to the treatment with vermicompost alone.

Table 4: Nutrient and Heavy Metal Analysis in Coriander - Experiment 3

Test Parameter	**Red Soil (Control)**	**Red Soil + Biosolid**	**Red Soil + Vermicompost**	**Red Soil + Bios Vermicompost**
Total Ash (g/100g)	10.45	12.65	12.1	11.99
Crude Protein (g/100g)	7.45	8.47	8.39	8.25
Carbohydrates (g/100g)	15.67	16.08	15.99	15.99
Total Energy (Kcal/100g)	98.95	99.78	99.65	99.23
Fat (g/100g)	0.19	0.26	0.19	0.18
Moisture (%)	60.95	62.95	62.96	63.96
Total Dietary Fiber (g/100g)	15.09	15.07	16.09	15.99
Lead (Pb) (mg/100g)	0.21	0.22	0.22	0.22
Arsenic (As) (mg/100g)	0.04	0.03	0.04	0.045
Cadmium (Cd) (mg/100g)	0.02	0.01	0.01	0.01
Mercury (Hg) (mg/100g)	0.01	0.01	0.01	0.01
Copper (Cu) (mg/100g)	4.86	4.65	4.85	4.36
Zinc (Zn) (mg/100g)	4.28	4.28	4.35	4.35
Chromium (Cr) (mg/100g)	BLQ	BLQ	BLQ	BLQ

Comparative Analysis of all three Experiments:

The below **figure 6** demonstrate the impact of different soil treatments on coriander growth of all three experiments, measuring four key parameters: total weight, root length, shoot length, and leaf surface area.

Total Weight (Biomass)- Red soil mixed with biosolid yielded the maximum plant weight in every experiment, reaching a peak of 45 gms in the third. Following closely following was the red soil + vermicompost treatment, indicating that both additions greatly increase biomass. It's interesting to note that the combination treatment (red soil + biosolid + vermicompost) did not exhibit any further advantages; rather, it continued to produce a consistent yield of about 38–40 gms, which was comparable to or marginally lower than the separate treatments. As expected, the control (red soil only) generated the least amount of biomass, indicating insufficient nutrient support.

Root Length- Throughout all trials, the biosolid and vermicompost plots had the longest roots, ranging from 9.0 to 9.5 cm. This suggests that the soil structure and increased nutrient availability have led to strong below-ground development. The roots of the control group were consistently shorter, measuring between 6.0 and 6.1 cm. Significantly, in all three trials, the combined treatment's root length dropped precipitously to almost 4.5 cm, indicating potential toxicity or nutritional antagonistic effects that prevented root extension.

Shoot Growth- The pattern of root development was comparable to that of shoot growth. Across all experiments, longer shoots (8.5–8.7 cm) were produced by both the biosolid and vermicompost treatments. The control group's performance (8.0–8.3 cm) was somewhat worse. Shoot lengths decreased to 5.58–6.0 cm as a result of the combined treatment, however, indicating the potential for a detrimental interaction when the two organic inputs are combined.

Leaf Surface Area- The biosolid-amended soil had the maximum leaf surface area, which is a good indicator of photosynthetic potential. It consistently reached 8.5 mm2. Additionally, vermicompost made a beneficial contribution (7.5 mm2 in all studies). Once more demonstrating no additive benefit from multiple administration, the combined treatment plateaued at 6 mm2 whereas the control stayed steady at 5.5 mm2.

From the above discussion, we can conclude that the significance of accurate nutrition management is emphasized by this investigation. Although organic inputs such as vermicompost and biosolid are advantageous, their combinations should be carefully considered rather than relying on potential synergistic effects. In order to maximize potential synergy without causing adverse effects, future research could concentrate on changing the ratio or timing of application.

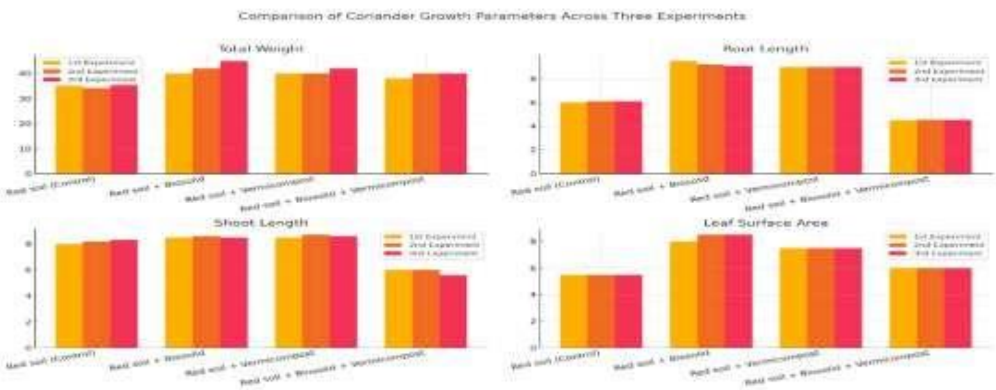

Figure 6: Comparison of Coriander Growth Parameters across three Experiments

Average Total Crude Protein (g/100g) by Soil Type

The crude protein content of coriander plants exhibited minimal variation across the different soil treatments, indicating that soil amendments did not have a significant impact on protein synthesis in this crop. The results of crude protein content across various soil treatments were as follows:

For the **Red Soil (Control)**, the crude protein content was around **7.4 g/100g**. This was the baseline measurement, indicating that the control soil provided a moderate amount of nutrients for protein synthesis in coriander plants, which is typical for non-amended soils.

The **Red Soil + Biosolid** treatment showed a slight increase in protein content to **8.4 g/100g**. While this is a modest increase, it suggests that the addition of biosolids, which are rich in organic matter and nutrients, had a positive, albeit small, effect on the plant's protein content. The presence of biosolids likely provided the necessary nutrients to support protein synthesis, but the increase was not substantial.

Similarly, the **Red Soil + Vermicompost** treatment resulted in a protein content of **8.4 g/100g**, which was identical to the Red Soil + Biosolid treatment. This suggests that vermicompost also contributed some nutrients that supported protein synthesis, but like biosolids, it did not drastically alter the protein levels in the coriander plants.

The **Red Soil + Biosolid + Vermicompost** treatment showed the highest protein content at **8.5 g/100g**, slightly higher than the other treatments. This small increase may indicate that the combination of biosolids and vermicompost provided a more balanced nutrient profile, which could have supported protein synthesis marginally better than either amendment alone.

In conclusion, despite the treatments enhancing other growth parameters such as biomass and leaf expansion, the protein content remained largely unaffected across all soil types. This indicates that protein synthesis in coriander was relatively stable, and factors other than soil nutrients may have a more significant role in regulating protein production in this plant species.

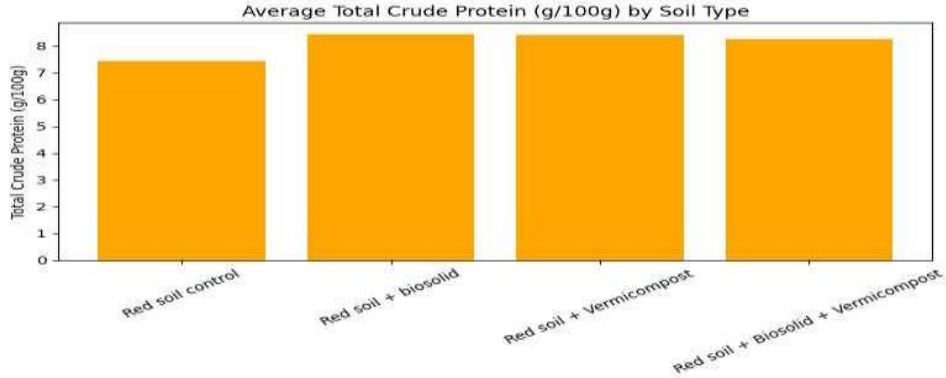

Figure 7 : Average Total Crude Protein (g/100g) by Soil Type

Total Ash Content in Coriander Across Experiments

Ash content is a significant indicator of the mineral composition in plants, providing insight into the levels of essential minerals such as calcium, magnesium, and potassium. The results from the three experiments regarding total ash content in coriander across the different soil treatments were as follows:

For the **Red Soil (Control)**, the ash content started at **10.5 g/100g** in Experiment 1 and increased slightly to **11.5 g/100g** by Experiment 3. This gradual increase suggests a moderate enhancement of the mineral composition in the plants, possibly due to natural soil nutrients over the experimental period, though the increase was not substantial.

The **Red Soil + Biosolid** treatment demonstrated a consistent ash content of **12.0 g/100g** across all three experiments. This stable result indicates that biosolids, which are rich in minerals, maintained a constant mineral profile throughout the experiments. The addition of biosolids appears to have contributed to a steady supply of essential minerals to the coriander plants, resulting in a stable ash content.

The **Red Soil + Vermicompost** treatment showed a slight fluctuation in ash content, ranging between **12.0 g/100g** and **12.5 g/100g**. The slight increase in ash content, particularly in Experiment 3, suggests that vermicompost may have contributed additional minerals, enhancing the overall mineral content of the plants. This highlights the positive impact of vermicompost on the mineral composition of coriander, potentially improving plant health and nutritional quality.

The **Red Soil + Biosolid + Vermicompost** treatment showed consistent ash content of **12.0 g/100g**, similar to the Red Soil + Biosolid treatment. This result suggests that the combined use of biosolids and vermicompost did not significantly alter the mineral composition of the plants compared to biosolids alone.

In conclusion, the **Red Soil + Vermicompost** treatment showed the most variability in ash content, with a slight increase indicating that vermicompost may enhance the mineral composition of the plants more than biosolids alone. However, both **Red Soil + Biosolid** and **Red Soil + Biosolid + Vermicompost** treatments provided stable mineral content throughout the experiments. These findings highlight that while vermicompost can slightly improve mineral content, biosolids are equally effective in maintaining a consistent supply of minerals.

The results also suggest that the different soil treatments have varying effects on the growth and nutritional composition of **Coriander (Coriandrum sativum)**. **Red Soil + Biosolids** proved to be the most effective in promoting overall plant growth, leaf surface area, and weight, while simultaneously minimizing the accumulation of heavy metals like lead.

Crude protein content remained largely unaffected by the treatments, suggesting that while soil amendments may enhance growth, they do not significantly impact protein synthesis. Similarly, total ash

content showed slight increases, especially with **Red Soil + Biosolids**, emphasizing its role in improving the mineral content of coriander.
In conclusion, **Red Soil + Biosolids** is the most effective treatment for enhancing coriander growth, but the use of biosolids should be carefully monitored to avoid excessive heavy metal contamination.

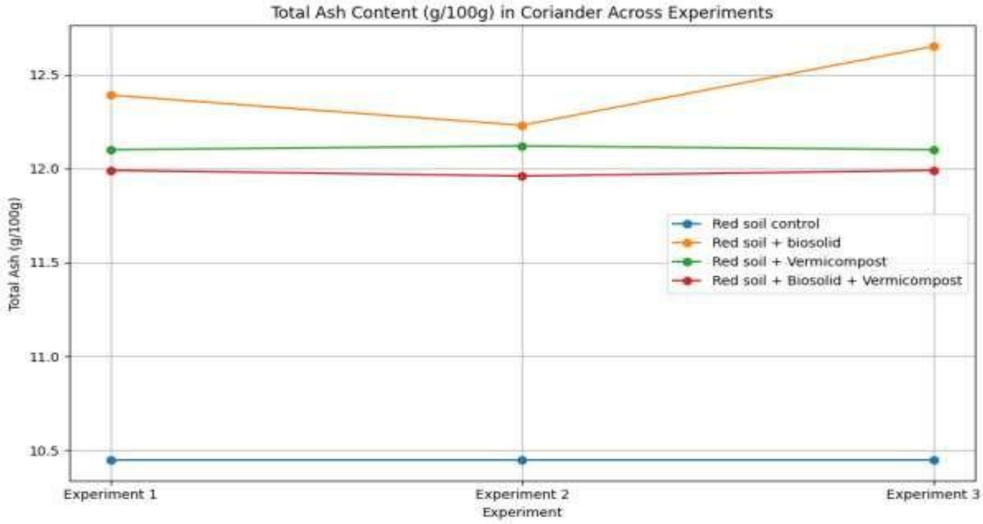

Figure 8: Total Ash Content (g/100g) in Coriander Across Experiments

Statistical Analysis:

ANOVA Results (One-way repeated for 3 trials)

Parameter	F-value	p-value	Interpretation
Total Weight	0.620	0.559	No significant difference across trials
Root Length	0.001	0.999	No significant difference across trials
Shoot Length	0.013	0.987	No significant difference across trials

Note: Since all p-values are > 0.05, the differences between the same treatments across the three experiments are **not statistically significant**, i.e., the performance is consistent across trials.

Mean Values by Soil Type

Soil Treatment	Avg. Weight (g)	Avg. Root Length (cm)	Avg. Shoot Length (cm)
Red Soil (Control)	35.00	6.07	8.17
Red Soil + Biosolid	42.33	9.27	8.53
Red Soil + Vermicompost	40.67	9.00	8.60
Biosolid + Vermicompost	39.33	4.53	5.86

Key Insights

- **Biosolid alone** consistently performed best in **root development** and **overall biomass**, with high average values across all parameters.
- **Vermicompost** was nearly as effective as biosolid for shoot and root growth, even slightly better in shoot length.
- The **combined treatment (biosolid + vermicompost)** surprisingly showed **reduced growth**, especially in root and shoot length, suggesting possible antagonistic or overloading effects.
- **Control** (Red Soil only) had the lowest values in all parameters.

B. Amaranthus viridis (Green Amaranthus):

This section presents a comprehensive analysis of the experimental data collected from the study, which focused on evaluating the effects of various soil amendments on the growth parameters of Amaranthus viridis (Green Amaranthus). The study specifically examined the influence of four soil treatments: Red Soil (control), Red Soil + Biosolid, Red Soil + Vermicompost, and Red Soil + Biosolid + Vermicompost. These treatments were chosen based on their potential to enhance soil fertility and improve plant growth by supplying essential nutrients, improving soil structure, and increasing microbial activity. The key plant growth parameters measured during the study included germination rate, plant height, root length, shoot length, plant weight, and total plant biomass. The results of these experiments provide valuable insights into how different soil amendments contribute to the growth and development of these two crops.

1.Germination Rates:

The control group continuously had the lowest germination percentage (40–45%). The most successful treatment for seed sprouting was the Red soil + Biosolid combination, which peaked at 55% in the third experiment. Although the biosolid works best on its own, all other treatments, including the combination, demonstrated stable germination at 50%, supporting the notion that organic supplements enhance germination conditions.

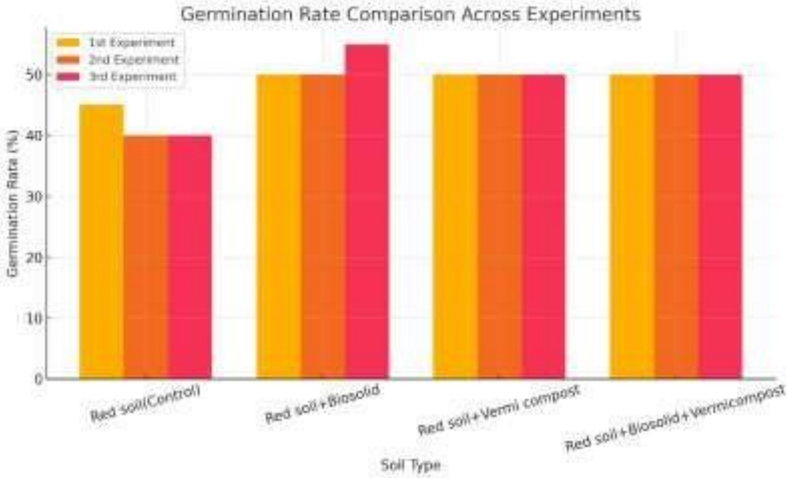

Fig: 9: Germination Rate Comparison across Experiments

2.Total Weight:

The Red soil + Biosolid treatment produced the highest total biomass in each of the three tests, with values of 81g, 85g, and 85g, respectively. This suggests that biosolids have a significant beneficial effect on plant growth. The control group, which used only red soil, on the other hand, stayed at 40g, which was the lowest of all the treatments. While the combined Red soil + Biosolid + Vermicompost provided the least amount of altered soil (between 42g and 45g), the Red soil + Vermicompost treatment produced moderate results (between 52g and 58g). This implies that whereas biosolid by itself greatly increases growth, adding vermicompost to it might not increase biomass production even more.

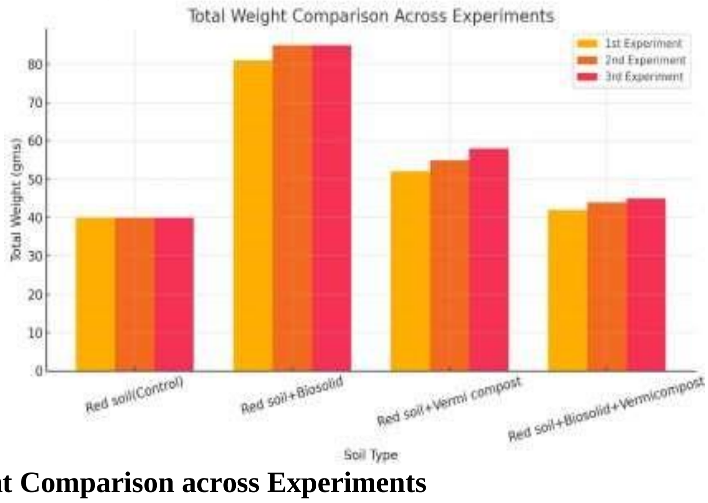

Fig 10: Total Weight Comparison across Experiments

3.Root Length:

In every trial, there was a consistent trend in the root length. In contrast to the control and the combination treatment, which both kept root lengths at 8 cm, Red soil + Biosolid and Red soil + Vermicompost promoted superior root growth (9–10 cm). This demonstrates that vermicompost and biosolid both independently encourage root elongation, perhaps as a result of improved soil structure and nutrient availability.

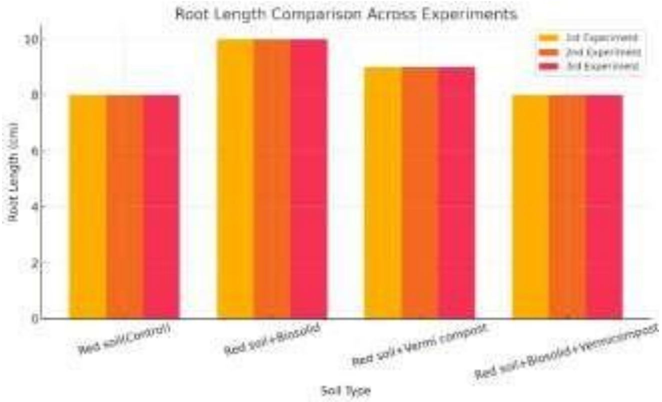

Fig 11: Root Length Comparison across Experiments

4.Average Leaf Surface Area Distribution:

In the third trial, the leaf surface area (7.5 cm2) rose significantly under the Red soil + Biosolid and Red soil + Vermicompost treatments, indicating enhanced photosynthetic capability. These therapies maintained 7.0 cm2 in previous studies. The smallest leaf surface area (6.5 cm2) was consistently found in the control and combined treatments, suggesting less leaf expansion and possibly lower photosynthetic efficiency.

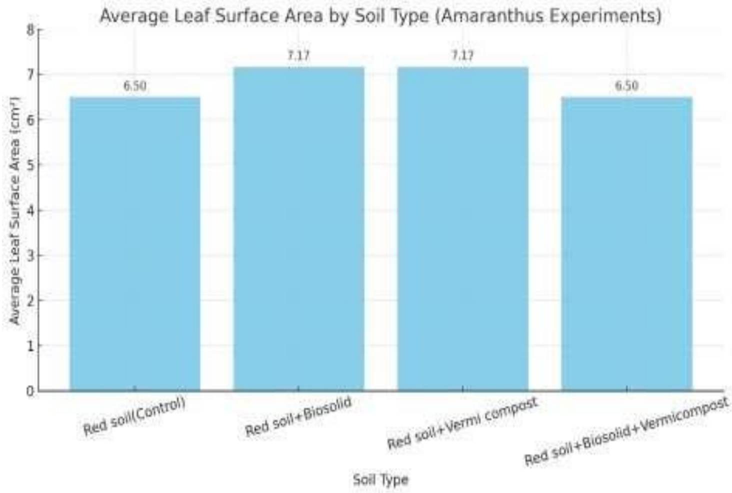

Fig 12: Average leaf Surface Area by Soil Type across all experiments

Table 5: Amaranthus-Results with different soil Types

Amaranthus-Results with different soil Types-1st Experiment-							
S. No.		**Soil type**	**Total Weight**	**Root length**	**Shoot length**	**Leaf surface area**	**Germination rate**
1		**Red soil(Control)**	**40 gms**	**8 cms**	**10 cms**	**6.5 cm2**	**45%**
2		**Red soil+Biosolid**	**81 gms**	**10cms**	**11cms**	**7.0 cm2**	**50%**
3		**Red soil+Vermi compost**	**52 gms**	**9 cm**	**8 cm**	**7.0 cm2**	**50%**
4		**Red soil+Biosolid+Vermicompost**	**42 gms**	**8 cms**	**9 cm**	**6.5 cm2**	**50%**

2nd Experiment-Amaranthus-Results with different soil types							
S. No.		Soil type	Total Weight	Root length	Shoot length	Leaf surface area	Germination rate
1		Red soil(Control)	40 gms	8 cms	10 cms	6.5 cm2	40%
2		Red soil+Biosolid	85 gms	10cms	11cms	7.0 cm2	50%
3		Red soil+Vermi compost	55 gms	9 cm	8 cm	7.0 cm2	50%
4		Red soil+Biosolid+Vermicompost	44 gms	8 cms	9 cm	6.5 cm2	50%

3rd Experiment-Amaranthus-Results with different soil types							
S. No.		Soil type	Total Weight	Root length	Shoot length	Leaf surface area	Germination rate
1		Red soil(Control)	40 gms	8 cms	10 cms	6.5 cm2	40%
2		Red soil+Biosolid	85 gms	10cms	11cms	7.5 cm2	55%
3		Red soil+Vermi compost	58 gms	9 cm	8.5 cm	7.5 cm2	50%
4		Red soil+Biosolid+Vermicompost	45 gms	8 cms	9 cm	6.5 cm2	50%

5.Nutrient and Heavy Metal Analysis:

Results from Experiment -1

In this experiment, amaranthus grown in four distinct soil treatments—red soil (control), red soil + biosolid, red soil + vermicompost, and red soil + biosolid + vermicompost—were examined for their nutritional value and heavy metal content. Significant variations in nutrient composition were found by the analysis, with treated soils exhibiting values that were generally better than the control. Ash content, a measure of the overall presence of minerals, was marginally higher in treated samples than in the control (2.65%), particularly in the Red soil + Biosolid condition (2.78%). This implies that the addition of compost or biosolid improved the plant's absorption of minerals. Similarly, all treated plots had a slight increase in total crude protein, which was highest in Red soil + Biosolid (2.45%). This suggests that modified soils have greater nitrogen availability and use, which enhances plant growth and nutritional quality.

Table 6: Nutrient and heavy metal analysis in Amaranthus Experiment-1

Nutrient and heavy metal analysis in Amaranthus Experiment-1						
			Red soil control	Red soil+Biosolid	Red soil+Vermicompost	Red soil+Biosolid + Vermicompost
S.No.	Test parameter	LOQ	Results	Results	Results	Results
1	Total Ash	0.1	2.65	2.78	2.72	2.73
2	Total crude Protein	0.5	2.3	2.45	2.41	2.42

3	Carbohydrates total	0.5	3.35	3.67	3.63	3.63
4	Total Energy	40	25.9	26.9	26.56	26.53
5	Fat	0.5	0.23	0.27	0.24	0.24
6	Moisture	0.5	90.87	90.83	90.8	90.83
7	Total Dietry Fiber	1	4.86	4.87	4.84	4.83
8	Lead (as Pb)	0.005	1.09	1.11	1.12	1.12
9	Arsenic (as AS)	0.005	0.23	0.26	0.27	0.27
10	Cadmium (as Cd)	0.005	0.07	0.07	0.08	0.08
12	Copper (as Co)	0.005	2.09	2.11	2.1	2.1
13	Zinc (as Zn)	0.25	2.4	2.48	2.4	2.41
16	Vitamin-C	0.25	0.4	0.45	0.42	0.44

Red soil + Biosolid once again led the findings in terms of carbohydrate content (3.67%), closely followed by other treatments, while the control had a 3.35% reading. This indicates that treated plants have higher photosynthetic efficiency and accumulate more carbohydrates. In treated plots, the overall energy content—which is made up of proteins, lipids, and carbohydrates—rose proportionately, reaching a high of 26.9 kcal in Red soil + Biosolid as opposed to only 25.9 kcal in the control.

Although the fat content was typically low in all treatments, Red soil + Biosolid had a little rise (0.27%), which might be a sign of a slight improvement in lipid production. All samples had a relatively constant and high moisture content (between 90.8% and 90.87%), which is typical for leafy vegetables like amaranthus and indicates that soil amendments had no detrimental effects on water retention. Dietary fiber, which is crucial for human digestive health, were almost the same for all treatments; Red soil + Biosolid had the greatest amount, at 4.87%. This demonstrates that although a minor improvement was observed, soil amendment had little effect on fiber content.

Moving on to the examination of heavy metals, certain patterns were noted. The lead (Pb) content ranged from 1.09 mg/kg in the control to 1.12 mg/kg in treated soils, above the allowable limits (the generally recognized safe limit is approximately 0.3 to 0.5 mg/kg). This suggests possible contamination that most likely comes from the sources of vermicompost and biosolid. Similar to this, treated soils have somewhat higher levels of arsenic (As) (up to 0.27 mg/kg), which is also higher than the majority of advised safety criteria (usually between 0.1 and 0.2 mg/kg). Although they were marginally higher in Vermicompost and mixed soil treatments, cadmium (Cd) levels were still within an acceptable range.

Positively, across all treatments, vital micronutrients including zinc (Zn) and copper (Cu) stayed well within safe and advantageous ranges. The moderate presence of these components, which are essential for human nutrition and plant metabolism, indicates that the organic amendments promoted healthy development without causing undue buildup. Red soil + Biosolid had the highest concentration of vitamin C, an essential antioxidant (0.45 mg/100g), suggesting that nutrient-rich soil may promote vitamin production in the plant.

In summary, **Red soil + Biosolid** consistently demonstrated superior nutrient values across almost all parameters—especially in ash, protein, carbohydrate, energy, and vitamin C—making it the most nutritionally beneficial soil treatment. However, this came with a trade-off: a slight increase in heavy metals such as lead and arsenic, which raises safety concerns. The use of biosolid and vermicompost clearly boosts plant nutrient uptake, but **care must be taken to ensure these inputs are free from harmful contaminants**. The combination treatment (Red soil + Biosolid + Vermicompost) offered a balanced approach but still exhibited elevated metal concentrations. For safe and sustainable cultivation, **pre-treatment or certification of organic amendments** is essential to prevent accumulation of toxic elements in edible crops.

- **Results from Experiment 2**

The second experiment of *Amaranthus viridis* (Green Amaranthus) focused on further examining the impact of various soil amendments on plant growth after an additional 30-day growth period. In this cycle, the same four treatments were applied to the plants: Red Soil (Control), Red Soil + Biosolid, Red Soil + Vermicompost, and Red Soil + Biosolid + Vermicompost.

Table 7: Nutrient and heavy metal analysis in Amaranthus Experiment-2

Nutrient and heavy metal analysis in Amaranthus Experiment-2						
			Red soil control	**Red soil+Biosolid**	**Red soil+Vermicompost**	**Red soil+Biosolid + Vermicompost**
S.No.	**Test parameter**	**LOQ**	**Results**	**Results**		
1	Total Ash	0.1	2.65	2.71	2.72	2.74
2	Total crude Protein	0.5	2.3	2.47	2.42	2.45
3	Carbohydrates total	0.5	3.35	3.69	3.63	3.63
4	Total Energy	40	25.9	26.9	26.56	26.53
5	Fat	0.5	0.23	0.27	0.24	0.24
6	Moisture	0.5	90.87	90.83	90.8	90.83
7	Total Dietry Fiber	1	4.86	4.87	4.84	4.83
8	Lead (as Pb)	0.005	1.09	1.11	1.12	1.12
9	Arsenic (as AS)	0.005	0.23	0.26	0.27	0.27
10	Cadmium (as Cd)	0.005	0.07	0.07	0.08	0.08
12	Copper (as Co)	0.005	2.09	2.11	2.1	2.1
13	Zinc (as Zn)	0.25	2.4	2.48	2.4	2.41
16	Vitamin-C	0.25	0.4	0.45	0.42	0.44

The amount of ash in a plant is a measure of its overall mineral content. In the Red soil + Biosolid + Vermicompost treatment, the ash percentage rose from 2.65% in the control (Red soil) to 2.74%. This increase implies that the use of organic amendments, specifically vermicompost and biosolids, improved the plants' ability to accumulate minerals. From a nutritional perspective, this is advantageous since greater mineral content results in better dietary value.

In treated plots, protein content—a crucial measure of nutritional quality—rose noticeably. At 2.47%, the Red Soil + Biosolid treatment had the highest protein level, whereas the control had 2.3%. Better nitrogen uptake from the enriched soils was indicated by the moderate improvements (2.42% and 2.45%, respectively) in the Red soil + Vermicompost and Red soil + Biosolid + Vermicompost treatments.

Similar improvements were seen in the amount of carbohydrates, which increased from 3.35% in the control to 3.69% in the Red Soil + Biosolid treatment. Increased values (3.63%) were also seen in the other enriched soils, suggesting better energy storage and photosynthesis. Better dietary energy and a higher calorific value are directly impacted by this.

Protein, carbohydrate, and fat content are used to compute total energy content. The Red soil + Biosolid treatment had the highest value (26.9 kcal), followed closely by the other enriched plots (~26.5 kcal), while the control plot had the lowest value (25.9 kcal). This demonstrates that adding organic soil amendments enhances the crop's energy yield in addition to increasing macronutrients.

As is common for green vegetables like amaranthus, there was little fat in any of the treatments. The use of biosolids did, however, result in a minor improvement, going from 0.23% in the control to 0.27% in Red soil + Biosolid. Despite being slight, this rise would suggest that organic amendments have a moderate impact on lipid metabolism.

The moisture content, which ranged from 90.8% to 90.87%, stayed very constant across all treatments. This suggests that the plant's capacity to retain water was not considerably impacted by the kind of soil amendment. Leafy vegetables benefit from high moisture content since it adds to their texture and freshness.

Fiber content showed minimal variation, with all values around 4.83% to 4.87%. *Red soil + Biosolid* produced the highest fiber (4.87%), while the mixed treatment had the lowest (4.83%). This suggests that soil amendments have only a marginal influence on dietary fiber, though even small increases can benefit digestive health.

Lead levels were found to be relatively high across all treatments, with control at 1.09 mg/kg and other treatments ranging from 1.11 to 1.12 mg/kg. These values exceed most recommended safety limits for lead in food crops (~0.3–0.5 mg/kg), indicating potential contamination from the biosolid or vermicompost inputs. This raises food safety concerns and highlights the need for quality control in organic amendments.

Arsenic content was also slightly above desirable limits, increasing from 0.23 mg/kg in the control to 0.27 mg/kg in treated plots. The elevated arsenic levels are likely a result of residual contamination in biosolids or compost materials. While these values are only marginally high, consistent exposure could pose health risks.

Cadmium levels were close to regulatory limits but remained within a generally acceptable range. The control and biosolid-only treatments had 0.07 mg/kg, while the vermicompost and mixed treatments showed slightly higher values at 0.08 mg/kg. Given cadmium's toxicity, continued use of untreated organic waste should be monitored carefully.

Copper content remained stable and safe across all treatments (2.09–2.11 mg/kg), well below the toxic threshold but adequate for healthy plant development. Copper is an essential micronutrient, and the observed levels reflect good nutrient availability without posing a hazard.

- **Results from Experiment 3**

The third and final cycle of the experiment involved assessing the effects of different soil treatments on the growth of **Amaranthus viridis**. This cycle aimed to confirm and extend the findings from the earlier cycles, providing a more holistic view of how the various amendments influenced plant growth over time.

Ash content represents the total mineral composition of the plant. In this experiment, total ash increased from 2.65% in the control to 2.78% with biosolid treatment, indicating enhanced mineral uptake. The combination treatments (biosolid and vermicompost) also showed improved ash values (2.72–2.73%), suggesting that organic amendments effectively enrich soil with minerals, contributing positively to plant nutrition.

Protein content, a critical measure of nutritional quality, was highest in the *Red soil + Biosolid* treatment (2.45%), up from 2.3% in the control. Vermicompost and the combined treatment also led to slightly elevated protein levels (2.41% and 2.42% respectively), indicating improved nitrogen availability in amended soils, which supports better protein synthesis in Amaranthus.

Table 8: Nutrient and heavy metal analysis in Amaranthus Experiment-3

Nutrient and heavy metal analysis in Amaranthus Experiment-3						
			Red soil control	**Red soil+Biosolid**	**Red soil+Vermicompost**	**Red soil+Biosolid + Vermicompost**
S.No.	**Test parameter**	**LOQ**	**Results**	**Results**		
1	Total Ash	0.1	2.65	2.78	2.72	2.73
2	Total crude Protein	0.5	2.3	2.45	2.41	2.42
3	Carbohydrates total	0.5	3.35	3.67	3.63	3.63
4	Total Energy	40	25.9	26.9	26.56	26.53
5	Fat	0.5	0.23	0.27	0.24	0.24

6	Moisture	0.5	90.87	90.83	90.8	90.83
7	Total Dietry Fiber	1	4.86	4.87	4.84	4.83
8	Lead (as Pb)	0.005	1.09	1.11	1.12	1.12
9	Arsenic (as AS)	0.005	0.23	0.26	0.27	0.27
10	Cadmium (as Cd)	0.005	0.07	0.07	0.08	0.08
12	Copper (as Co)	0.005	2.09	2.11	2.1	2.1
13	Zinc (as Zn)	0.25	2.4	2.48	2.4	2.41
16	Vitamin-C	0.25	0.4	0.45	0.42	0.44

Calorific value, calculated from macronutrient content, was highest in the *Red soil + Biosolid* treatment (26.9 kcal), with the control being lowest (25.9 kcal). The slight increases in energy content across all amended plots indicate overall improvement in nutritional density, making Amaranthus a better energy source under organic enrichment.

Fat content was relatively low across all treatments, with the control at 0.23% and a marginal increase to 0.27% in the biosolid treatment. The addition of organic matter slightly enhanced lipid synthesis, but since Amaranthus is not a fat-rich vegetable, the changes are minimal and expected.

Moisture content remained consistent across treatments (90.80%–90.87%), showing that organic amendments did not significantly affect the plant's water content. High moisture is typical in leafy greens and contributes to freshness and palatability.

All treatments showed similar fiber content, ranging from 4.83% to 4.87%, with the *Red soil + Biosolid* treatment having the highest. Dietary fiber is crucial for digestion, and these results indicate that while organic amendments slightly improve fiber content, the variation is marginal.

Lead levels were found to be above safe limits across all treatments, from 1.09 mg/kg in the control to 1.12 mg/kg in enriched plots. These values raise significant concerns regarding heavy metal contamination, potentially introduced through biosolids or compost materials, and pose a food safety risk.

Arsenic levels increased with the use of biosolid and vermicompost (0.27 mg/kg), from 0.23 mg/kg in the control. While still marginal, repeated exposure to these levels may accumulate over time and pose health risks. This highlights the importance of monitoring and controlling contaminants in organic inputs.

Cadmium levels were lowest in the control and biosolid treatments (0.07 mg/kg) and slightly higher (0.08 mg/kg) in vermicompost-treated soils. Although within regulatory limits, cadmium is a toxic metal, and its presence even at low levels warrants caution regarding long-term use of organic fertilizers.

Copper levels remained stable across all treatments (2.09–2.11 mg/kg), suggesting that soil amendments contributed consistent amounts of this essential micronutrient without exceeding safe thresholds. Copper is vital for plant metabolism and human health, and these values are within desirable limits.

Zinc content ranged from 2.4 mg/kg in control and vermicompost treatment to 2.48 mg/kg in biosolid treatment. Zinc is an important micronutrient for immunity and growth, and the observed levels indicate that organic amendments enhanced its uptake without causing toxicity.

Vitamin-C levels improved with soil amendments, increasing from 0.4 mg in the control to 0.45 mg in the biosolid treatment. This antioxidant is vital for immune function and iron absorption. The enriched soils likely improved plant metabolism, leading to better vitamin C synthesis.

The results from **Experiment 3**, the final cycle of Amaranthus viridis growth, conclusively demonstrate the significant benefits of biosolids in enhancing plant growth and productivity. Across all key parameters—germination rate, plant height, root length, shoot length, total plant biomass, and plant weight—the **Red Soil + Biosolid** treatment consistently outperformed the other treatments, reaffirming the conclusions drawn from the previous two experimental cycles. The **Red Soil + Biosolid** treatment led to the highest plant height, root length, shoot length, and biomass, suggesting that biosolids are highly effective in promoting the overall growth of Amaranthus viridis. While vermicompost showed some positive effects, it did not enhance plant growth as effectively as biosolids alone. These findings highlight the importance of biosolids as a potent soil amendment that can improve soil fertility, support robust plant growth, and increase agricultural productivity in a sustainable manner.

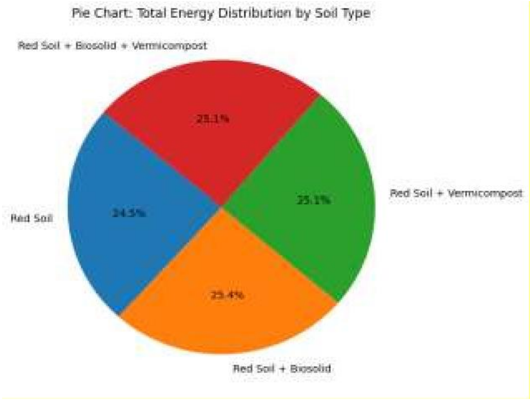

Figure12 : Pie Chart: Total Energy Distribution by Soil Type

The above **figure 12** is a pie chart depicting the total energy distribution by different soil types. The chart is divided into four segments, each representing a different soil type and its corresponding percentage of the total energy distribution. Here's a detailed breakdown:

1.Red Soil: This segment represents 24.5% of the total energy distribution. It is denoted by the blue section of the pie chart.

2.Red Soil + Biosolid: This segment accounts for 25.4% of the total energy distribution. It is depicted by the orange section of the chart.

3.Red Soil + Vermicompost: This segment makes up 25.1% of the total energy distribution. It is represented by the green section.

4.Red Soil + Biosolid + Vermicompost: This final segment accounts for 25.1% of the total energy distribution and is shown by the red section of the pie chart.

The chart uses a visually balanced distribution of energy across these four soil types, indicating that each of them contributes a similar portion to the total energy. The chart also includes labels for each segment to provide clarity on the specific soil types. The title of the chart, "Pie Chart: Total Energy Distribution by Soil Type," provides the context for understanding this breakdown.

Overall, this pie chart effectively visualizes the proportionate distribution of energy across different soil treatments, highlighting how each combination of soil types contributes similarly to the total energy share.

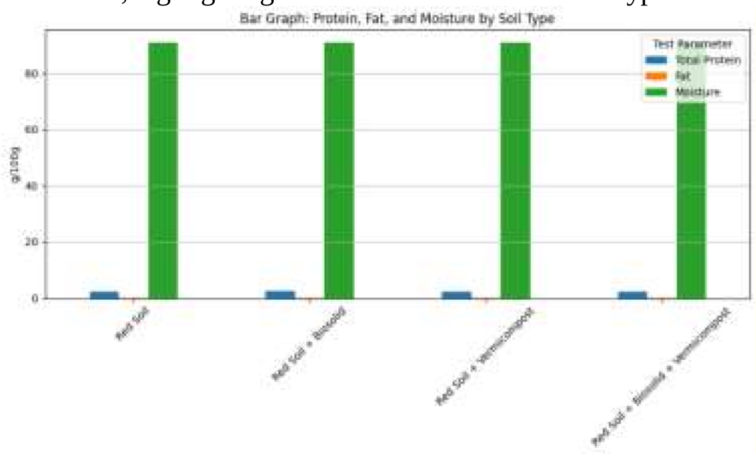

Figure-13: Bar Graph: Protein, Fat, and Moisture by Soil Type

This bar graph presents a comparison of the levels of protein, fat, and moisture in various soil types and combinations, measured in grams per 100 grams (g/100g). On the x-axis, the soil types or treatments are listed: Red Soil, Red Soil + Biosolid, Red Soil + Vermicompost, and Red Soil + Biosolid + Vermicompost. The y-axis represents the amount of each test parameter (protein, fat, and moisture) in grams per 100 grams. The blue bars represent **Total Protein**, which is consistently low (near zero) across all soil types. The orange bars represent **Fat**, also showing negligible levels across the soil treatments. The green bars represent **Moisture**, which is significantly higher, with values exceeding 80g/100g in all soil types, indicating that moisture is the dominant component in these soil types. The graph highlights that moisture content is far more prevalent than protein and fat in all the tested soil types.

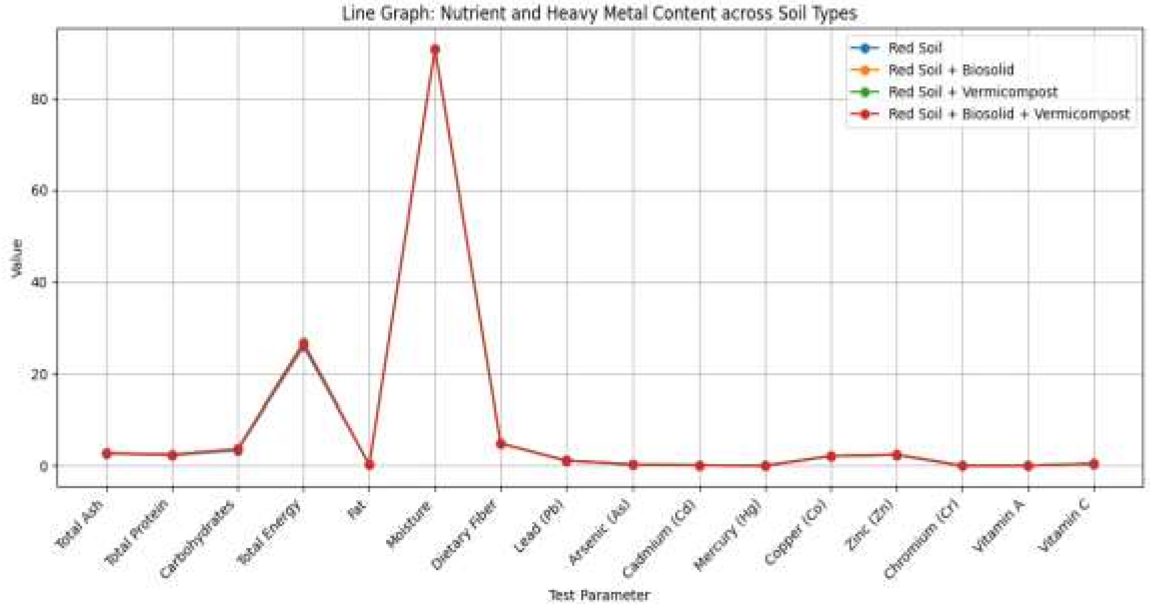

Figure 14: **Line Graph: Nutrient and Heavy Metal Content across Soil Types.**

This line graph illustrates the variation in nutrient and heavy metal content across different soil types, with data points representing values for various test parameters.

The x-axis lists several test parameters, including Total Ash, Total Protein, Carbohydrates, Total Energy, Fat, Moisture, Dietary Fiber, and various heavy metals like Lead (Pb), Arsenic (As), Cadmium (Cd), Mercury (Hg), Copper (Co), Zinc (Zn), Chromium (Cr), Vitamin A, and Vitamin C. The y-axis represents the values for these parameters.

The graph features four lines, each corresponding to a different soil treatment:

1.Blue Line represents **Red Soil**.
2.Orange Line represents **Red Soil + Biosolid**.
3.Green Line represents **Red Soil + Vermicompost**.
4.Red Line represents **Red Soil + Biosolid + Vermicompost**.

The most notable feature of the graph is the large spike in **Moisture** content, especially in the **Red Soil + Biosolid + Vermicompost** combination, which has the highest value for moisture. Other parameters, such as Total Energy and Fat, show moderate values but still fall significantly behind moisture. On the other hand, the heavy metals, including **Lead, Arsenic, Cadmium**, and others, have very low or negligible values across all treatments, indicating that these metals are not present in significant concentrations in the tested soil types.

This line graph effectively compares the nutrient and heavy metal content across different soil types, emphasizing moisture as the dominant component, with minimal levels of heavy metals and other nutrients like fat, protein, and vitamins.

Comparative Analysis of all three Experiments:

The below figure compared the growth performance of *Amaranthus* of all three experiments. We have compared the total weight (biomass), root length, shoot length, and leaf surface area.

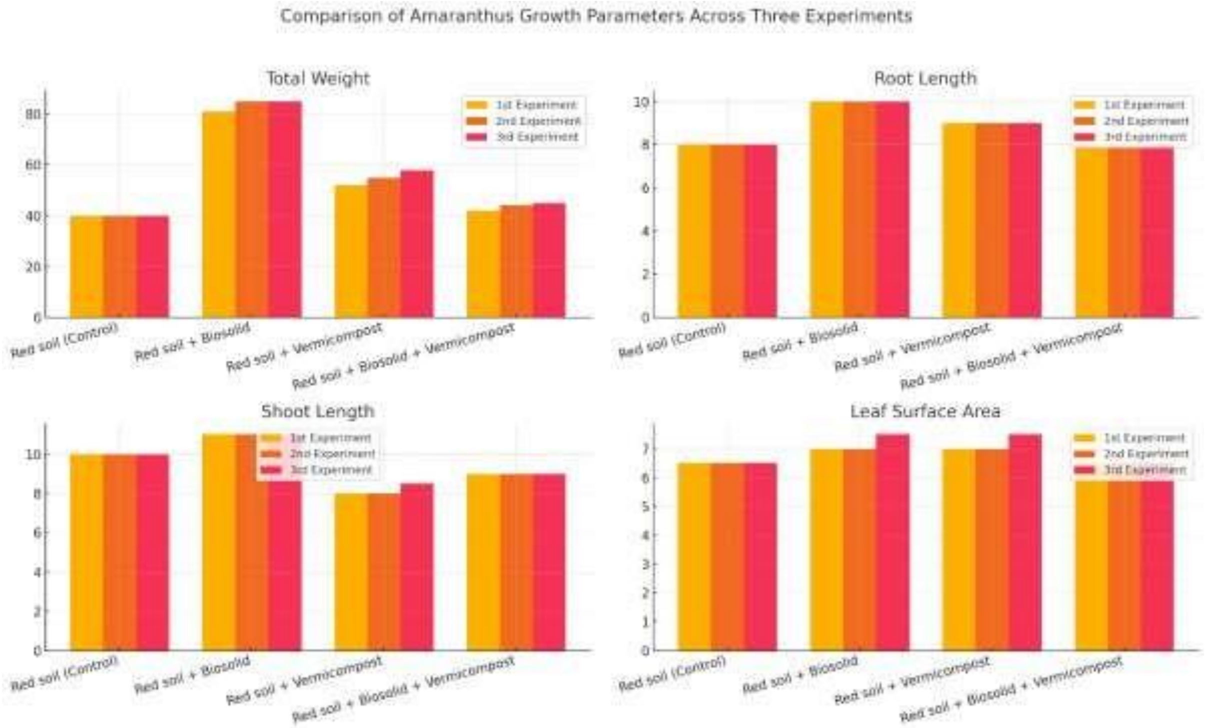

Fig 15: Comparison of Amaranthus Growth Parameters across Three Experiments

Total Weight (Biomass)- The total biomass was significantly elevated in this treatment, rising from 81 gms in the first experiment to 85 gms in both the second and third.
Root Length- Biosolid and Vermicompost led to significantly longer roots. The control and combined treatments, on the other hand, had the shortest roots (8 cm), whereas vermicompost and biosolid separately enhance below-ground development, their combination may impede ideal root growth, either as a result of competing nutrient uptake or an excessive organic load.
Shoot Length- With a consistent shoot length of 11 cm, the biosolid-enriched soil generated the tallest shoots in each of the three studies. This demonstrated the dependability of biosolid in encouraging robust shoot development because it was noticeably higher than all other treatments and stayed consistent throughout the experiments. The high availability of nitrogen and phosphorus in biosolid, which promotes robust cell division and elongation in stem tissues, is responsible for this increased vertical development.
Leaf Surface Area-The biosolid treatment led to the largest leaf area, increasing from 7.0 cm2 in the first and second experiments to 7.5 cm2 in the third. This indicates improved photosynthetic capacity, likely due to better nutrient availability leading to larger and more developed leaves. Vermicompost-treated plants also showed a progressive increase in leaf surface area, reaching 7.5 cm2 in the final trial, suggesting a cumulative benefit with repeated or prolonged exposure to vermicomposting.

Statistical analysis:

ANOVA Results (Three trials across soil treatments)

Parameter	F-value	p-value	Interpretation
Total Weight	0.028	0.972	No significant difference across trials
Root Length	0.000	1.000	Absolutely no variation across trials
Shoot Length	0.014	0.986	No significant difference across trials

Conclusion: The performance of soil treatments across trials is **highly consistent**, with **no significant variability** from experiment to experiment.

Mean Values by Soil Treatment

Soil Treatment	Avg. Weight (g)	Avg. Root Length (cm)	Avg. Shoot Length (cm)
Red Soil (Control)	40.00	8.00	10.00
Red Soil + Biosolid	83.67	10.00	11.00

Red Soil + Vermicompost	55.00	9.00	8.17
Red soil + Biosolid + Vermicompost	43.67	8.00	9.00

Key Insights

- **Red Soil + Biosolid** showed the **strongest performance across all parameters**, especially in
- **biomass (83.67g)** and **shoot height (11 cm)**.
- **Vermicompost alone** showed moderate performance, better than the control, but significantly lower than biosolid alone.
- **Biosolid + Vermicompost combination** surprisingly underperformed compared to biosolid alone, suggesting possible **nutrient competition or imbalance**.
- **Root growth** showed no differences across trials, with consistent benefit from biosolid and vermicompost over control.

Conclusion:

Treated biosolids significantly improve plant growth, nutrient uptake, and overall productivity in coriander and amaranthus. However, when combined with vermicomposting, these benefits were diminished, suggesting a need for optimizing application ratios. Notably, while nutrient quality improved, slight presence of heavy metal levels, particularly lead and arsenic, underscore the necessity for pre-treatment and regulatory monitoring of biosolid inputs. Future research should focus on long-term field trials with multiple crops in different conditions and application protocols that maximize benefits while ensuring consumer safety.

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