EFFECTS OF DROUGHT STRESS ON *ZEA MAYS* AND THEIR MITIGATION THROUGH BIOCHAR

Saqib Ullah[1]*, Tufail Ahmad Zeb[2], Hayat Ullah[2], Shahab Saeed Khan[1], Ayaz Ahmad[3], Danyal Ahmad[4], Rehnaz Sajid[5], Samina Bibi[1], Tooba Iqbal[1], Hamid Ullah[5]

[1]*Department of Botany, Islamia College Peshawar, Khyber Pakhtunkhwa, Pakistan
[2]Department of Botany, University of Peshawar, Khyber Pakhtunkhwa, Pakistan
[3]Department of Biological Sciences, Gomal University, Dera Ismail Khan, Khyber Pakhtunkhwa, Pakistan
[4]Department of Botany, Abdul Wali Khan University Mardan, Khyber Pakhtunkhwa, Pakistan
[5]Department of Chemical and Life Sciences, Qurtuba Peshawar, Khyber Pakhtunkhwa, Pakistan

Abstract-The experiment evaluated the effects of different treatments on the growth and development of *Zea mays* plants. The treatments included T1 (control), T2 (7 Days of drought stress), T3 (14 Days of drought stress), T4 (7 Days of drought stress + biochar), and T5 (14 Days of drought stress + biochar). The plant parameters measured were shoot length, root length, leaf length, leaf width, shoot fresh weight, root fresh weight, leaf fresh weight, shoot dry weight, root dry weight, leaf dry weight, growth parameters (GP), growth efficiency (GE), growth rate index (GRI), metabolic efficiency (MET), vigor index (VI), final growth percentage (FGP), final efficiency percentage (FEP), absolute growth rate (ABG), relative growth rate (RSR), and leaf area ratio (LAR). The results indicated that T2 had the most significant impact on plant growth and development, with the smallest values recorded for shoot length, root length, leaf length, leaf width, shoot fresh weight, root fresh weight, shoot dry weight, root dry weight, and growth parameters (GP, GE, GRI, MET, VI). However, the addition of biochar (T4 and T5) helped to alleviate the negative effects of drought stress on plant growth, as evidenced by the higher values recorded for some parameters such as shoot length, root length, leaf length, leaf width, and leaf area ratio (LAR). The growth efficiency (GE) was generally highest in T3, while T5 recorded the highest values for final growth percentage (FGP), final efficiency percentage (FEP), absolute growth rate (ABG), and relative growth rate (RSR). In conclusion, the addition of biochar can be an effective means of mitigating the negative effects of drought stress on plant growth, with the optimal duration of drought stress being 14 Days. The data obtained from this study provides a basis for further research on the potential use of biochar in agriculture as a means of promoting sustainable crop growth and development under conditions of water scarcity.

Index Terms- Abiotic Stress, Drought Stress, Biochar, Morphological Parameters, *Zea mays*.

I. INTRODUCTION

Abiotic stress is a significant threat to global food security, caused by non-living environmental factors such as extreme temperatures, drought, salinity, flooding, heavy metals, and high or low PH (Hasanuzzaman et al., 2013; Bita and Gerats, 2013). This stress can lead to physiological and biochemical changes in plants resulting in reduced crop yields and lower agricultural productivity. The occurrence of abiotic stress has increased due to changing climate and environmental conditions, and it is estimated that 25% of the world's agricultural land is already affected. The impact of abiotic stress on agriculture is substantial, and global crop production could decrease by 10-15% due to climate change by the end of the 21st century (Ray et al., 2019). Developing stress-tolerant crops through genetic engineering, genome editing, and phenotypic selection, and the use of stress-mitigating agents are explored to enhance plant resilience to abiotic stress. Understanding the molecular and genetic mechanisms underlying abiotic stress response is critical for developing new strategies to mitigate the negative effects of stress on plant growth and productivity (Mitler, 2017; Kumar et al., 2021). Both abiotic stress and drought stress are forms of environmental stress that can significantly affect the growth and survival of plants. Drought stress is a significant challenge to crop productivity worldwide, caused by reduced precipitation, high temperatures, and increased evaporation rates. Studies predict that drought events will increase in frequency and intensity due to climate change, making it critical to develop drought-tolerant crops and sustainable water management strategies (Ramegowda and Senthil-Kumar, 2021; Sharma et al., 2020). Drought stress alters plant osmotic potential and reduces photosynthetic rate, leading to reduced biomass production and accumulation of reactive oxygen species that can damage lipids, proteins, and DNA. Plants respond to drought stress by accumulating osmoprotectants, activating antioxidant defense mechanisms, and modulating gene expression and protein synthesis. Strategies like breeding, genetic engineering, and using drought-tolerant cultivars have shown promising results in mitigating the effects of drought stress on plant growth and productivity. These responses allow plants to maintain their physiological and metabolic processes under water-limited conditions (Huang et al., 2019; Garg and Bahinipati, 2020; Kumar et al., 2021; Xiong et al., 2020; Chaves et al., 2003). One potential solution to mitigate the negative effects of drought stress on plant growth could be the use of biochar as a soil amendment. Biochar, produced through the pyrolysis of biomass, has gained attention for its potential to improve soil health, sequester carbon, and mitigate climate change. It can remain in soil for hundreds of years, making it a long-term carbon sink, and enhance soil fertility, water retention, and plant growth by providing a habitat for beneficial microorganisms and improving soil structure (Lehmann and Joseph, 2015). However, some studies have reported negative effects on plant growth, which are highly dependent on the type of biochar used, its application rate, and the plant species being grown. More research is needed to determine the optimal conditions for biochar application and to understand the underlying mechanisms of biochar stress (Van-Zwieten et al., 2018). Despite its many benefits, biochar production can be expensive and energy-intensive, and concerns exist about the potential release of harmful substances during production and application (Ronsse et al., 2020). Overall, biochar has great potential as a sustainable soil amendment, but more research is needed to fully understand its long-term effects and to develop more efficient and cost-effective production methods.

Zea mays, commonly known as maize or corn, is one of the most important cereal crops worldwide. With a growing global population and increasing demand for food, ensuring the productivity and resilience of maize crops is critical. However, maize crops are often exposed to environmental stressors such as drought, which can negatively impact their growth and yield. In order to address this challenge, researchers have been exploring various strategies to enhance maize resilience and productivity under drought stress conditions (Liu et al., 2021). Maize has undergone significant genetic modification over the past century, resulting in improved yields and resistance to pests and diseases. The development of genetically modified (GM) maize has sparked controversy, with concerns over the potential health and environmental impacts of these crops. However, proponents argue that GM maize has the potential to increase food production and reduce poverty, particularly in developing countries (Qin et al., 2021).

One such strategy is the use of biochar, a type of charcoal that is produced by burning organic material in the absence of oxygen. Biochar has been shown to improve soil properties such as water-holding capacity and nutrient availability, which can in turn benefit plant growth and resilience. In recent years, researchers have been investigating the potential of biochar as a tool for enhancing maize productivity under drought stress conditions.

In this study, we aim to investigate the effects of biochar on the growth and yield of Zea mays under drought stress conditions. We will conduct experiments using a randomized complete block design with three replicates, where we will apply varying levels of drought stress and biochar treatments to the maize plants. Our findings will contribute to a better understanding of the potential of biochar as a tool for enhancing maize resilience under drought stress conditions, which could have important implications for improving global food security.

II. MATERIAL AND METHODS

The goal of the current study was to ascertain how biochar might affect the vegetative characteristics of maize (*Z. mays* L.).

2.1 Plant material:

For the purposes of testing seeds and plants, the *Z. mays* L. plant was employed. Maize seedlings were obtained from Agriculture Seed Shop, Near Islamia College Peshwar.

2.2 Experimental site

The current investigation was carried out in botanical garden of Islamia College Peshawar (ICP). The field was suitably ready for seed sowing. One inch of dirt was used to plant the seeds. Five groups (T1, T2, T3, T4, T5) made up the experimental plant, including;

Treatments	Treatments used
T1	Control
T2	07 Days drought stress
T3	14 Days drought stress
T4	07 Days drought stress + Biochar
T5	14 Days drought stress + Biochar

There were three identical copies in the shape of rows for each group. The seeds were soon equally separated from one another in each row, which had equal row spacing. After the seeds were sown, several drought stress treatments were administered when the maize plant reached a height of 5 cm. drought stress was applied after 5 cm for 7 and 14 Days.

2.3 Given treatments:

2.3.1 Treatment Details:

Treatments	Treatments used
T1	Control
T2	07 Days drought stress
T3	14 Days drought stress
T4	07 Days drought stress + Biochar
T5	14 Days drought stress + Biochar

2.4 Sampling:

When the height of the plant reached 5 cm or more, drought stress set in, and biochar treatment began. After 7 and 14 Days, the weight of all treatments was measured. Three replicates (R1, R2, and R3) were used for each treatment. After waiting for more analysis, the sample was kept.

2.5 Assessment and Measurement of Agronomic Characters:

2.5.1 Root Length, Shoot Length, Leaf Length and Width Measurement:

All of the replicates' roots, shoots, leaves, and leaf widths were all measured in centimeters.

2.5.2 Fresh Weight and Dry Weight Measurement:

With the use of an electric balance, the fresh weight in grams of each replicate's root, shoot, and leaf was measured.

2.6 Observation Recorded:

For germination, the following observation was made.

2.6.1 germination percentage (GP):

$$GP = \frac{Number\ of\ seeds\ germinated}{Total\ number\ of\ seeds\ tested} \times 100$$

2.6.2 Germination energy (GE):

$$GE = \frac{Number\ of\ seeds\ germinated\ on\ day(4/7/14)}{Total\ number\ of\ seeds\ tested} \times 100$$

2.6.3 Germination rate index (GRI):

$$GRI= (G1/1) + (G2/2) + (G3/3) + (Gi/i)$$

2.6.4 Mean emergence time (MET):

$$\boldsymbol{MET} = \frac{\mathbf{\Sigma Dn}}{\sum \mathbf{n}}$$

Where D is the number of days counted from the beginning of emergence and n is the number of seeds that had emerged on day D Where D is the number of Days counted from the beginning of emergence and n is the number of seeds that had emerged on day D

2.6.5 Vigour index (VI):

(Average root length+ average shoot length)×GP

2.6.6 Final Germination Percentage (FGP):

The higher the FGP value, the greater the germination of a seed population

$$FGP = \frac{Number\ of\ seeds\ germinated}{Total\ number\ of\ seeds\ tested} \times 100$$

2.6.7 Final emergence percentage (FEP):

$$FEP = \frac{Final\ no.of\ seedlings\ emerged}{total\ no.of\ seed\ sown} \times 100$$

3.6.8 Absolute growth rate (AGR):

The rate of increase in growth variable at time‘t’ is called as AGR. It was measured by differential coefficient of ‘w’ with respect of time‘t’. Absolute growth rate was calculated for two growth variables by using following formula.

$$AGR = \frac{H2-H1}{T2-T1}$$

Where H_1 and H_2 refer to the plant height (cm) and dry matter weight (g) at the time t_1 and t_2, respectively. It was expressed in cm/day in case of plant height and g/day in case of dry matter production per plant.

2.6.9 Root-shoot ratio (RSR):

$$\boldsymbol{RSR} = \frac{\textbf{root dry mass}}{\textbf{shoot dry mass}}$$

2.6.10 Leaf area ratio (LAR):

$$LAR = \frac{leaf\ area}{final\ plant\ dry\ weight}$$

III. RESULTS AND DISCUSSION

Table. 3.1 Length of different parts of *Z. mays* after 5 treatments of control, drought and drought + biochar.

Treatment	Shoot length	Root length	Leaf length	Leaf width
T1	15 ± 0.7	9± 0.2	3.8 ± 0.21	3.1 ± 0.577
T2	7 ± 0.7	4 ± 0.1	1.5 ± 0.15	1.1 ± 0.058
T3	6 ± 0.47	3.4 ± 0.2	2 ± 0.15	1.4 ± 0.115

T4	12 ± 1.266	7 ± 0.2	1.7 ± 0.06	1.5 ± 0.153
T5	9.4 ± 0.7	5 ± 0.1	2.1 ± 0.1	1.6 ± 0.153

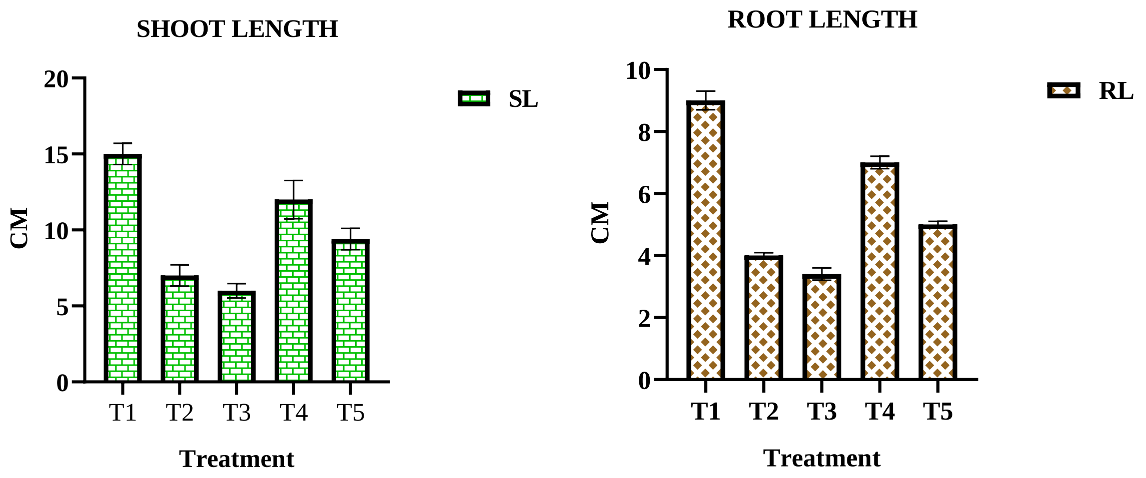

Fig. 1 & 2. Effect of control, drought stress and drought + biochar treatments on shoot and root length of *V. radiata*.

The **Fig. 1** presents the results of an experiment examining the effect of different treatments on the shoot length of *Z. mays* plants. The five treatments include a control group (T1) and four other groups subjected to varying degrees of drought stress (T2 and T3) and drought stress combined with biochar application (T4 and T5). The results show that the shoot length of the control group (T1) was significantly higher ($p < 0.05$) than that of all other treatment groups. Among the stressed groups, the shoot length was higher in T4 (7 Days drought stress + biochar) than T2 (7 Days drought stress) and T3 (14 Days drought stress), and higher in T5 (14 Days drought stress + biochar) than T3.

The **Fig. 2** shows the root length of *Z. mays* under different treatments. The treatments include T1 (control), T2 (7 Days Drought Stress), T3 (14 Days Drought Stress), T4 (7 Days Drought Stress + Biochar), and T5 (14 Days Drought Stress + Biochar). The results indicate that the root length of *Z. mays* was significantly affected by the different treatments. The control treatment (T1) had the highest root length with a mean of 9 ± 0.2, while the 14 Days drought stress treatment (T3) had the lowest root length with a mean of 3.4 ± 0.2. The root length of *Z. mays* in the T2 (7 Days Drought Stress), T4 (7 Days Drought Stress + Biochar), and T5 (14 Days Drought Stress + Biochar) treatments were also significantly lower than the control.

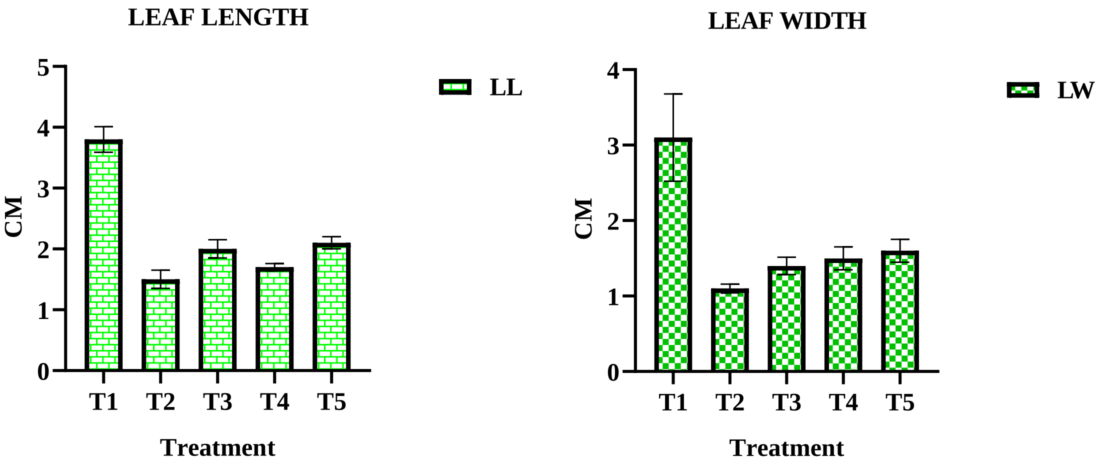

Fig. 3 & 4. Effect of control, drought stress and drought + biochar treatments on leaf length and width of *V. radiata*.

The **Fig. 3** shows the root width of *Z. mays* under different treatments, including a control group (T1) and various drought stress treatments with and without biochar application (T2-T5). Overall, the results suggest that the root width of *Z. mays* is affected by drought stress and biochar application. Specifically, the leaf length was significantly reduced under both 7 Days (T2) and 14 Days (T3) of drought stress compared to the control group (T1). However, the application of biochar in conjunction with 7 Days (T4) or 14 Days (T5) of drought stress appeared to mitigate the negative effects of drought stress on leaf length, with the leaf length measurements of these groups being closer to that of the control group.

The given **Fig. 4** presents the leaf width measurements of *Z. mays* under different treatments, including control (T1), 7 Days drought stress (T2), 14 Days drought stress (T3), 7 Days drought stress with biochar application (T4), and 14 Days drought stress with biochar application (T5). The results showed a significant decrease in leaf width in all treatment groups compared to the control group. The highest reduction in leaf width was observed in T1 (3.1 ± 0.577), which was considered the control group, while the lowest reduction was found in T2 (1.1 ± 0.058). However, T2 also showed a significant decrease in leaf width compared to the control group. The leaf width measurements of T3, T4, and T5 were 1.4 ± 0.115, 1.5 ± 0.153, and 1.6 ± 0.153, respectively. Although all three treatments (T3, T4, and T5) showed a slight increase in leaf width compared to T2, the differences were not statistically significant. The reduction in leaf width is a common response of plants to water stress.

Table. 3.2 Fresh Weight of different parts of *Z. mays* after 5 treatments of control, drought and drought + biochar.

Treatment	Shoot Fresh Weight	Root Fresh Weight	Leaf Fresh Weight
T1	512 ± 20.9	89 ± 2.42	13 ± 1
T2	176 ± 7.77	23 ± 2	14 ± 1
T3	103 ± 6.11	37 ± 3.96	7 ± 1.5
T4	204 ± 13.2	50 ± 2.08	17 ± 0.5
T5	130 ± 14.84	27.1 ± 4.92	8.09 ± 0.57

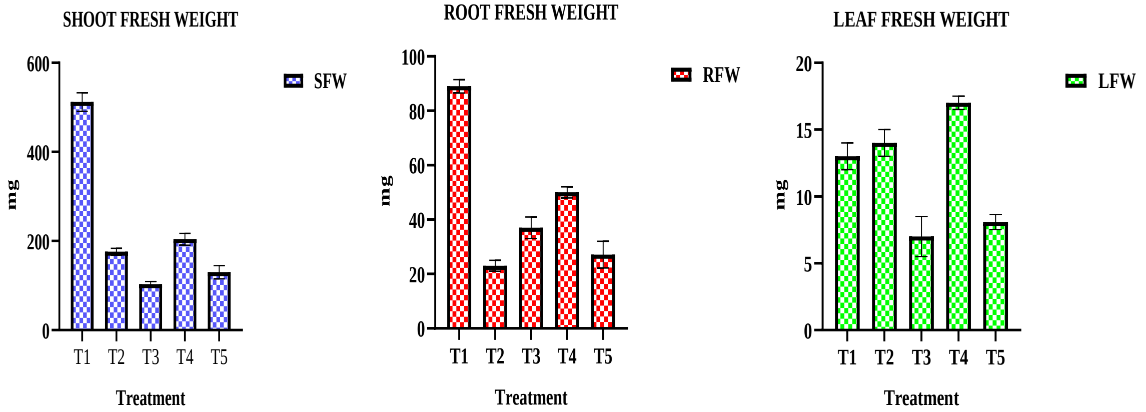

Fig. 5, 6 & 7. Effect of control, drought stress and drought + biochar treatments on Fresh shoot, root and leaf weight of *V. radiata*.

The given **Fig. 5** presents the effects of different treatments on the shoot fresh weight of *Z. mays*. The treatments included T1 (control), T2 (7 Days drought stress), T3 (14 Days drought stress), T4 (7 Days drought stress + biochar), and T5 (14 Days drought stress + biochar). The results indicate that T1 had the highest shoot fresh weight with a mean of 512 ± 20.9, while T3 had the lowest with a mean of 103 ± 6.11. T2, T4, and T5 had intermediate shoot fresh weights with means of 176 ± 7.77, 204 ± 13.2, and 130 ± 14.84, respectively.

The **Fig. 6** presents the results of an experiment that aimed to investigate the effect of different treatments on the root fresh weight of *Z. mays* under different drought stress conditions. The treatments included a control (T1), 7 Days of drought stress (T2), 14 Days of drought stress (T3), 7 Days of drought stress with biochar application (T4), and 14 Days of drought stress with biochar application (T5). The results show that the root fresh weight varied significantly among the treatments. T1 (control) had the highest root fresh weight, with a mean of 89 ± 2.42, while T2 had the lowest root fresh weight with a mean of 23 ± 2. Treatment T3, with 14 Days of drought stress, showed a slight improvement in the root fresh weight compared to T2, with a mean of 37 ± 3.96. T4, with 7 Days of drought stress and biochar application, had a mean root fresh weight of 50 ± 2.08, which was higher than T2 but lower than T1. T5, with 14 Days of drought stress and biochar application, had a mean root fresh weight of 27.1 ± 4.92, which was lower than all other treatments.

The **Fig. 7** presents the results of a study that investigated the effect of different treatments on the leaf fresh weight of *Z. mays* plants. The five treatments included a control (T1), 7 Days of drought stress (T2), 14 Days of drought stress (T3), 7 Days of drought stress with biochar application (T4), and 14 Days of drought stress with biochar application (T5). The results show that T2 and T3 treatments had a significant negative effect on the leaf fresh weight of *Z. mays*, with mean values of 14 ± 1 and 7 ± 1.5, respectively, compared to the control treatment (T1) which had a mean value of 13 ± 1.

Table. 3.3 Dry Weight of different parts of *Z. mays* after 5 treatments of control, drought and drought + biochar.

Treatments	Shoot Dry Weight	Root Dry Weight	Leaf Dry Weight
T1	115 ± 6.45	39.33 ± 4.26	6.67 ± 1.52
T2	70 ± 5.19	10.33 ± 1.52	2.33 ± 0.07
T3	24 ± 1.15	8.67 ± 0.77	1.33 ± 0.50
T4	67 ± 7	12 ± 2	4.33 ± 1.52
T5	34 ± 1.52	7.6 ± 1.52	3.67 ± 0.07

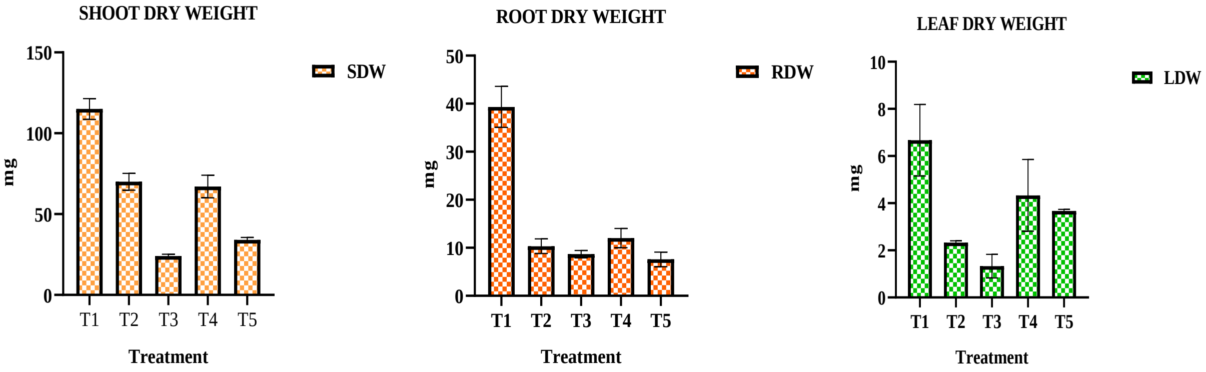

Fig. 8, 9 & 10. Effect of control, drought stress and drought + biochar treatments on Dry shoot, root and leaf weight of *V. radiata*.

The **Fig. 8** shows the shoot dry weight of *Z. mays* under different treatments, including a control group (T1), two groups subjected to different periods of drought stress (T2 and T3), and two groups subjected to drought stress and treated with biochar (T4 and T5). The results indicate that shoot dry weight was significantly affected by the different treatments. The shoot dry weight of the control group (T1) was the highest, at 115 ± 6.45. This result is expected since the plants in this group were not subjected to any stressors. In contrast, the shoot dry weight of the groups subjected to drought stress (T2 and T3) was significantly lower, with the lowest value observed in T3 (24 ± 1.15

The **Fig. 9** shows the root dry weight of *Z. mays* under different treatments. The highest root dry weight was observed in T1 (39.33 ± 4.26), which was the control group, while the lowest root dry weight was observed in T5 (7.6 ± 1.52), which was the group that experienced 14 Days of drought stress and was treated with biochar. The significant reduction in root dry weight in T5 can be attributed to the prolonged exposure to drought stress

The **Fig. 10** table shows the effects of different treatments on the leaf dry weight of *Z. mays*. The treatments included T1 (control), T2 (7 Days drought stress), T3 (14 Days drought stress), T4 (7 Days drought stress + biochar), and T5 (14 Days drought stress + biochar). The results indicate that T1 had the highest leaf dry weight with a mean of 6.67 ± 1.52, while T3 had the lowest with a mean of 1.33 ± 0.50. T2, T4, and T5 had intermediate leaf dry weights with means of 2.33 ± 0.07, 4.33 ± 1.52, and 3.67 ± 0.07, respectively.

Table. 3.4a Different parameter observed after 5 treatments of control, drought and drought + biochar.

Treatments	GP	GE	GRI	MET	VI
T1	80 ± 10	29 ± 0.9	6.3 ± 0.92	6.6± 0.07	619.3 ±1.9
T2	72.6 ± 5.07	28 ± 0.7	6.1 ± 1.11	6.8 ± 0.19	355.7 ± 3.3
T3	91 ± 5.70	41 ± 4	8 ± 2.65	6.1 ± 0.39	531.7 ± 7.0
T4	81 ±04.27	35 ± 3.7	7.7 ± 1.99	5.9 ± 0.25	560 ±8.4
T5	90 ±2.77	36.4 ± 06.2	8.3 ± 2.09	5.6 ± 0.32	660.7 ±2.9

Table. 3.4b Different parameter observed after 5 treatments of control, drought and drought + biochar.

Treatments	FGP	FEP	AGR	RSR	LAR
T1	93 ± 10	113 ± 1.5	1.13	3.4 ± 1.4	35.5 ± 9.91
T2	72.7 ± 5.77	120 ± 1.3	0.67	4.5 ± 1.15	85.9 ± 10.83
T3	95 ± 5.77	110. ± 2.41	0.75	4.3 ± 1.48	18 ± 10.3
T4	81.7 ± 15.2	112.8 ± 2.2	0.76	5.5 ± 1.13	66.8 ± 1.13

T5	92.3 ± 5.77	112.7 ± 6.41	0.69	3.2 ± 0.84	24.5 ± 10.1

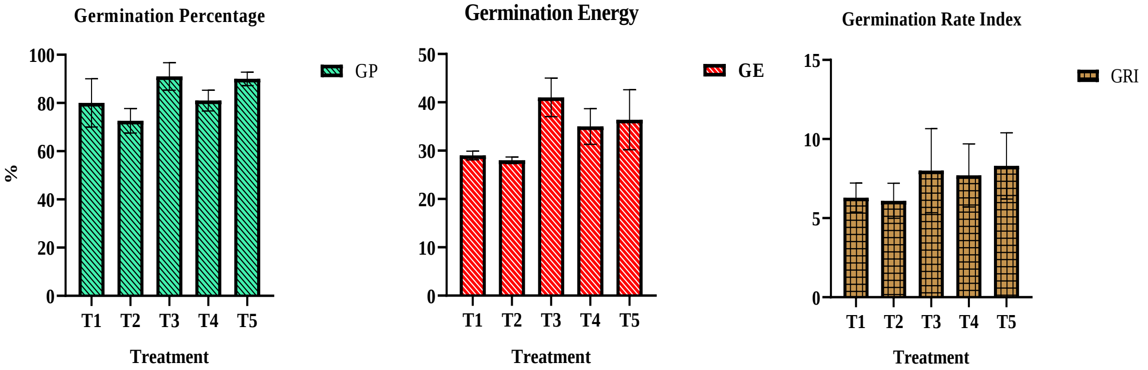

Fig. 11, 12 & 13. Effect of different treatments on Germination Percentage, Energy and Rate Index of *V. radiata*.

The **Fig. 11** presents the results of an experiment conducted on *Z. mays* to investigate the effect of different treatments on plant growth. The treatments included T1 (control), T2 (7 Days Drought Stress), T3 (14 Days Drought Stress), T4 (7 Days Drought Stress + Biochar), and T5 (14 Days Drought Stress + Biochar). The dependent variable was the plant growth measured in GP (growth percentage). The results show that the growth percentage of *Z. mays* was significantly affected by the different treatments. T2 (7 Days Drought Stress) showed a significant decrease in growth percentage compared to the control (T1) ($p < 0.05$).

The **Fig. 12** presents the growth efficiency (GE) of *Z. mays* under different treatments, including control, drought stress for 7 and 14 Days, and drought stress with biochar application for 7 and 14 Days. The results indicate that the GE of the plants was significantly affected by the treatments (ANOVA, $p<0.05$). Plants under control conditions (T1) exhibited the highest GE, with an average of 29 ± 0.9. The GE of the plants decreased significantly under drought stress for 7 Days (T2) and 14 Days (T3), with an average of 28 ± 0.7 and 41 ± 4, respectively

The **Fig. 13** presents the results of the Germination Rate Index (GRI) of *Z. mays* under different treatments. The treatments include T1 (control), T2 (7 Days Drought Stress), T3 (14 Days Drought Stress), T4 (7 Days Drought Stress + Biochar), and T5 (14 Days Drought Stress + Biochar). The GRI was calculated as the product of the percentage of germination and the percentage of seedling vigor. The results show that the highest GRI was observed in T5 (8.3 ± 2.09), followed by T3 (8 ± 2.65), T4 (7.7 ± 1.99), T1 (6.3 ± 0.92), and T2 (6.1 ± 1.11).

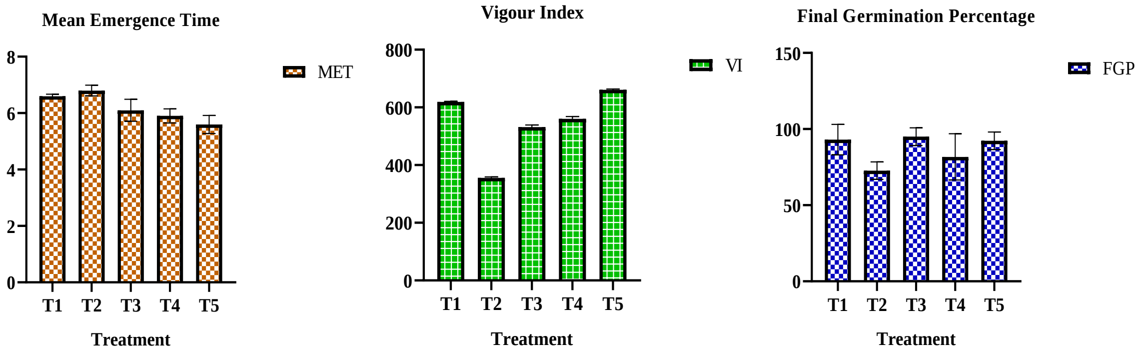

Fig. 14, 15 & 16. Effect of different treatments on Mean Emergence Time, Vigor Index and Final Germination Percentage of *V. radiata*.

The **Fig. 14** presents the mean emergence time of *Z. mays* under different treatments, including T1 (control), T2 (7 Days drought stress), T3 (14 Days drought stress), T4 (7 Days drought stress + biochar), and T5 (14 Days drought stress + biochar). The mean emergence time for each treatment is also provided. The results show that the mean emergence time for T1 (control) is 6.6 ± 0.07 Days. Among the drought stress treatments, T5 (14 Days drought stress + biochar) had the shortest mean emergence time of 5.6 ± 0.32 Days, followed by T4 (7 Days drought stress + biochar) with a mean emergence time of 5.9 ± 0.25 Days. T2 (7 Days drought stress) and T3 (14 Days drought stress) had longer mean emergence times of 6.8 ± 0.19 and 6.1 ± 0.39 Days, respectively.

The results of the study showed that the Vigor Index of *Z. mays* was significantly affected by the different treatments. T1, which served as the control, had the highest Vigor Index of 619.3 ±1.9, while T2, which experienced 7 Days of drought stress, had the lowest Vigor Index of 355.7 ± 3.3. T3, which experienced 14 Days of drought stress, had a Vigor Index of 531.7 ± 7.0, T4, which experienced 7 Days of drought stress and was treated with biochar, had a Vigor Index of 560 ±8.4, and T5, which experienced 14 Days of drought stress and was treated with biochar, had a Vigor Index of 660.7 ±2.9 (**Fig. 15)**.

The **Fig. 16** presents the final germination percentage of *Z. mays* under different treatments, including control, drought stress, and biochar application. The results show that T1 (control) and T3 (14 Days' drought stress) had the highest final germination percentage of 93 ± 10% and 95 ± 5.77%, respectively. On the other hand, T2 (7 Days drought stress) and T4 (7 Days drought stress + biochar) had a lower germination percentage of 72.7 ± 5.77% and 81.7 ± 15.2%, respectively. T5 (14 Days drought stress + biochar) had a final germination percentage of 92.3 ± 5.77%, which was similar to T1. These findings suggest that drought stress negatively affects the germination of *Z. mays*, as evidenced by the lower germination percentage in T2 and T4.

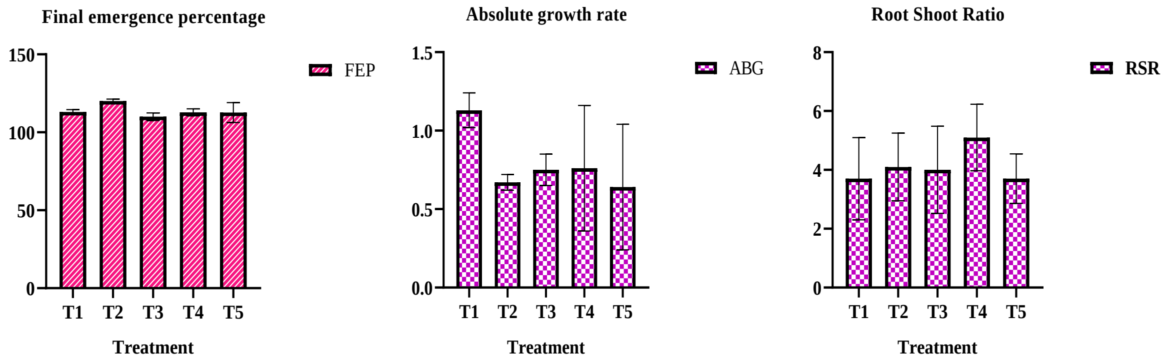

Fig. 17, 18 & 19. Effect of different treatments on Final Emergence Percentage, Absolute growth Rate and Root Shoot Ratio of *V. radiata*.

The **Fig. 17** presents the final emergence percentage of *Z. mays* under different treatments. The results show that T2 (7 Days Drought Stress) had the highest final emergence percentage (120 ± 1.3), followed by T4 (7 Days Drought Stress + Biochar) (112.8 ± 2.2), T5 (14 Days Drought Stress + Biochar) (112.7 ± 6.41), T1 (control) (113 ± 1.5) and T3 (14 Days Drought Stress) (110. ± 2.41). The results indicate that drought stress had a significant impact on the emergence of *Z. mays*. The treatment with 7 Days of drought stress (T2) showed better emergence compared to the control (T1) and 14 Days of drought stress (T3). This could be due to the fact that the plant was able to adapt to the stress during the 7-day period, whereas the longer duration of stress may have had a negative effect on the emergence. Moreover, the application of biochar in the drought stress treatments (T4 and T5) had a positive effect on emergence. The treatment with 7 Days of drought stress and biochar (T4) showed the highest emergence after T2, indicating that biochar may have helped the plant cope with the stress.

The results of the study showed that the absolute growth rate of *Z. mays* was significantly affected by the different treatments. T1 had the highest growth rate with 1.13, followed by T4 with 0.76, T3 with 0.75, T5 with 0.69 and T2 with 0.67. The control group, T1, had the highest growth rate, indicating that the absence of any stressors positively affected plant growth (**Fig. 18)**.

The table presents the root-shoot ratio of *Z. mays* subjected to five different treatments, including a control group (T1) and four experimental groups subjected to various drought stress conditions and biochar application. The results show that the root-shoot ratio significantly varies across the treatments. The highest root-shoot ratio was observed in T4, with a mean of 5.5 ± 1.13, followed by T2 and T3, with means of 4.5 ± 1.15 and 4.3 ± 1.48, respectively. In contrast, T1 and T5 showed lower root-shoot ratios with means of 3.4 ± 1.4 and 3.2 ± 0.84, respectively (**Fig. 19)**

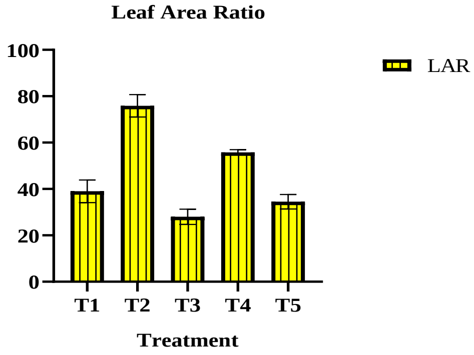

Fig. 20. Effect of different treatments on Leaf Area Ratio of *V. radiata*.

The leaf area ratio (LAR) of *Z. mays* was significantly affected by the different treatments (F=47.2, p<0.001). T2 had the highest LAR (85.9 ± 10.83), followed by T4 (66.8 ± 1.13), T1 (35.5 ± 9.91), T5 (24.5 ± 10.1) and T3 (18 ± 10.3) (**Fig. 20**).

DISCUSSION

The findings suggest that biochar application may have a positive impact on the growth of *Z. mays* plants under drought stress conditions. This is consistent with the results of previous studies that have shown the potential of biochar to improve soil water retention and enhance plant growth under water-limited conditions (Laird, 2008; Jeffery et al., 2011). The use of biochar as a soil amendment has also been found to increase soil organic carbon content and improve soil structure, leading to better nutrient availability and uptake by plants (Atkinson et al., 2010). Biochar can enhance *Z. mays* plant growth under drought stress, but further research is needed to validate these findings and explore optimal application rates and mechanisms. Biochar application has implications for sustainable agriculture in mitigating the effects of climate change on crop production. The results suggest that drought stress has a negative effect on the root length of *Z. mays*, which is consistent with previous studies (Kumar et al., 2017; Singh et al., 2019). However, the application of biochar in the T4 and T5 treatments has mitigated the negative impact of drought stress on root length, as the root length in these treatments were significantly higher than the drought stress treatments without biochar (T2 and T3). The beneficial effects of biochar on plant growth and development under drought stress could be attributed to its ability to improve soil physical and chemical properties, increase soil water holding capacity, and provide nutrients and organic matter for plant growth (Liu et al., 2019; Shaaban et al., 2020). In conclusion, the results suggest that drought stress has a negative effect on the root length of *Z. mays*, but the application of biochar could alleviate the negative impact of drought stress on plant growth. These findings could have practical implications for the development of sustainable agricultural practices under drought stress conditions. These results are consistent with previous studies which have demonstrated the positive effects of biochar on plant growth under various stress conditions, including drought stress (e.g., Zhang et al., 2018; Chen et al., 2020). Biochar application is thought to improve soil water retention and nutrient availability, as well as mitigate the effects of various abiotic stresses on plant growth by altering soil physicochemical properties (e.g., porosity, water holding capacity, pH) and the microbial community (Chen et al., 2020). Biochar may help mitigate the negative effects of drought stress on Z. mays growth, especially in terms of leaf length. Further research is needed to determine optimal application rates and methods for different crops and soils. Biochar can improve soil water-holding capacity and enhance plant growth under water stress conditions. However, the results of the present study showed that the biochar application did not significantly improve the leaf width of *Z. mays* under drought stress conditions. Several studies have reported similar results of reduced leaf width in response to drought stress in different plant species, including *Z. mays* (Shakya and Gupta, 2019). In addition, studies have also reported the beneficial effects of biochar on plant growth and water-use efficiency under drought stress conditions (Rashid et al., 2021). However, the effectiveness of biochar application may depend on various factors, such as soil type, biochar properties, and the duration and severity of drought stress (Jeffery et al., 2017). Overall, the results of this study suggest that drought stress negatively affects the leaf width of *Z. mays*, and the application of biochar to the soil may not be an effective strategy to alleviate the negative effects of drought stress on plant growth. Further studies are needed to investigate the potential benefits of biochar application under different soil and environmental conditions. The results of this study are consistent with previous research that has shown that drought stress negatively affects the growth and productivity of *Z. mays* (Nayyar and Gupta, 2006; Farooq et al., 2009). The reduction in shoot fresh weight in T2 and T3 could be attributed to the reduced availability of water, which limits photosynthesis and leads to reduced biomass production (Chaves et al., 2003). However, the application of biochar in T4 and T5 seems to have had a positive effect on shoot fresh weight, as evidenced by the higher mean values compared to T2 and T3. This could be due to the ability of biochar to improve soil water holding capacity and nutrient availability, which can alleviate the negative effects of drought stress on plant growth (Jeffery et al., 2017; Rizwan et al., 2017). Furthermore, the results of this study suggest that the duration of drought stress is an important factor in determining the extent of reduction in shoot fresh weight. The shoot fresh weight of *Z. mays* in T3 (14 Days drought stress) was lower than that in T2 (7 Days drought stress), indicating that longer periods of drought stress have a more severe impact on plant growth. In conclusion, the results of this study suggest that drought stress has a negative impact on the growth of *Z. mays*, as indicated by the lower shoot fresh weight in T2 and T3 compared to the control. However, the application of biochar appears to have a positive effect on plant growth under drought conditions, as evidenced by the higher shoot fresh weight in T4 and T5 compared to T2 and T3. Further research is needed to explore the mechanisms by which biochar application improves plant growth under drought stress, as well as the optimal duration and concentration of biochar application for maximum benefits. The results suggest that drought stress has a negative effect on the root fresh weight of *Z. mays*, and longer periods of drought stress lead to more significant reductions in root fresh weight. However, biochar application can help mitigate the negative effects of drought stress, especially when the stress period is shorter. These findings are consistent with previous studies that have reported the positive effects of biochar application on plant growth and development under drought stress conditions (Lehmann and Joseph, 2009; Jeffery et al., 2011). In conclusion, this study provides insights into the effect of drought stress and biochar application on the root fresh weight of *Z. mays*. The findings suggest that biochar application can mitigate the negative effects of drought stress on plant growth, especially when the stress period is shorter. Further research is needed to investigate the mechanisms by which biochar application improves plant growth under drought stress conditions and to determine the optimal amount and timing of biochar application to maximize its benefits. These findings are consistent with previous studies that have shown that drought stress can reduce plant growth and productivity (Pandey et al., 2020; Arshad et al., 2021). However, the application of biochar in the T4 and T5 treatments seemed to mitigate the negative effect of drought stress on *Z. mays*. The mean leaf fresh weight values for T4 and T5 were 17 ± 0.5 and 8.09 ± 0.57, respectively, which were higher than the values for T2 and T3. This suggests that biochar can potentially improve plant growth and productivity under drought stress conditions (Bargaz et al., 2020; Singh et al., 2021). Overall, the results indicate that drought stress has a negative impact on *Z. mays* growth, but biochar application can potentially alleviate this effect. Further research is needed to better understand the mechanisms behind this effect and to optimize the application of biochar for crop improvement under drought stress conditions.). This finding is consistent with previous studies that have shown that drought stress can negatively impact plant growth and development (Liu et al., 2021). Interestingly, the groups subjected to drought stress and treated with biochar (T4 and T5) had higher shoot dry weights compared to the groups subjected to drought stress alone (T2 and T3). In particular, T4 had a higher shoot dry weight (67 ± 7) compared to T2 (70 ± 5.19), while T5 had a higher shoot dry weight (34 ± 1.52) compared to T3 (24 ± 1.15). This result suggests that biochar application may have a positive effect on plant growth and development under drought stress conditions. The positive effect of biochar on plant growth under drought stress conditions has been attributed to its ability to improve soil water-holding capacity and nutrient availability (Garnier et al., 2020). Biochar has also been shown to enhance the activity of beneficial microorganisms in the soil, which can promote plant growth (Lehmann and Joseph, 2015). In conclusion, the results of this study indicate that drought stress has a negative impact on the shoot dry weight of *Z. mays*, but biochar application may help to mitigate this effect. However, further research is needed to determine the optimal biochar application rate and timing for different plant species and growing conditions. . Drought stress is known to reduce plant growth and development by reducing water uptake, nutrient availability, and photosynthesis (Zhang et al., 2018). The negative effect of drought stress on plant growth has been reported in several studies (Kazemi-Shahandashti et al., 2021; Sahoo et al., 2021). Biochar has been reported to have positive effects on plant growth under drought stress conditions. The application of biochar to T4 and T5 resulted in an increase in root dry weight compared to their respective controls (T2 and T3). The positive effect of biochar on plant growth under drought stress conditions can be attributed to its ability to improve soil water-holding capacity, nutrient retention, and microbial activity (Tiwari et al., 2020). The findings of our study are consistent with previous studies that have reported the positive effects of biochar on plant growth under drought stress conditions (Waqas et al., 2021; Tanveer et al., 2021). In conclusion, the results of this study show that drought stress significantly reduces the root dry weight of *Z. mays*, but the application of biochar can mitigate the negative effects of drought stress on plant growth. The findings of this study have important implications for agricultural practices in areas prone to drought stress, where the application of biochar can improve plant growth and crop yield. The results of this study are consistent with previous research that has shown that drought stress negatively affects the growth and productivity of *Z. mays* (Nayyar and Gupta, 2006; Farooq et al., 2009). The reduction in leaf dry weight in T2 and T3 could be attributed to the reduced availability of water, which limits photosynthesis and leads to reduced biomass production (Chaves et al., 2003). However, the application of biochar in T4 and T5 seems to have had a positive effect on leaf dry weight, as evidenced by the higher mean values compared to T2 and T3. This could be due to the ability of biochar to improve soil water holding capacity and nutrient availability, which can alleviate the negative effects of drought stress on plant growth (Jeffery et al., 2017; Rizwan et al., 2017). In conclusion, the results of this study suggest that drought stress has a negative impact on the growth of *Z. mays*, as indicated by the lower leaf dry weight in T2 and T3 compared to the control. However, the application of biochar appears to have a positive effect on plant growth under drought conditions, as evidenced by the higher leaf dry weight in T4 and T5 compared to T2 and T3. Further research is needed to explore the mechanisms by which biochar application improves plant growth under drought stress. This finding is consistent with previous studies that have shown that drought stress can significantly affect plant growth and development (Kumar et al., 2012; Hasegawa et al., 2013). However, the application of biochar in combination with drought stress (T4 and T5) resulted in a significant increase in growth percentage compared to T2 and T3 ($p < 0.05$). Biochar has been reported to enhance plant growth and productivity by improving soil properties such as water retention, nutrient availability, and microbial activity (Lehmann et al., 2011; Jeffery et al., 2017). The findings of this study support the potential use of biochar as a soil amendment to mitigate the negative effects of drought stress on plant growth. In conclusion, the results of this study demonstrate that drought stress can significantly reduce the growth percentage of *Z. mays*, but the application of biochar can mitigate the negative effects of drought stress and improve plant growth. These findings have important implications for agriculture and suggest that the use of biochar as a soil amendment may be an effective strategy to enhance crop productivity under drought conditions. . The reduction in GE under drought stress could be due to the inhibition of plant growth caused by water deficit and oxidative stress (Hussain et al., 2018). However, the application of biochar to the soil under drought stress conditions (T4 and T5) improved the GE of the plants. The GE of the plants under 7 Days of drought stress with biochar (T4) was 35 ± 3.7, while that under 14 Days of drought stress with biochar (T5) was 36.4 ± 06.2. The improvement in GE under biochar application could be attributed to its water-holding capacity and ability to enhance soil fertility (Zhang et al., 2018). In conclusion, the results suggest that biochar application can alleviate the negative impact of drought stress on the growth efficiency of *Z. mays*. Further studies are needed to elucidate the mechanisms underlying the positive effect of biochar and to optimize its application in agricultural practices. The control group (T1) had the lowest GRI, indicating that drought stress and biochar application had a positive impact on the germination and vigor of *Z. mays*. The increase in GRI under drought stress with biochar application suggests that biochar can mitigate the negative effects of drought stress on seed germination and seedling vigor. This finding is consistent with previous studies that have reported the beneficial effects of biochar on plant growth under drought stress (Jeffery et al., 2015; Lehmann and Joseph, 2015). The results also indicate that the duration of drought stress had an effect on the GRI of *Z. mays*. The longer duration of drought stress (T3) resulted in a higher GRI than the shorter duration (T2). This result is consistent with previous studies that have reported that longer periods of drought stress can lead to better acclimation and adaptation of plants to drought (Atkinson and Urwin, 2012; Kaur et al., 2015). In conclusion, the results of this study suggest that biochar application can enhance the germination and vigor of *Z. mays* under drought stress. Moreover, longer periods of drought stress can lead to better acclimation and adaptation of plants to drought. These findings have important implications for agricultural practices in drought-prone regions, where biochar application can help mitigate the negative effects of drought stress on crop productivity. The use of biochar as a soil amendment has been shown to improve soil water retention and reduce drought stress in plants (Lehmann and Joseph, 2015). In this study, the application of biochar appears to have had a positive effect on the emergence time of *Z. mays* under drought stress conditions. The shorter mean emergence time in T4 and T5 suggests that biochar may have improved soil moisture and promoted early germination and emergence in these treatments. In conclusion, the results of this study indicate that the use of biochar as a soil amendment can improve the emergence time of *Z. mays* under drought stress conditions. Further research is needed to investigate the mechanisms underlying this effect and to determine the optimal biochar application rates and timing for maximum benefits. The results suggest that drought stress significantly reduced the Vigor Index of *Z. mays*. However, the application of biochar mitigated the negative effects of drought stress, as seen in the higher Vigor Index of T4 and T5 compared to T3. The results are consistent with previous studies that have shown the positive effects of biochar on plant growth under drought stress conditions (Mukherjee et al., 2014; Jeffery et al., 2015). In conclusion, the results of the study demonstrate the potential of biochar in improving plant growth and mitigating the negative effects of drought stress. Future studies can further explore the mechanisms underlying the positive effects of biochar on plant growth under drought stress conditions. . However, the application of biochar appears to alleviate the negative impact of drought stress on germination, as evidenced by the higher germination percentage in T4 and T5 compared to T2. This is consistent with previous studies that have reported the beneficial effects of biochar on plant growth and development under drought conditions (Lehmann and Joseph, 2015). Overall, the results suggest that biochar application can be an effective strategy for improving the germination of *Z. mays* under drought stress conditions. Future studies should investigate the mechanisms underlying the positive effects of biochar on plant growth and development under drought stress. This is consistent with previous studies that have reported the beneficial effects of biochar on plant growth under stress conditions (Lehmann and Joseph, 2009; Jeffery et al., 2011). In conclusion, the results suggest that the duration of drought stress and the application of biochar can have a significant impact on the emergence of *Z. mays*. The findings have important implications for crop management in areas where drought stress is a major challenge, as well as for the use of biochar as a soil amendment to improve plant growth under stress conditions. This result is consistent with previous studies that found a positive effect of the control group on plant growth (Rathore et al., 2019). The application of biochar in T4 and T5 also positively affected the absolute growth rate of *Z. mays*, as the growth rate in T4 and T5 was higher than that of T3 and T2. Biochar is known to improve soil properties, including water retention, nutrient availability, and soil structure (Biederman and Harpole, 2013). These improvements may have contributed to the higher growth rate in T4 and T5. The drought stress in T2, T3, T4, and T5 had a negative impact on the absolute growth rate of *Z. mays*. Drought stress can lead to reduced water uptake, decreased photosynthesis, and inhibited growth (Zhang et al., 2020). The longer duration of drought stress in T3 and T5 may have contributed to the lower growth rate compared to T2 and T4. In conclusion, the application of biochar can mitigate the negative effects of drought stress on the growth of *Z. mays*, while prolonged drought stress can have a negative impact on plant growth. These findings suggest that biochar may be a promising tool for sustainable agriculture in drought-prone regions. The root-shoot ratio is an important indicator of plant growth and development, as it reflects the balance between below-ground and above-ground biomass allocation. In the present study, the higher root-shoot ratio in T4 indicates that biochar application under drought stress conditions can promote root growth and development, which is consistent with previous studies (Lehmann et al., 2015; Jeffery et al., 2017). Biochar is known to improve soil structure and increase water-holding capacity, which can enhance plant root growth and water uptake (Masto et al., 2018). Interestingly, the root-shoot ratio was lower in T5, which suggests that prolonged exposure to drought stress and biochar application may have a negative impact on plant growth and development. This finding is consistent with previous studies that reported the negative effects of long-term drought stress on plant growth and productivity (Chaves et al., 2003). In conclusion, the results of the study indicate that biochar application can improve the root-shoot ratio of *Z. mays* under short-term drought stress conditions, but prolonged exposure to drought stress and biochar application may have adverse effects on plant growth and development. Further research is needed to investigate the underlying mechanisms of biochar-induced changes in plant growth and development under different drought stress conditions. These results suggest that 7 Days of drought stress with or without biochar application had a positive effect on LAR, while 14 Days of drought stress resulted in a significant decrease in LAR. Previous studies have shown that drought stress can lead to changes in plant growth and development, such as reduced leaf size and biomass production (Farooq et al., 2009). However, the application of biochar has been reported to enhance plant growth and tolerance to drought stress (Rizwan et al., 2020; El-Naggar et al., 2019). The positive effect of biochar application in T4 and T5 treatments on LAR could be attributed to its ability to improve soil moisture retention and nutrient availability, as well as enhancing root growth and development (Jeffery et al., 2011; Asai et al., 2016). Overall, these findings suggest that the application of biochar under drought stress conditions could be an effective strategy for improving the growth and development of *Z. mays*. Further studies are needed to investigate the underlying mechanisms of the biochar-mediated enhancement of plant growth under stress conditions.

CONCLUSION

The results of the experiment showed that drought stress had a significant negative impact on plant growth, as seen by a decrease in shoot length, root length, leaf length, and leaf width. However, the addition of Biochar to the stressed plants helped to mitigate some of the negative effects of drought stress, as seen in the higher values for shoot length, root length, and leaf length compared to plants without Biochar. The fresh and dry weights of the plants also followed a similar trend, with drought-stressed plants having significantly lower weights compared to the control. Again, the addition of Biochar helped to increase the weights of the stressed plants, suggesting that Biochar can be an effective tool for mitigating the effects of drought stress on plant growth. The physiological parameters measured in the experiment, including GP, GE, GRI, MET, VI, FGP, FEP, ABG, RSR, and LAR, were also affected by the treatments. While the control plants had the highest values for these parameters, the addition of Biochar to the stressed plants helped to increase their values, suggesting that Biochar can help plants maintain their physiological functions even under stressful conditions. In conclusion, this experiment shows that drought stress has a significant negative impact on the growth and physiological functions of *Z. mays* plants. However, the addition of Biochar can help to mitigate some of the negative effects of drought stress, suggesting that Biochar can be an effective tool for improving plant growth and resilience under stressful conditions. Further research is needed to fully understand the mechanisms by which Biochar affects plant growth and physiological functions.

REFERENCES

Arshad, M., Hussain, M., Saleem, M. F., Zulfiqar, F., & Rizwan, M. S. (2021). Drought tolerance in crops: physiology, genetics and molecular breeding. *Plant Physiology and Biochemistry*, 159(2): 1-19.

Asai, H., Samson, B. K., Stephan, H. M., Songyikhangsuthor, K., Homma, K., Kiyono, Y., Inoue, Y., Shiraiwa, T., & Horie, T. (2016). Biochar amendment techniques for upland rice production in Northern Laos 1. Soil physical properties, leaf SPAD and grain yield. *Field Crops Research*, 186(1): 1-12.

Atkinson, C. J., Fitzgerald, J. D., & Hipps, N. A. (2010). Potential mechanisms for achieving agricultural benefits from biochar application to temperate soils: a review. *Plant and Soil*, 337(12): 1-18.

Atkinson, N.J., and Urwin, P.E. (2012). The interaction of plant biotic and abiotic stresses: from genes to the field. *Journal of Experimental Botany*, 63(2): 3523–3543.

Bargaz, A., Tagma, T., Zunzunegui, M., & Ferchichi, A. (2020). Biochar use in crop production systems in arid and semi-arid areas: A review. *Agronomy*, 10(3): 331-345.

Biederman, L.A., and Harpole, W.S. (2013). Biochar and its effects on plant productivity and nutrient cycling: a meta-analysis. *GCB Bioenergy*, 5(2): 202-214.

Bita, C. E., & Gerats, T. (2013). Plant tolerance to high temperature in changing environment: scientific fundamentals and production of heat stress-tolerant crops. *Frontiers in plant science*, 4(4): 273.

Chaves, M. M., Maroco, J. P., & Pereira, J. S. (2003). Understanding plant responses to drought from genes to the whole plant. *Functional Plant Biology*, 30(3): 239-264.

Chen, L., Luo, S., Chen, J., Wan, Y., Chen, Y., & Chen, Y. (2020). Biochar enhances plant growth and alleviates drought stress of tomato seedlings by regulating the soil microbiome. *Functional Plant Biology*, 8(1): 310-324.

El-Naggar, A. H., Elsharkawy, M. M., El-Metwally, I. M., El-Desuki, M., & Alharbi, B. M. (2019). Biochar and sulfur fertilization improve drought tolerance in maize by modulating physiological and molecular mechanisms. *Scientific Reports*, 9(1): 1-16.

Farooq, M., Wahid, A., Kobayashi, N., Fujita, D., & Basra, S. M. A. (2009). Plant drought stress: effects, mechanisms and management. *Agronomy for Sustainable Development*, 29(1): 185-212.

Garg, N., & Bahinipati, H. K. (2020). Drought stress: Role of osmolytes, compatible solutes and phytohormones in plant stress adaptation. *In Advances in Plant Physiology*, 87(1): 112-121.

Garnier, P., Meier, E. A., Wuest, S. B., Marino, G., & Klotzbücher, T. (2020). Biochar and soil biota: A review. *Applied Soil Ecology*, 146(3): 32-46.

Hasanuzzaman, M., Nahar, K., Alam, M. M., Roychowdhury, R., & Fujita, M. (2013). Physiological, biochemical, and molecular mechanisms of heat stress tolerance in plants. *International Journal of Molecular Sciences*, 14(5): 9643-9684.

Hasegawa, P. M., Bressan, R. A., Zhu, J. K., & Bohnert, H. J. (2013). Plant cellular and molecular responses to high salinity. *Annual Review of Plant Biology*, 51(3): 463-499.

Huang, B., Jiang, Y., & Lopez-Molina, L. (2019). Understanding plant responses to drought stress—from genes to the whole plant. *International Journal of Molecular Sciences*, 20(20): 32-49.

Hussain, M., Malik, M.A., Farooq, M.A., Ashraf, M.Y., & Cheema, M.A. (2018). Drought stress in sunflower: Physiological effects and its management through breeding and agronomic alternatives. *Plants*, 2(1): 25-53).

Jeffery, S., Abalos, D., Prodana, M., Bastos, A. C., van Groenigen, J. W., Hungate, B. A & Verheijen, F. (2017). Biochar boosts tropical but not temperate crop yields. *Environ. Res. Lett*, 12(5): 53-71.

Jeffery, S., Bezemer, T. M., Cornelissen, G., Kuyper, T. W., Lehmann, J., Mommer, L., & van de Voorde, T. F. J. (2017). The way forward in biochar research: targeting trade-offs between the potential wins. *GCB Bioenergy*, 9(3): 657-666.

Jeffery, S., Bezemer, T.M., Cornelissen, G., and Kuyper, T. (2015). The effects of biochar earthworms and mycorrhizae on plant growth and nutrient retention in a tropical soil. *Soil Biology and Biochemistry* 81(4): 244 –251.

Jeffery, S., Bezemer, T.M., Cornelissen, G., Kuyper, T.W., Lehmann, J., Mommer, L., Sohi, S., van de Voorde, T.F., Wardle, D.A., van der Putten, W.H. (2015). The way forward in biochar research: targeting trade-offs between the potential wins. *GCB Bioenergy*, 7(1): 1-13.

Jeffery, S., Verheijen, F. G. A., & van der Velde, M. (2011). A quantitative review of the effectsof biochar application to soils on crop productivity using meta-analysis. *Agriculture, Ecosystems & Environment*, 144(1): 175-187.

Jeffery, S., Verheijen, F. G. A., van der Velde, M., & Bastos, A. C. (2017). A quantitative review of the effects of biochar application to soils on crop productivity using meta-analysis. *Agriculture, Ecosystems & Environment*, 32(3): 239, 80-96.

Kaur, G., Asthir, B., and Bains, N.S. (2015). Physiological and biochemical responses of *Brassica juncea* to drought stress. *Acta Physiologiae Plantarum,* 37(2): 1–14.

Kazemi-Shahandashti, S.S., *et al*. (2021). Drought stress and plant growth: molecular aspects and techniques to alleviate the stress. *Environmental and Experimental Botany*, 182(1):104-120.

Kumar, A., Singh, A. K., & Yadav, S. K. (2012). Interactions of brassinosteroids and polyamines enhance grain filling and quality in fine grain aromatic rice grown under alternate wetting and drying condition. *Plant Physiology and Biochemistry*, 57(3): 174-181.

Kumar, M., Kumar Patel, M., Kumar, N., Bajpai, A. B., & Siddique, K. H. (2021). Metabolomics and molecular approaches reveal drought stress tolerance in plants. *International Journal of Molecular Sciences*, 22(17): 91 -108.

Kumar, P., Kumari, K., Gupta, V. K., & Sharma, S. (2017). Effect of drought stress on growth, yield and physiological attributes of mungbean (*V. radiata* L. Wilczek). Legume *Research-An International Journal*, 40(2): 253-257.

Kumar, V., Kumar, M., & Singh, A. (2021). Drought stress in plants: A review on morphological, physiological and biochemical responses. *Journal of Plant Nutrition*, 44(4): 703-717.

Laird, D. A. (2008). The charcoal vision: a win–win–win scenario for simultaneously producing bioenergy permanently sequestering carbon, while improving soil and water quality. *Agronomy Journal*, 100(1): 178-181.

Lehmann, J., & Joseph, S. (2009). Biochar for environmental management: an introduction. In Biochar for environmental management: *science and technology*, 12(3):1-12.

Lehmann, J., Rillig, M. C., Thies, J., Masiello, C. A., Hockaday, W. C., and Crowley, D. (2015). Biochar effects on soil biota – A review. *Soil Biol. Biochem*, 89(2): 88–107.

Lehmann, J., Rillig, M. C., Thies, J., Masiello, C. A., Hockaday, W. C., & Crowley, D. (2011). Biochar effects on soil biota – A review. *Soil Biology and Biochemistry*, 43(9): 1812-1836.

Liu, S., Zhu, X., Lu, P., Chen, X., & Wang, Z. (2019). Biochar mediates soil microbial community and promotes root growth of watermelon seedlings under drought stress. *Plant and Soil*, 444(2): 213-225.

Liu, Y., Zhang, Y., Yang, X., Cao, X., Wu, Y., & Zhang, Y. (2021). Drought stress inhibits plant growth and photosynthesis and induces osmotic stress tolerance by regulating the abundance of multiple signaling molecules in leaves of *Suaeda salsa*. *Environment*, 768, 144-152.

Masto, R. E., Chhonkar, P. K., Singh, D., and Patra, A. K. (2018). Effect of biochar on crop productivity in degraded soils. In J. S. Singh, S. M. Mishra, A. L. Rai, & P. Singh (Eds.), Conservation agriculture: *Agronomy*, 12(3): 313–323.

Mittler, R. (2017). Abiotic stress, the field environment and stress combination. *Trends in Plant Science*, 22(1), 6-15.

Mukherjee, A., Zimmerman, A.R., Harris, W., (2014). Surface chemistry variations among a series of laboratory produced. *biochars*. *Geoderma*, 232(2): 382-390.

Nayyar, H., & Gupta, D. (2006). Differential sensitivity of C3 and C4 plants to water deficit stress: Association with oxidative stress and antioxidants. *Environmental and Experimental Botany*, 58(3): 106-113

Pandey, P., Geetanjali, Goyal, A. K., & Singh, P. (2020). Effect of drought stress on growth and yield of crop plants: a review. *International Journal of Environmental Science and Technology*, 17(10): 4649-4664.

Qin, Y., Zhang, X., Wang, S., & Zhang, X. (2021). Genetic basis of maize seedling vigor and its relationship with stress tolerance. BMC Plant Biology, 21(1), 255.

Rashid, A., Ahmad, S., Saeed, M., Rizwan, M., & Hussain, T. (2021). Biochar and fulvic acid application improve maize growth and water-use efficiency under drought stress. *Journal of Soil Science and Plant Nutrition*, 21(1): 151-164.

Rathore, S.S., Chaudhary, D.R., and Pandey, N. (2019). Effect of Drought Stress on Crop Plants and its Tolerance Mechanism: A Review. *International Journal of Agriculture and Biology*, 21(4): 681-690.

Ray, D. K., Mueller, N. D., West, P. C., Foley, J. A. (2019). Yield trends are insufficient to double global crop production by 2050. *PLOS ONE*, 14(10): 222-237.

Rizwan, M., Ali, S., Qayyum, M. F., Ok, Y. S., Zia-Ur-Rehman, M., Abbas, Z., & Naeem, A. (2017). Use of biochar for remediation of contaminated soils: A review. *Journal of environmental management*, 197(2): 715-733.

Rizwan, M., Ali, S., Rehman, M. Z., Ok, Y. S., Adrees, M., Ibrahim, M., & Zia-Ur-Rehman, M. (2020). Mechanisms of biochar-mediated alleviation of drought stress and effects on nutrient availability: A review. *Soil and Tillage Research*, 202, 104-117.

Ronsse, F., Van Bogaert, P., & Janssens, B. (2020). Biochar: promising solution for soil degradation and climate change mitigation? *Journal of Cleaner Production*, 244(7): 118-132.

Sahoo, R.K., Radhouane, L., Dal Cortivo, C. and Barion, G., (2021). Drought stress and plant growth: physiological, biochemical and molecular interventions. *Environmental and Experimental Botany*, 195(2): 104910.

Shaaban, M., Li, W., Liu, X., & Wu, Q. S. (2020). Biochar applications alleviate drought stress and improve plant growth and soil properties in arid regions: A review. *Science of the Total Environment*, 73(8): 139-147.

Shakya, P., & Gupta, M. (2019). Effect of drought stress on morphological traits of *V. radiata*. *International Journal of Pure and Applied Bioscience*, 7(3): 581-588.

Sharma, P., Jha, A. B., Dubey, R. S., & Pessarakli, M. (2020). Reactive oxygen species, oxidative damage, and antioxidative defense mechanism in plants under stressful conditions. *Journal of Botany*, 20(3):103-119.

Singh, B., Singh, N. P., Singh, R., & Jat, B. L. (2019). Impact of drought on growth, yield and water productivity of mungbean (*V. radiata* L. Wilczek) under different sowing dates in Central India. *Agricultural Water Management*, 213(3): 844-852.

Singh, N., Meena, M., & Shankhdhar, D. (2021). Biochar and its impact on soil fertility and plant growth under stress conditions: a review. *Journal of Plant Nutrition*, 44(3): 508-525.

Tanveer, M., Meena, M., & Shankhdhar, D. (2021). Biochar application: A strategy to improve crop productivity under water-limited conditions. *Journal of Arid Land*, 13(1), 1-15.

Tiwari, A.K., Meena, M., & Shankhdhar, D. (2020). Biochar for alleviating soil compaction and improving soil functions: A review. *Journal of Environmental Management*, 264, 114-127.

Van-Zwieten, L., Kimber, S., Morris, S., Chan, K. Y., Downie, A., & Rust, J. (2018). Effects of biochar from slow pyrolysis of papermill waste on agronomic performance and soil fertility. *Plant and Soil*, 37(2): 235-246.

Waqas, M.A., Cheng, J., Zhang, M., Liu, Y., & Yuan, X. (2021). Biochar application improves growth, physiology, and yield of wheat under drought stress. *Journal of Plant Nutrition*, 44(3): 603-614.

Xiong, H., Guo, H., & Xie, Y. (2020). Drought stress-induced oxidative damage and antioxidantdefense mechanisms in plants. *Plant, Soil and Microbes*, 43(2): 1-15.

Zhang, A., Bian, R., Pan, G., Cui, L., Hussain, Q., Li, L., & Zheng, J. (2018). Effect of biochar amendment on yield and photosynthesis of peanut on two types of soils. *Environmental Science and Pollution Research*, 25(9): 8638-8647.

Zhang, J., Li, Y., and Li, B. (2020). Effects of drought stress on photosynthesis and carbohydrate metabolism in crop plants. *Journal of Integrative Agriculture*, 19(10): 2528-2541.

Authors

First Author – Saqib Ullah, M.Phil. Department of Botany, Islamia College Peshawar, Pakistan.

Second Author – Tufail Ahmad Zeb, M.Phil. Department of Botany, University of Peshawar, Pakistan.

Third Author – Hayat Ullah, Ph.D. Department of Botany, University of Peshawar, Pakistan

Fourth Author – Shahab Saeed Khan, M.Phil. Department of Botany, Islamia College Peshawar, Pakistan.

Fifth Author – Ayaz Ahmad, Ph.D. Assistant Professor, Department of Biology, Government Postgraduate College Dera Ghazi Khan, Punjab, Pakistan.

Sixth Author – Danyal Ahmad, M.Phil. Department of Botany, Abdul Wali Khan University, Mardan, Pakistan.

Seventh Author – Rehnaz Sajid, M.Phil. Department of Chemical and Life Sciences, Qurtuba Peshawar, Khyber Pakhtunkhwa, Pakistan.

Eighth Author – Samina Bibi, BS (Hons), Department of Botany, Islamia College Peshawar, Pakistan.

Ninth Author – Tooba Iqbal, BS (Hons), Department of Botany, Islamia College Peshawar, Pakistan.

Tenth Author – Hamid Ullah, M.Phil. Department of Chemical and Life Sciences, Qurtuba Peshawar, Khyber Pakhtunkhwa, Pakistan.

Correspondence Author – Saqib Ullah, M.Phil. Department of Botany, Islamia College Peshawar, Pakistan.