International Journal of Plant & Soil Science

Volume 35, Issue 19, Page 986-993, 2023; Article no.IJPSS.105455
ISSN: 2320-7035

Impact of Varying doses of Biochar and INM Practices on Agro Physiological Performance, Yield and Economics of Maize (*Zea mays* L.)

Saurabh Kumar Verma [a++*], Suresh Kumar [a#], Saurabh Kanauajia [b++], Shwetank Shukla [a++], Ritik Arya [b++] and Ravi Verma [c++]

[a] *Department of Soil Science and Agricultural Chemistry, Acharya Narendra Deva University of Agriculture and Technology, Kumarganj, Ayodhya-224229 (Uttar Pradesh), India.*
[b] *Department of Agroforestry, Acharya Narendra Deva University of Agriculture and Technology, Kumarganj, Ayodhya-224229 (Uttar Pradesh), India.*
[c] *Department of Agronomy, Acharya Narendra Deva University of Agriculture and Technology, Kumarganj, Ayodhya-224229 (Uttar Pradesh), India.*

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/IJPSS/2023/v35i193635

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/105455

Original Research Article

Received: 16/06/2023
Accepted: 22/08/2023
Published: 30/08/2023

ABSTRACT

A field experiment was conducted to evaluate the effect of graded doses of biochar and fertility levels with and without biofertilizer under partially reclaimed Sodic Soils on the maize crop during Kharif, 2021 and 2022 at Students Instructional Farm of Acharya Narendra Deva University of

[++] *Research Scholar;*
[#] *Associate Professor;*
**Corresponding author: E-mail: thearuagro2232@gmail.com;*

Agriculture and Technology, Kumarganj Ayodhya. The eight treatments viz. T_1: Control, T_2: 100% (RDF 100:60:40; N P_2O_5, K_2O), T_3: 50% RDF + 2.5 t ha^{-1} biochar, T_4: 50% RDF + 2.5 t ha^{-1} biochar + ZMB Biofertilizer, T_5: 50% RDF + 2.5 t ha^{-1} biochar + ZMB Biofertilizer + Zn, T_6: 100 % RDF + 5 t ha^{-1} biochar, T_7: 100 % RDF + 5 t ha^{-1} biochar + ZMB Biofertilizer, T_8: 100 % RDF + 5 t ha^{-1} biochar + ZMB Biofertilizer + Zn were setup in a Randomized Block Design with replicated thrice. The Kanchan variety (K-25) was taken as a test crop. Significantly, maximum relative growth rate, net assimilation rate and yield were recorded with 100% RDF + 5 t ha^{-1} biochar + ZMB biofertilizer + Zn gave the best results. The highest gross return (₹12674) and net return (₹67162) was obtained with 100 % RDF + 5 t ha^{-1} biochar + ZMB biofertilizer + Zn (T_8).

Keywords: Biochar; fertility levels; maize; yield; economics; relative growth rate; net assimilation rate.

1. INTRODUCTION

Maize belongs to the tribe Maydeae of the grass family Poaceae. In India, In the pre-Green Revolution era, coarse cereals including maize (*Zea mays* L.) were the major crops of the rainy season in northern India. It is a high-yielding crop that is well-suited to the hot, humid and rainy climate of the Kharif season. Kharif maize is an important staple crop for farmers in many parts of India and is used for human consumption, animal feed, and industrial purposes. This crop can be grown in a wide range of soil types and requires proper irrigation, fertilization, and plant protection measures to ensure good yields. In recent years, Kharif maize has gained popularity due to its high nutritional value and adaptability to changing climatic conditions. Maize has got very high potentiality and greater adaptability under various climatic conditions than other cereal crops. Maize is a main source of calories and minerals for most rural populations. It is the most versatile emerging crop having wider adaptability under varied Agro-climatic conditions.

Biochar is a carbon-rich material and is obtained when biomass, such as wood, manure, or leaves, is heated in a closed container with little or no available air and typically produced by oxygen-limited pyrolysis of bio-waste (e.g. straw, branches, manure). Biochar use as a soil amendment could improve the fertility and productivity of degraded soils [1,2,3]. Biochar, the carbonaceous solid product from the pyrolysis of organic material, has great potential as a valuable soil amendment in agriculture. Carbon (C) sequestration, the addition of mineral nutrients, improvement of soil structure and water-holding capacity are some of the potential beneficial effects of biochar application to soil [4]. However, biochar properties are diverse depending on production technology, production temperature, and feedstock type [5]. Accordingly, different biochar can have divergent effects on soil properties and plant growth [6].

Zinc is the most important micronutrient for the development of human health; immune system and brain function in humans and also plays an important role in enzymatic reactions and metabolic activities in plant system [7,8]. It is also called the “metal of life.” Zinc has diverse physiological functions in biological systems. Zinc is required in small but critical concentrations to allow several key plant physiological pathways to function normally. In plants, zinc plays a key role as a structural constituent or regulatory cofactor of a wide range of different enzymes and proteins in many important biochemical pathways and these are mainly concerned with: carbohydrate metabolism, both in photosynthesis and in the conversion of sugars to starch, protein metabolism, auxin (growth regulator) metabolism, pollen formation, the maintenance of the integrity of biological membranes, and resistance to infection by certain pathogens [9].

2. METHODS AND MATERIALS

A field experiment was conducted during kharif seasons of 2021 and 2022 at the Students' Instructional Farm of Acharya Narendra Deva University of Agriculture and Technology, Kumarganj, Ayodhya (Uttar Pradesh, India), which is situated at the latitude of 26˚ 54′ North and longitude 81˚ 82' East and at an altitude of 113 meters above mean sea level. The experiment was conducted in randomized Block Design which comprised eight treatments with three replications. There are: viz. T_1: Control, T_2: 100% (RDF 100:60:40), T_3: 50 % RDF + 2.5 t ha^{-1} biochar, T_4: 50 % RDF + 2.5 t ha^{-1} biochar + ZMB Biofertilizer, T_5: 50% RDF + 2.5 t ha^{-1} biochar + ZMB Biofertilizer + Zn, T_6: 100 % RDF + 5 t ha^{-1} biochar, T_7: 100 % RDF + 5 t ha^{-1}

biochar + ZMB Biofertilizer, T_8: 100 % RDF + 5 t ha^{-1} biochar + ZMB Biofertilizer + Zn. The climate of the site is semi-arid with hot summer and cold winter with the average rainfall received during the cropping period (June-September) was 670.94 mm. The soil of the experimental field had clay loam texture, bulk density (1.35 Mg m^{-3}), pH 8.92, EC (0.23 dSm^{-1}), high organic carbon (0.41%), low available N (200.40 kg ha^{-1}), medium available P (15.40 kg ha^{-1}) and high available K (246.31 kg ha^{-1}). The nutrients were supplied by biochar (containing 5.3 g kg^{-1} N, 0.99 g kg^{-1} P and 3.48 g kg^{-1} K), urea, diammonium phosphate and muriate of potash respectively. The observations were recorded on growth indices and the yield of the maize crop. The grain and stover yield were computed from the harvest of the net plot area from the individual plots and the weight of produce was recorded in kg plot^{-1} and finally converted into q ha^{-1} using the conversion factor. The data collected for different parameters was subjected to appropriate statistical analysis under Randomized Block Design (RBD) by following the procedure of ANOVA analysis of variance (SAS Software packages, SAS EG 4.3). The significance of the difference between means was tested through the 'F' test and the least significant difference (LSD) was worked out where the variance ratio was found significant for the treatment effect. The treatment effects were tested at a 5% probability level for their significance.

3. RESULTS AND DISCUSSION

3.1 Relative Growth Rate (RGR)

The Table 1 presents the relative growth rate (mg g^{-1} day^{-1}) at 0-30 DAS, 30-60 DAS, and 60-90 DAS. The data revealed the impact of biochar and fertility levels on the relative growth rate of the crop throughout the different growth stages in both years of investigation. The control treatment (T_1), which did not receive any biochar or biofertilizer, exhibited a relatively lower RGR in all growth stages. However, treatments with biochar with biofertilizer consistently showed higher RGR values compared to the control.

Treatments with biochar (T_2-T_8) consistently displayed higher RGR values compared to the control treatment (T_1). For example, at 0-30 DAS in 2021, the control treatment (T_1) had an RGR of 0.03 mg g^{-1} day^{-1}, while treatment T_6 had an RGR of 0.04 mg g^{-1} day^{-1}. This trend was observed across all growth stages and in both years, indicating the positive impact of biochar on the relative growth rate.

Treatments with higher doses of biochar (T_6, T_7, and T_8) consistently showed slightly higher RGR values compared to treatments with lower doses (T_3, T_4, and T_5) at all growth stages and in both years. However, the differences in RGR among these treatments were relatively small.

Table 1. Effect of graded doses of biochar and fertility levels with and without biofertilizer on RGR at different growth stages of the crop

Treatments	Relative growth rate (RGR) mg g^{-1}day^{-1}					
	0-30 DAS		30-60 DAS		60-90 DAS	
	2021	2022	2021	2022	2021	2022
T_1: Control	0.03	0.03	1.04	1.0	0.30	0.28
T_2: 100% (RDF100:60:40, N P_2O_5, K_2O)	0.04	0.04	1.03	1.0	0.37	0.38
T_3: 50 % RDF + 2.5 t ha^{-1} biochar	0.03	0.04	1.09	1.03	0.30	0.32
T_4: 50 % RDF + 2.5 t ha^{-1} biochar + ZMB Biofertilizer	0.03	0.03	1.07	1.03	0.31	0.31
T_5: 50% RDF + 2.5 t ha^{-1} biochar + ZMB Biofertilizer + Zn (Zinc sulphate)	0.03	0.04	1.08	1.03	0.34	0.34
T_6: 100 % RDF + 5 t ha^{-1} biochar	0.04	0.04	1.07	1.1	0.36	0.34
T_7: 100 % RDF + 5 t ha^{-1} biochar + ZMB Biofertilizer	0.04	0.04	1.07	1.1	0.37	0.37
T_8: 100 % RDF + 5 t ha^{-1} biochar + ZMB Biofertilizer+ Zn (Zinc sulphate)	0.04	0.04	1.08	1.1	0.36	0.36
SEm±	0.002	0.003	0.010	0.030	0.013	0.014
CD at 5%	0.005	NS	0.031	NS	0.039	0.042

In classical growth analysis,

Relative growth rate (RGR) is calculated as RGR = (ln W2 - ln W1)/(t2 - t1),

Where,

W1 and W2 are plant dry weights at times t1 and t2.

The inclusion of biofertilizer in some treatments (T_4, T_5, T_7, and T_8) slightly enhanced the relative growth rate. These treatments exhibited slightly higher RGR values compared to treatments without biofertilizer at all growth stages and in both years. The differences in RGR between treatments with and without biofertilizer were relatively small.

Overall, the results indicate that biochar and biofertilizer have a slightly positive influence on the relative growth rate of the crop at different growth stages. The observed increase in RGR with the application of biochar suggests its potential to promote plant growth and development. However, the differences in RGR among treatments were relatively small indicating that other factors such as soil nutrient availability and environmental conditions might also play a role in influencing the relative growth rate of the crop. Furthermore, the dose-response relationship for biochar was not prominently evident, suggesting that the optimal dose of biochar might have already been achieved at the lower doses tested in this study. Additional research is needed to explore the potential long-term effects of higher doses of biochar on the crop's growth and overall performance. Overall, while the study provides insights into the effects of biochar and biofertilizer on the relative growth rate of the crop, further investigations are warranted to fully understand the mechanisms underlying these responses and to assess the overall implications of these practices on crop productivity and sustainable agriculture. Abid et al. [10].

3.2 Net Assimilation Rate (NAR)

The Table 2 presents the net assimilation rate (g m^{-2} day^{-1}) at 0-30, 30-60, and 60-90 DAS for both the years of investigations. The study includes eight treatments, each representing different combinations of biochar, fertility levels, and biofertilizer, along with the corresponding standard error of the mean (SEm±) and critical difference at the 5% level of significance.

The data reveal the influence of biochar and fertility levels on the net assimilation rate of the crop during different growth stages in both years. Treatments with biochar and biofertilizer generally exhibited higher NAR values compared to the control treatment (T_1), which did not receive biochar with biofertilizer.

Treatments with biochar (T_2-T_8) consistently displayed higher NAR values compared to the control treatment (T_1) throughout all growth stages in both years. For instance, at 0-30 DAS in 2021, the control treatment (T_1) had a NAR of 33.4 gm^{-2} day^{-1}, while treatment T_8 (100% RDF 100:60:40, N P_2O_5, K_2O with biochar and biofertilizer+ Zn) had a NAR of 36.1 gm^{-2} day^{-1}. This trend was evident across all growth stages, indicating that the application of biochar positively influenced the net assimilation rate of the crop.

It is synonymous with the term net assimilation rate.

The usual symbol is E:

The rate of dry weight production expressed per unit of total leaf area, LA.

Its dimensions are mass per area per time, typically mg mm^{-2} day^{-1} or g m^{-2} day^{-1}. Instantaneously, $E = (1/LA)\,(dW/dt)$.

The treatments with higher doses of biochar (T_6, T_7 and T_8) showed slightly higher NAR values compared to treatments with lower doses (T_3, T_4 and T_5) at various growth stages and in both years. However, the differences in NAR among these treatments were relatively small. Effect of Biofertilizer: Treatments with biofertilizer (T_4, T_5, T_7, and T_8) displayed slightly higher NAR values compared to treatments without biofertilizer at different growth stages and in both years. The differences in NAR between treatments with and without biofertilizer were relatively small.

The results demonstrate that the application of biochar with biofertilizer has a positive effect on the net assimilation rate of the crop during different growth stages. The observed increase in NAR with the application of biochar suggests that it enhances the assimilation of carbon and nutrients by the crop, promoting its overall growth and productivity.

Table 2. Effect of graded doses of biochar and fertility levels with and without biofertilizer on NAR at different growth stages of the crop

Treatments	Net assimilation rate g m^{-2} day^{-1}					
	0-30 DAS		30-60 DAS		60-90 DAS	
	2021	2022	2021	2022	2021	2022
T_1: Control	33.4	34.3	34.5	34.3	9.91	9.20
T_2: 100% (RDF100:60:40, N P_2O_5, K_2O)	35.7	37.4	34.5	33.0	12.3	12.7
T_3: 50 % RDF + 2.5 t ha^{-1} biochar	33.1	35.0	36.4	34.7	10.2	10.7
T_4: 50 % RDF + 2.5 t ha^{-1} biochar + ZMB Biofertilizer	34.1	34.8	35.6	35.4	10.2	10.4
T_5: 50% RDF + 2.5 t ha^{-1} biochar + ZMB Biofertilizer + Zn (Zinc sulphate)	34.1	35.5	35.9	35.2	11.3	11.3
T_6: 100 % RDF + 5 t ha^{-1} biochar	35.1	35.8	35.8	35.7	12.0	11.5
T_7: 100 % RDF + 5 t ha^{-1} biochar + ZMB Biofertilizer	35.4	35.8	35.7	35.6	12.3	12.2
T_8: 100 % RDF + 5 t ha^{-1} biochar + ZMB Biofertilizer+ Zn (Zinc sulphate)	36.1	36.9	35.9	35.3	11.9	11.8
SEm±	0.29	0.58	0.30	0.73	0.42	0.47
CD at 5%	0.90	1.79	0.92	NS	1.28	1.44

Furthermore, the slightly higher NAR values observed with the inclusion of biofertilizer in some treatments indicate its potential to supplement the nutrient requirements of the crop, leading to improved assimilation and growth. However, the differences in NAR between treatments with and without biofertilizer were relatively small, suggesting that other factors such as soil nutrient content and environmental conditions might also contribute to the assimilation process.

Overall, the findings highlight the importance of biochar and biofertilizer as potential agronomic interventions to enhance the net assimilation rate and productivity of crops. However, further research is necessary to elucidate the underlying mechanisms and to optimize the application rates of these amendments to achieve maximum benefits in different agricultural systems and environmental conditions. Similar findings were also reported by Tabrizi et al. [11] and Afzal et al. [12].

3.3 Yield (kg ha^{-1})

The yield of maize was significantly influenced by graded doses of biochar and fertility levels during course of the study (Table 4). Application of treatment T_8 resulted in enhanced grain yield by 138.4% and 131% which was statistically at par with T_7 and significantly higher than the remaining treatments. During the first year, a significant maximum stover yield was noticed under T_8 followed by T_7 and T_6 but during the second year, a higher stover yield was noticed under T_8, which was statistically at par with T_7 and significantly higher than the remaining treatments respectively. The treatment T_8 yielded maximum values of biological yield as compared to the other treatments but remained at par with T_7 during both years of experimentation. It might be due to treatments with higher doses of biochar generally more significant improvements in yield attributes and yield compared to treatments with lower doses. Because it has a high surface area and a porous structure that can adsorb and retain nutrients, such as nitrogen, phosphorus, and potassium. This prevents nutrient leaching and increases the availability of essential nutrients to maize plants, promoting healthier growth and better yield attributes that result more yield [13]. Enhancement in growth and yield attributes leads to better photosynthetic partitioning and source-sink relationships, which gave higher yield in maize. Similar findings were reported by Dawadi and Sah, [14]; Adhikari et al. [15] and Pal et al. (2017).

3.4 Economics

The values regarding the economics presented in Table 3 focus on the impact of graded doses of biochar and varying fertility levels, with and without biofertilizer, for the investigation years 2021 and 2022. The cost of cultivation varied across the treatments, with the control (T_1) having the lowest cost at ₹24,890 ha^{-1} in both 2021 and 2022. Treatment T_6, involving the application of 100% recommended dose of fertilizer (RDF 100:60:40, N P_2O_5, K_2O) and 5 t ha^{-1} of biochar, showed the highest cost of cultivation at ₹56,634 ha^{-1} in 2021 and ₹56,710 ha^{-1} in 2022. The increase in cost of biochar application can be attributed to the additional expenses associated with procuring and applying biochar to the soil. The gross returns exhibited a variation among the treatments. Treatment T_2, which received 100% RDF (100:60:40, N P_2O_5, K_2O) with a B:C ratio of 2.60 in 2021 and 2.59 in 2022, generated the highest gross returns of ₹1,11,628 ha^{-1} in 2021 and ₹1,12,002 ha^{-1} in 2022. On the other hand, the control (T_1) yielded the lowest gross returns with ₹53,679 ha^{-1} in 2021 and ₹55,484 ha^{-1} in 2022. These results indicate that higher fertilizer doses positively influenced the crop yield and overall economic returns.

Table 3. Effect of graded doses of biochar and fertility levels with and without biofertilizer on yield of the crop

Treatments	Yield (q ha^{-1})					
	Grain		Stover		Biological yield	
	2021	2022	2021	2022	2021	2022
T_1: Control	24.29	25.21	36.66	38.10	60.95	61.86
T_2: 100% (RDF100:60:40, N P_2O_5, K_2O)	50.80	51.00	75.63	76.21	126.43	126.63
T_3: 50 % RDF + 2.5 t ha^{-1} biochar	46.30	47.21	69.12	70.27	115.42	117.48
T_4: 50 % RDF + 2.5 t ha^{-1} biochar + ZMB Biofertilizer	47.40	47.60	68.63	71.24	116.72	118.84
T_5: 50% RDF + 2.5 t ha^{-1} biochar + ZMB Biofertilizer + Zn (Zinc sulphate)	48.70	48.80	71.91	74.17	120.61	122.97
T_6: 100 % RDF + 5 t ha^{-1} biochar	52.33	52.51	77.89	78.24	130.22	130.75
T_7: 100 % RDF + 5 t ha^{-1} biochar + ZMB Biofertilizer	54.71	55.11	78.83	82.85	133.34	137.96
T_8: 100 % RDF + 5 t ha^{-1} biochar + ZMB Biofertilizer+ Zn (Zinc sulphate)	57.74	58.24	83.56	84.84	141.30	143.08
SEm±	1.486	0.95	1.563	1.157	2.682	1.373
CD at 5%	4.55	2.92	4.786	3.544	8.213	4.21

Table 4. Economics of different graded doses of biochar and fertility levels with and without biofertilizer under partially reclaimed Sodic Soils in maize

Treatments	Cost of cultivation (₹ ha^{-1})		Gross return (₹ ha^{-1})		Net return (₹ ha^{-1})		B:C Ratio	
	2021	2022	2021	2022	2021	2022	2021	2022
T_1: Control	24890	24890	53679	55484	28789	30594	1.16	1.23
T_2: 100% (RDF100:60:40, N P_2O_5, K_2O)	31031	31221	111628	112002	80597	80781	2.60	2.59
T_3: 50 % RDF + 2.5 t ha^{-1} biochar	41064	41165	102883	103444	61819	62279	1.51	1.51
T_4: 50 % RDF + 2.5 t ha^{-1} biochar + ZMB Biofertilizer	41264	41310	103730	104104	62466	62794	1.51	1.52
T_5: 50% RDF + 2.5 t ha^{-1} biochar + ZMB Biofertilizer + Zn (Zinc sulphate)	44014	44116	106645	106832	62631	62716	1.42	1.42
T_6: 100 % RDF + 5 t ha^{-1} biochar	56634	56710	115604	117661	58971	61028	1.04	1.08
T_7: 100 % RDF + 5 t ha^{-1} biochar + ZMB Biofertilizer	56834	56893	120785	121814	63952	64980	1.13	1.14
T_8: 100 % RDF + 5 t ha^{-1} biochar + ZMB Biofertilizer+ Zn (Zinc sulphate)	59584	59626	126605	126886	67022	67302	1.12	1.13

The net returns, which represent the profit after deducting the cost of cultivation from the gross returns, showed a similar trend. Treatment T_2 displayed the highest net returns with ₹80,597 ha^{-1} in 2021 and ₹80,781 ha^{-1} in 2022. Conversely, the control (T_1) showed the lowest net return, with ₹28,789 ha^{-1} in 2021 and ₹30,594 ha^{-1} in 2022. The benefit-cost ratio (B:C ratio) indicates the economic feasibility of the treatments. Treatments T_2, T_3, T_4, T_5, T_7, and T_8 exhibited B:C ratios greater than 1 in both 2021 and 2022, signifying that these treatments were economically profitable. However, treatments T_1 and T_6 showed B:C ratios slightly above 1, implying marginal profitability. Overall, the economic analysis indicates that the application of biochar, biofertilizer, and zinc in combination with the recommended dose of fertilizer (RDF) positively influenced the economic returns of crop production in partially reclaimed sodic soils. Higher fertilizer doses, when combined with biochar and biofertilizer, resulted in increased crop yields and improved economic viability. It is important to consider that the cost of cultivation associated with biochar application may be offset by enhanced gross returns and improved soil health in the long run.

Overall, the integration of biochar and biofertilizer with recommended fertilizer doses demonstrated its potential for enhancing agricultural productivity and economic returns in partially reclaimed sodic soils. The application of biochar, in combination with biofertilizer and zinc, increased crop yields, leading to improved economic viability. Although the cost of biochar application might be a concern, the enhanced gross returns and improved soil health, in the long run, can potentially offset this expense. However, further economic evaluations and field trials are warranted to assess the long-term sustainability and profitability of these practices for farmers in sodic soil regions. The findings emphasize the importance of adopting sustainable agricultural practices that can boost productivity and improve overall economic gains for farmers operating in challenging soil conditions. The results obtained in the study are in tune with the observations made by Singh et al. [16].

4. CONCLUSION

Based on the findings of the two-year study, it can be inferred that treatment T_8 exhibited remarkable improvements in various relative growth rates, net assimilation rate, yield and economics compared to the control treatment. Specifically, it showed a significant increase of 138.4% in grain yield and 134% in stover yield. These findings highlight the positive impact of treatment T_8 on the overall productivity and yield potential of the crop, indicating its effectiveness in enhancing relative growth rate, net assimilation rate, economics and harvest outcomes when compared to the control group.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Álvarez-Campos P, Taboada S, San Martín G, Leiva C, Riesgo A. Phylogenetic relationships and evolution of reproductive modes within flattened syllids (Annelida: Syllidae) with the description of a new genus and six new species. Invertebrate Systematics. 2018;32(1):224-251.
2. Al-Wabel MI, Hussain Q, Usman AR, Ahmad M, Abduljabbar A, Sallam AS, Ok YS. Impact of biochar properties on soil conditions and agricultural sustainability: A review. Land Degradation & Development. 2018;29(7):2124-2161.
3. Yu F, Yang C, Zhu Z, Bai X, Ma J. Adsorption behavior of organic pollutants and metals on micro/nanoplastics in the aquatic environment. Science of the Total Environment. 2019;694:133643.
4. Lehmann J, Joseph S. (Eds.). Biochar for environmental management: Science, technology and implementation. Routledge; 2015.
5. Gul S, Khan MH, Khanday BA, Nabi S. Effect of sowing methods and NPK levels on growth and yield of rainfed maize (*Zea mays* L.). Scientifica; 2015.
6. Manolikaki II, Mangolis A, Diamadopoulos E. The impact of biochars prepared from agricultural residues on phosphorus release and availability in two fertile soils. Journal of environmental management. 2016;181:536-543.
7. Subramanian S, Huq S, Yatsunenko T, Haque R, Mahfuz M, Alam MA, Gordon JI. Persistent gut microbiota immaturity in malnourished Bangladeshi children. Nature. 2014;510(7505):417-421.
8. Suganya A, Saravanan A, Manivannan N. Role of zinc nutrition for increasing zinc availability, uptake, yield, and quality of

maize (*Zea mays* L.) grains: An overview. Commun. Soil Sci. Plant Anal. 2020;51(15):2001-2021.

9. Sadeghzadeh B. A review of zinc nutrition and plant breeding. Journal of soil science and plant nutrition. 2013;13(4):905-927.
10. Abid M, Qayyum A, Dasti A, Wajid R. Effect of salinity and sar of irrigation water on yield, physiological growth parameters of maize (*Zea mays* L.) and properties of the Soil. J Res Sci. 2001;12(1):26-33.
11. Farajzadeh Memari Tabrizi E, Yarnia M, Khorshidi MB, Ahmadzadeh V. Effects of micronutrients and their application method on yield, crop growth rate (CGR) and net assimilation rate (NAR) of corn cv. Jeta. Journal of Food, Agriculture and Environment. 2009;7(2):611-615.
12. Afzal S, Akbar N, Ahmad Z, Maqsood Q, Iqbal MA, Aslam MR. Role of seed priming with zinc in improving the hybrid maize (*Zea mays* L.) yield. Crops. 2013;8:10.
13. Gudade BA, Malik GC, Das A, Babu S, Kumar A, Singh R, Bhupenchandra I. Effect of biochar levels and integrated nutrient-management practices on agro-physiological performance and productivity of maize (*Zea mays*). Indian Journal of Agronomy. 2022;67(4):380-385.
14. Dawadi DR, Sah SK. Growth and yield of hybrid maize (*Zea mays* L.) in relation to planting density and nitrogen levels during winter season in Nepal; 2012.
15. Adhikari K, Bhandari S, Aryal K, Mahato M, Shrestha J. Effect of different levels of nitrogen on growth and yield of hybrid maize (*Zea mays* L.) varieties. Journal of Agriculture and Natural Resources. 2021;4(2):48-62.
16. Singh J, Partap R, Singh A. Effect of nitrogen and zinc on growth and yield of maize (*Zea mays* L.). International Journal of Bio-resource and Stress Management. 2021;12(Jun, 3):179-185.

Peer-review history:
The peer review history for this paper can be accessed here:
https://www.sdiarticle5.com/review-history/105455