Influence of biochar and amendment application on performance of wheat in sodic soils

ABSTRACT

Soil sodicity poses significant challenges to agriculture, particularly in arid and semi-arid regions, by deteriorating soil structure, reducing fertility, and constraining crop productivity. In the Ravi-Tawi Command area of Jammu, nearly 7,500 hectares of sodic soils limit wheat yields during the rabi season. This study evaluates the effects of biochar, farmyard manure (FYM), halophilic bioformulations, and gypsum, applied individually and synergistically, on the growth, yield, and physiological responses of wheat grown under sodic conditions. The application of acidified biochar at 5.0 t ha^{-1} combined with FYM, Consortia, and 50% gypsum recommendation (F_4 treatment) significantly improved growth and yield parameters, with plant height increasing from 19.97 cm (control) to 58.21 cm, grains per spike rising from 20.67 to 69.33, and grain yield improving from 15.13 q ha^{-1} to 27.34 q ha^{-1}. These enhancements were attributed to improved soil structure, nutrient retention, and reduced sodium toxicity, fostering better nutrient uptake and plant growth. This research demonstrates the potential of integrated soil amendments in reclaiming sodic soils, promoting sustainable agricultural practices, and ensuring food security in salt-affected regions.

Keywords: Biochar, acidified biochar; wheat yield; sodic soils; gypsum requirement; halophilic bioformulations

INTRODUCTION

Salt affected soils pose a critical challenge to agricultural productivity worldwide (Chadha et al., 2024a). Soil sodicity is a critical challenge in agricultural systems, particularly in arid and semi-arid regions, where high levels of exchangeable sodium deteriorate soil structure, reduce fertility, and constrain crop productivity. Sodic soils are typically characterized by high pH, low permeability, and poor aeration, which impair root development and nutrient availability, ultimately threatening global food security (Rengasamy, 2010). In the Ravi-Tawi Command area of the Jammu region, nearly 7,500 hectares of land are salt-affected, primarily sodic in nature (Sharma et al. 2012). Mismanagement of water has often been observed as a reason for low productivity (Sharma and Sharma, 2004); and in this area indirectly through promoting sodicity. Wheat, the dominant crop during the rabi season in this region, plays a crucial role in providing daily calories and protein to the local population. However, the crop often experiences significant yield reductions due to its sensitivity to salinity and sodicity stress

(Munns and Tester, 2008). Therefore, addressing the adverse effects of sodic soils through effective reclamation and management strategies is critical for sustaining agricultural productivity.

Amendments like biochar, farmyard manure (FYM), halophilic bioformulations, and gypsum effectively mitigate the negative effects of sodic soils and enhance crop performance. Biochar improves soil properties by increasing aggregate stability, water retention, and sodium ion adsorption, which alleviates salt stress and promotes better root growth. This leads to taller plants, improved nutrient uptake, and increased grain yield by enhancing nutrient availability and reducing sodium toxicity. Biochar also boosts chlorophyll content and photosynthetic efficiency, contributing to higher grain production and overall vegetative growth, resulting in greater yield (Lehmann and Joseph, 2015; Akhtar et al. 2015; Thomas et al. 2013). Farmyard manure (FYM) is a valuable source of organic matter and nutrients that enhances microbial activity, soil fertility, and nutrient cycling in degraded soils. It promotes root and shoot growth, leading to healthier plants and increased plant height. By improving aeration and root-zone conditions, FYM enhances root elongation and reduces sodium toxicity, supporting better flowering, grain development, and an increased number of grains per spike. FYM also improves the availability of essential nutrients like potassium and phosphorus, promoting longer spikes and higher grain yield. The reduction in sodium toxicity leads to better nutrient uptake, improved grain filling, and higher yield (Tejada et al. 2006). Halophilic bioformulations, which consist of salt-tolerant microorganisms, promote plant growth under saline and sodic conditions by aiding in sodium detoxification, nitrogen fixation, and phosphorus solubilization. These microorganisms produce phytohormones that enhance cell elongation and division, boosting plant height. They also improve sodium efflux, potassium uptake, and nutrient availability, which supports grain formation and increased grains per spike. By reducing oxidative stress and enhancing nutrient uptake, these bioformulations improve spike elongation, grain yield, contributing to overall plant vigor (Ruppel et al. 2013; Egamberdieva et al. 2013; Kumar et al. 2024).

Gypsum ($CaSO_4 \cdot 2H_2O$) is an effective chemical amendment for reducing sodicity by replacing sodium with calcium ions on soil exchange sites, improving soil structure and permeability (Sumner, 1993). It enhances root growth, water and nutrient uptake, and promotes taller plants (Qadir et al. 2007). The calcium from gypsum supports cell division and elongation, aiding plant height and improving flowering and grain development (Choudhary et al. 2004). By reducing sodium toxicity, gypsum increases grains per spike and enhances soil structure, leading to longer spikes (Minhas and Sharma, 1986). It improves nutrient availability, boosting grain yield, photosynthetic efficiency, and straw biomass (Rashid et al. 2008).

The synergistic application of biochar, FYM, halophilic bioformulations, and gypsum offers a comprehensive solution for rehabilitating sodic soils by addressing their physical, chemical, and biological challenges. This study evaluates the individual and combined effects of these amendments on the growth, yield, and physiological responses of wheat under sodic conditions. The research aims to promote sustainable agricultural practices, enhance crop productivity, and restore soil health, providing practical recommendations for managing sodic soils and ensuring food security in affected regions.

MATERIALS AND METHODS

STUDY AREA

The experiment was conducted at the Division of Soil Science and Agricultural Chemistry, Sher-e-Kashmir University of Agricultural Sciences and Technology, Jammu (J&K). The study area lies in the subtropical zone of Jammu and Kashmir, at a latitude of 32.43° North and a longitude of 74.54° East which is strategically located near the banks of the Tawi River, which flows through the city of Jammu. The river not only supports the irrigation systems in the surrounding areas but also influences the local microclimate. The northern part of the command area features a slightly hilly terrain with rolling topography and falls within the drought-prone Kandi belt of Jammu, whereas the southern part is relatively plain (Sharma et al., 2012).

COLLECTION OF SOIL SAMPLES

Bulk soil was collected from the Organic Farming Research Centre (OFRC) at SKUAST Jammu, ground, and sieved through a 5.0-mm mesh. A total of 12 kg of soil was placed in each of 60 pots. Sodicity was induced by applying a solution of 24 g sodium bicarbonate dissolved in 2 liters of deionized water three times per pot until the pH exceeded 9 (Chadha et al. 2024b). After several days, a stable pH of 9.46 ± 0.10 was achieved.

EXPERIMENTAL METHODOLOGY

A pot study was conducted using a factorial completely randomized design (CRD) with two factors: biochar types and soil amendments, resulting in 20 treatment combinations and 60 pots with three replications. Treatments included control (F_1), biochar with FYM (F_2), biochar with FYM + consortia (F_3), and biochar with FYM + consortia + 50% gypsum (F_4). Two biochar types were used: normal biochar and acidified biochar, both derived from rice straw in a laboratory furnace at 300°C. Acidified biochar was prepared by washing with 0.1 N HCl and drying at 60°C. The experiment used the wheat variety DBW 173, known for high yield and disease resistance. Ten seeds were sown per pot at the recommended depth for uniform germination. Seeds were treated with bioformulations (Halo-Mix: Halo-Azo, Halo-PSB, and Halo-Zinc) developed from salt-affected soils and evaluated for plant growth-promoting properties under salt stress. The details of the experimental treatments are provided in Table 1.

Table1: Details of treatment combinations

FACTOR 1: Biochar

Rate of application (t ha^{-1})		
No Biochar	0 (B_0)	
Normal Biochar	2.5 (B_1)	5 (B_2)
Acidified Biochar	2.5 (B_3)	5 (B_4)

FACTOR 2: Amendments

F_1	Control
F_2	FYM
F_3	FYM + Consortia*
F_4	FYM + Consortia* + 50 % Gypsum (RDF)

*Consortia: (Halo-Mix) *ie.,* (Halo-Azo + Halo-PSB + Halo- Zinc inoculation)

Growth and Yield Parameters

At the harvesting stage in the last week of April, plant samples were collected from each experimental pot to measure growth and yield parameters. Plant height was recorded from the soil surface to the tip of the plant. Ten effective spikes were randomly selected, threshed, and averaged to determine the number of grains per spike and grain yields were carefully recorded by threshing the plants, cleaning the grains, and weighing them for accuracy.

RESULTS AND DISCUSSION

The results revealed that the application of acidified biochar at 5.0 t ha^{-1}, particularly in combination with FYM (farmyard manure), Consortia, and 50% Gypsum under the F_4 treatment, resulted in notable improvements across various growth and yield parameters. Plant height, an important indicator of vegetative growth, ranged from 19.97 cm in the untreated control (B_0) to 58.21 cm under the F_4 treatment, indicating a substantial improvement due to the synergistic effects of biochar and nutrient amendments (Fig 1). Similarly, reproductive traits such as the number of grains per spike were significantly enhanced. Grains per spike, which are critical for grain yield, increased from 20.67 in the control to 69.33 under F_4 treatment (Table 2).

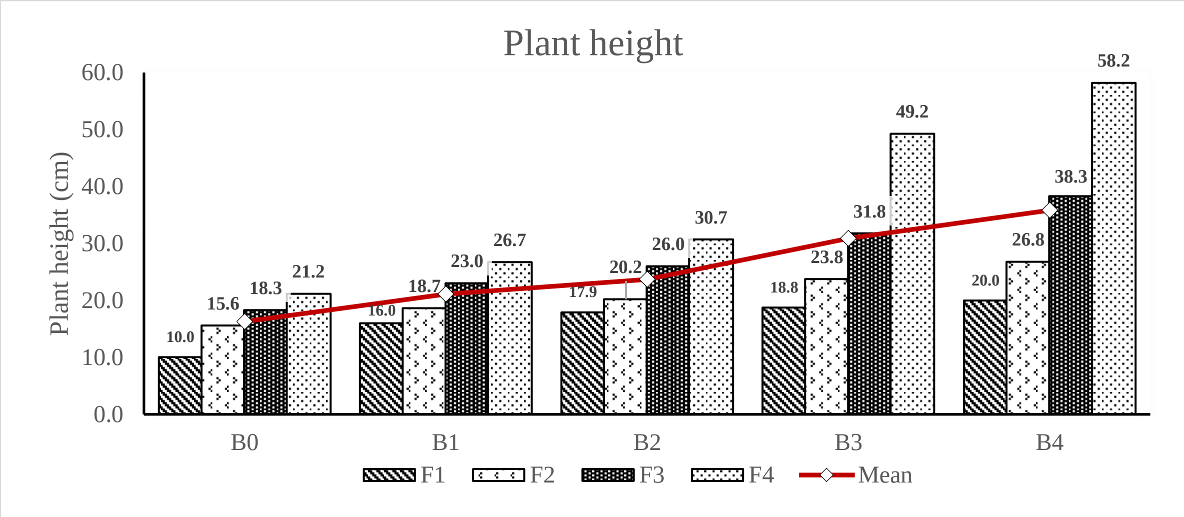

Fig 1: Effect of different levels of biochar and amendments on plant height (cm) at harvest of wheat crop

These improvements suggest that biochar creates a favourable soil environment that enhances nutrient uptake and utilization, thereby promoting robust plant growth and reproductive success. These findings are consistent with those of Farid et al. (2025), who reported that biochar-enriched soil leads to significant improvements in plant height, number of plants per pot, and the number of spikes per plant. They also highlighted that the highest increases were observed when acidified biochar was applied at 10 g kg^{-1}. This reinforces the idea that biochar's effectiveness depends on its dosage and chemical modification. Acidification of biochar likely enhances its surface area, porosity, and cation exchange capacity (CEC), allowing for better nutrient retention and availability to plants.

Table2: Effect of biochar and amendments on number of grains per spike and grain yield of wheat crop at harvest stage.

	Number of grains per spike								**Grain yield (q ha^{-1})**			
	**B_0	B_1	B_2	B_3	B_4	**Mean**	B_0	B_1	B_2	B_3	B_4	**Mean**
*F_1	5.00	8.00	10.00	15.33	20.67	11.80	7.90	9.10	10.48	13.29	15.13	11.18
F_2	7.67	10.67	12.33	22.67	31.67	17.00	11.92	13.25	15.18	19.31	22.17	16.37
F_3	8.67	13.33	16.00	38.33	52.00	25.67	13.24	15.36	18.22	22.52	25.40	18.95
F_4	10.67	19.33	22.00	50.33	69.33	34.33	16.32	18.64	20.28	24.87	27.34	21.49
Mean	8.00	12.83	15.08	31.67	43.42		12.35	14.09	16.04	20.00	22.51	
ANOVA	CD	F Test					**ANOVA**	CD	F Test			
B	5.11	S					**B**	1.12	S			

F	4.57	S
B*F	3.58	S

F	1.00	S
B*F	NS	NS

***F_1: Control; F_2: FYM; F_3: FYM + Consortia; F_4: FYM + Consortia + 50% Gypsum Requirement**

****B_0: 0 t ha^{-1} (No biochar); B_1: 2.5 t ha^{-1} (Normal Biochar); B_2: 5 t ha^{-1} (Normal biochar); B_3: 2.5 t ha^{-1} (Acidified biochar); B_4: 5 t ha^{-1} (Acidified biochar)**

Grain yield improved substantially from 15.13 q ha^{-1} in the control treatment (B_0) to 27.34 q ha^{-1} in the F_4 treatment (table 2). These results demonstrate the efficacy of biochar in enhancing crop productivity, as all biochar treatments showed significant improvements compared to the control, with the F_4 treatment consistently achieving the highest values across all measured parameters. Similar trends were observed in the study by Bekele et al. (2021), where the application of biochar and gypsum improved wheat grain yield grown on saline-sodic soil. They reported that highest grain yield (3015.30 kg ha^{-1}) was obtained with the sole application of 100% gypsum, while the lowest (2506.90 kg ha^{-1}) was recorded with 4 t ha^{-1} biochar. The enhanced yields were attributed to the amendments' ability to improve the physical, chemical, and biological properties of salt-affected soils. These improvements mitigate the adverse effects of salinity, which is known to disrupt nutrient uptake (e.g., K, Ca, Mg, P) and cause yield losses (Grattan and Grieve, 1998). Akhtar et al. (2015) further supported these findings by demonstrating that biochar reduces Na^+ uptake in wheat under salinity stress, thereby enhancing growth and yield. Additionally, Zhang et al. (2021) reported an average 32.98% increase in sorghum yield with acidic corn stalk biochar (ACSBC) application, with significant increases of 51.37% and 47.33% observed at rates of 0.6 t ha^{-1} and 1 t ha^{-1}, respectively. The improvement in sorghum yield was attributed to ACSBC's role in enhancing soil chemical properties, such as increasing water retention, cation exchange capacity (CEC), and micronutrients, while reducing pH, electrical conductivity (EC), and exchangeable sodium percentage (ESP). These long-term improvements create a more favourable environment for plant growth and yield enhancement (Saifullah et al. 2018; Zhao et al. 2020).

CONCLUSION

The study demonstrated that the application of acidified biochar, particularly at 5.0 t ha^{-1} in combination with FYM, Consortia, and 50% Gypsum (F_4 treatment), significantly improved wheat growth and yield parameters. Plant height, number of grains per spike and grain yield showed remarkable increases compared to the control. These results highlight the synergistic effects of biochar and nutrient amendments in creating a favourable soil environment that enhances nutrient availability and uptake. Similar findings from other studies confirm that biochar improves soil physical, chemical, and biological properties, thereby mitigating the adverse effects of salinity and enhancing crop productivity. Proper dosage and chemical modifications, such as acidification, further enhance biochar’s effectiveness, making it a valuable amendment for improving agricultural performance in challenging soil conditions.

PRACTICAL APPLICABILITY FOR FARMERS

Based on the study’s findings, farmers can enhance wheat growth and yield by applying acidified biochar at a rate of 5.0 t ha^{-1}, particularly when combined with organic amendments like farmyard manure (FYM), microbial consortia, and 50% gypsum. This combination has been shown to significantly improve plant height, number of grains per spike, and overall grain yield. To implement this in practice, farmers should first conduct soil tests to assess nutrient needs and salinity levels, ensuring the right amendments are chosen. Applying biochar and the other amendments before planting or during early growth stages will help improve soil structure, nutrient availability, and water retention. Farmers may also consider conducting small-scale trials to determine the optimal dosage and combination for their specific soil conditions. Over time, the use of these treatments can lead to long-term improvements in soil health, reducing the reliance on chemical fertilizers and boosting overall crop productivity in challenging soil environments.

FUTURE RESEARCH

Future research could explore the long-term effects of acidified biochar on soil health and crop productivity across multiple seasons. Studies could also investigate the optimal application rates and combinations of biochar with other amendments for different crops and soil types. Understanding the mechanisms behind biochar's impact on nutrient availability and microbial activity would help tailor its use in diverse agricultural systems. Additionally, research could focus on evaluating its economic feasibility and role in carbon sequestration, as well as its potential in mitigating soil salinity and desertification in various regions.

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