

RESEARCH PAPER

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Alleviating salinity stress in lettuce (*Lactuca sativa* L.) through bamboo-based biochar application**Gerlie B. Hardy^{*1}, Lyle B. Sumer¹, Marvin V. Baloloy¹, Monsour R. Lang-es², Jeff M. Opeña³**¹*Cagayan State University-Gonzaga Campus, College of Agriculture, Flourishing, Gonzaga, Cagayan, Philippines*²*Municipal Agriculture Office, Pugo, La Union, Philippines*³*Don Mariano Marcos Memorial State University-North La Union Campus, College of Agriculture, Bacnotan, La Union, Philippines***Key words:** Bamboo biochar, Organic amendment, Salinity stress, Soil conditioner**Received:** June 28, 2026**Accepted:** July 08, 2026**Published:** July 15, 2026**DOI:** <https://dx.doi.org/10.12692/ijb/29.1.97-103>**ABSTRACT**

The reliance on commercial fertilizers contributes to soil pollution through nutrient leaching and runoff, while rising costs burden small farmers. Soil salinity aggravates abiotic stress, reducing plant growth, nutrient availability, and crop yields. This study investigated the potential of bamboo-based biochar, derived from locally-available materials, to alleviate salinity stress in lettuce (*Lactuca sativa* L.) grown under 0, 100, 200, and 300 mM NaCl concentrations with 20 g plant⁻¹ bamboo-based biochar amendment. Results showed that plant length parameters (shoot, root, and whole plant), root weights, leaf production, and chlorophyll content were unaffected by biochar application ($p > 0.05$), indicating maintained growth and photosynthetic capacity despite salinity stress. However, shoot and whole plant fresh weights significantly decreased with increasing NaCl concentrations ($p \leq 0.05$). Overall, bamboo-based biochar supports lettuce growth under salinity stress by conserving physiological traits.

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INTRODUCTION

The massive use of commercial fertilizers has been labeled by environmentalists as the main source of soil environmental pollutants such as leaching and runoff of nutrients, especially nitrogen (Chen *et al.* 2018) and fertilizer prices are increasing day by day so becoming unaffordable by small and marginal farmers (Kumar and Kumar, 2019). Another constraint in crop production is the excess soluble salts in the soil which create difficulties for plant growth and lower nutrient availability in the soil (Ding *et al.*, 2021). It is abiotic stress for plant growth and development, which ultimately causes a reduction in crop yield. Salt stress in soils triggers inhibition in plant development and yields by imposing osmotic stress, causing ion toxicity and nutrient imbalance in plants (Soothar *et al.*, 2021).

Many research studies have reported different strategies to minimize and prevent the effect of salt stress on plants. Some of these include agricultural management practices like leaching of salts from the root zone, the introduction of salt-tolerant varieties (Soothar *et al.*, 2021), better irrigation practices, alteration in the farming system, shifting the crop calendars (Shrivastava and Kumar, 2015), mulching and grafting; biotechnology, plant genetic engineering, and nano fertilizers (Alkharabsheh *et al.* 2021); plant adaption mechanisms like replacement of Na⁺ application of gypsum (CaSO₄); phytoremediation (Soothar *et al.*, 2021); biosynthesis of antioxidants (Grieve *et al.*, 2012); plant growth-promoting bacteria (PGPB) (Shrivastava and Kumar, 2015); and application of various organic materials (plant residue, compost, biochar, organic matter, poultry manure, rice straw manure). Organic ameliorants like biochar have received great attention among researchers for their positive effects of mitigating salinity stress in plant growth and soil properties (Ding *et al.*, 2021).

Recently, clean agriculture depends upon using organic fertilizers like organic ameliorants such as compost and biochar in order to produce high yields with the best commodity quality without

contamination, and less accumulation of heavy metals and one of the most effective treatments for soil improvement and salt stress alleviation (Ding *et al.*, 2021).

Biochar is one of the biofertilizers being used nowadays. It is a carbon-enriched product obtained by heating biomass under low-oxygen or oxygen-free conditions. Biochar possesses specific properties, such as a porous structure, a relatively large surface area, a large number of functional groups, and abundant mineral elements, that benefit the immobilization of heavy metals and the loading of fertilizer nutrients in the soil. Several studies demonstrated that biochar, which contains many functional groups, strongly adsorbs various nutrient ions, including nitrate, ammonium, phosphate, and potassium ions, to load nutrients and reduce soil nitrogen nutrient loss (Kimetu and Lehmann 2010; Mizuta *et al.* 2004) and ameliorates the negative effects of salinity stress in plants and soil properties (Ali *et al.*, 2017).

Biochar is pyrolyzed product of different biomass wastes that can be used as feedstock such as agricultural wastes, animal husbandry waste, and municipal sludge by heating at various temperatures.

Recently, bamboo charcoal has been recognized as regenerative biochar for carbon capture because it is cost-effective and environmentally friendly (Ji *et al.*, 2022). Since bamboo leaves and culms are not utilized and have been considered wastes, there is a need to transform bamboo and other organic materials as potential fertilizer and soil conditioner for high-value leafy vegetables like lettuce. In the study of Ngongo *et al.* (2018), research result shows that the utilization of bamboo waste biochar dose of 10 tons per hectare gave the highest dry weight of corn seed per hectare of 8.12 tons, with an increase of 32.77% compared with no application of biochar of 6.12 tons. Aside from these, it is also an effective treatment for alleviating salt stress as reported in the study of Ali *et al.* (2017) that bamboo biochar ameliorated okra seed germination, growth process and yield due to

salt stress and significantly reduced leaching of nitrate, total nitrogen, and total phosphorus in soils.

Since bamboo leaves and culms are not utilized and have been considered wastes, there is a need to transform bamboo and other organic materials as potential fertilizer and soil conditioner for high-value leafy vegetables like lettuce. This research utilized biochar made from bamboo and other locally available materials as a potential soil conditioner, evaluates its responses on the growth and development of lettuce and its mitigating effects in salinity stress conditions, and provides information on the edaphic benefits of bamboo-based biochar in terms of soil nutrition and plant absorption in saline soil.

MATERIALS AND METHODS

Experimental set-up

The experiment was laid out employing a Completely Randomized Design with three replications of 10 sample plants each. The lettuce plants were grown in the greenhouse for 60 days after transplanting (DAT). The soil chemical properties (electrical conductivity [EC], pH, organic matter, phosphorus, potassium, copper, zinc, iron, and manganese), growth (leaf production; root and shoot lengths; shoot, root, and whole plant fresh weights), weekly SPAD reading, and the nutritional content (nitrogen, phosphorus, potassium, copper, zinc, iron, and manganese) of the lettuce plants were evaluated 60 DAT.

Preparation of the bamboo biochar

Bamboo-based biochar (1.79±0.10 % moisture, pH 6.55±0.06, 0.50±0.03 % N, 0.60±0.06 % P, 1.18±0.07 % K, 66.67±15.96 ppm Zn, 17.50±7.50 ppm Cu, 423.33±63.25 ppm Mn, 1,207.50±168.76 ppm Fe) was formulated by mixing 469 g kg⁻¹ bamboo charcoal powder from partially dried bamboo poles, 65.30 g kg⁻¹ partially decomposed bamboo leaf powder, 82.60 g kg⁻¹ vermicompost, 41.30 g kg⁻¹ goat manure powder and 41.30 g kg⁻¹ cattle manure powder, 8.30 g kg⁻¹ mycorrhizal fungi biofertilizer, 165.30 g kg⁻¹ zeolite clay, and 550 ml kg⁻¹ diluted molasses. The mixture was pelletized using a feed pelletizer machine, and sundried for 2-3 days.

Establishment of the experimental plants

Lettuce seeds (Condor, Allied Botanical Corporation, Philippines) were germinated in seedling trays filled with garden soil and carbonized rice hull for 23 days inside the greenhouse. The lettuce seedlings were transplanted in pots filled with 5 kg dw⁻¹ garden soil with one seedling per pot. The base of the pots was lined with plastic mulch to prevent the direct contact of the roots to other soil surfaces. The plants were acclimatized for 7 days in the greenhouse of the Cagayan State University-Gonzaga (CSU-G), Flourishing, Cagayan, Philippines (Latitude: 18.2492050N, Longitude: 122.0013970E, Elevation: 49.0 m asl) before fertilizer application.

Bamboo-based biochar application in the lettuce plants

The 30-day old lettuce plants were applied with 20 g plant⁻¹ bamboo-based biochar at 7 DAT. The biochar was applied to the plants by incorporating in the soil prior to salinity stress. The plants were irrigated after biochar application. The plants were misted/irrigated thrice a week. The lettuce plants were not applied with inorganic/chemical fertilizers during their growing period.

Salinity stress imposition in the lettuce plants

To impose salinity stress in the plants, the lettuce plants were irrigated thrice (one application per week) with 50 ml plant⁻¹ varying salt solutions (0 mM, 100 mM, 200 mM, and 300 mM NaCl) with EC values of 0 dS m⁻¹, 11.04 dS m⁻¹, 21.10 dS m⁻¹, and 30.30 dS m⁻¹, respectively. EC readings were measured using a portable electrical conductivity meter (Suntex Cond SC-230, Suntex Instruments Co., Ltd., New Taipei City, Taiwan) at 14, 21 and 28 days after biochar application. The plants were misted in the remaining days after salinity stress imposition.

Growth and leaf chlorophyll concentration of the lettuce plants

Leaves per plant that are green, fully developed, expanded, and are not dried were counted. Shoot and root were measured from the base of the plant to the tip of the longest shoot and root, respectively using a

ruler. Fresh weights (shoot, root, and whole plant) were measured using a digital weighing scale.

Meanwhile, the weekly SPAD reading was measured using a portable chlorophyll meter (Biobase CM-B, Biobase Biodustry Co., Ltd., Shandong, China) at 14, 21, 28, and 35 DAT. SPAD readings of the lettuce plants were measured following the procedure of Opeña and Sotto (2020). Leaf chlorophyll content (LCC, in $\mu\text{g cm}^{-2}$) was calculated using the formula provided by (Zhang *et al.*, 2022):

$$\text{LCC} = 0.0893 \times (10^{\text{SPAD}\alpha}); \text{ where } \alpha = 0.265$$

Plant and soil nutrient analyses

Lettuce plants and saline soils applied with bamboo-based biochar were subjected to plant tissue analysis and soil chemical analysis following the procedures of the Bureau of Soil and Water Management System (2021). Analyses were carried out in three replications of each treatment. The total N, total P, total K, and total trace elements (Zn, Cu, Mn, Fe) of the lettuce plant tissues were analyzed through Steam distillation, Vanadomolybdophosphoric acid colorimetric, Flame photometric, and Microwave plasma-atomic emission spectroscopic tests, respectively. Soils applied with bamboo-based biochar and varying salt solutions were tested through Potentiometric (soil pH), EC meter (soil electrical conductivity), Walkey and Black Spectrophotometric (OM), Olsen method (Available P), Cold sulfuric extraction using flame photometer (Available K), and diethylenetriaminepentaacetic acid

[DTPA] extraction using microwave plasma atomic emission spectroscopy [Agilent MP-AES, Agilent, United States] (Available Zn, Cu, Mn, Fe).

Data analysis

Data were subjected to one-way analysis of variance (ANOVA) using the Statistical Tool for Agricultural Research (STAR) version 2.0.1, 2013 (International Rice Research Institute, Los Baños, Laguna, Philippines). Statistical differences were determined using Tukey's Honest Significant Difference Test (HSD) ($P \leq 0.05$). Standard errors (SE) were calculated and represented by error bars.

RESULTS

Length and fresh biomass of lettuce plants grown in saline soils applied with bamboo-based biochar

The plant size and plant fresh biomass are presented in Fig. 1. Shoot, root, and whole plant lengths of the lettuce plants were not statistically affected by the application of biochar in saline soils ($p > 0.05$). Meanwhile, shoot and whole plant biomass of the lettuce plants were statistically affected by saline soils ($p < 0.05$). Growing the plants in soils with varying sodium chloride concentrations of 100 mM (16.97 g lower shoot weight and 16.86 g lower whole plant weight), 200 mM (38.02 g lower shoot weight and 41.29 g lower whole plant weight), and 300 mM (37.38 g lower shoot weight and 40.19 g lower whole plant weight), produced lighter plants than the control plants. However, the weights of the roots were not significantly affected by soil salinity ($p > 0.05$).

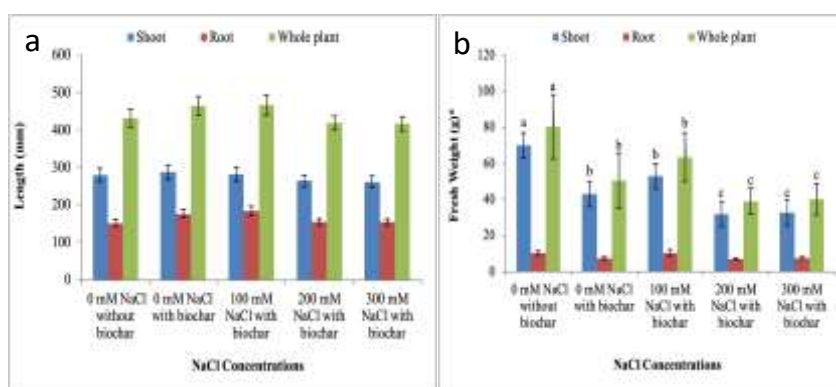


Fig. 1. Length (a) and fresh biomass (b) of lettuce plants grown in saline soils applied with bamboo-based biochar. $n = 30$, $\pm$ SE, *significant at ≤ 0.05 using HSD

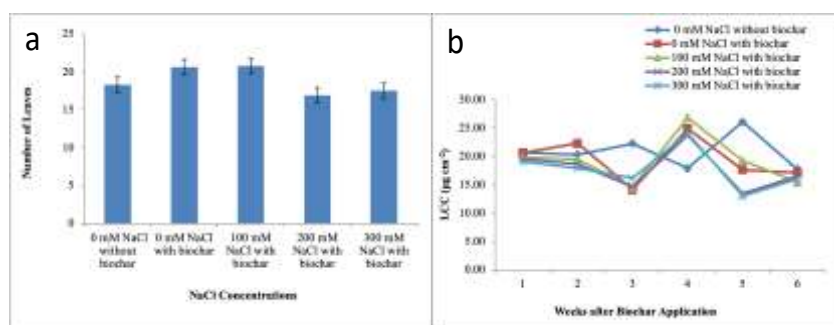


Fig. 2. Leaf production (a) and leaf chlorophyll content (b) of lettuce plants grown in saline soils applied with bamboo-based biochar. $n=30$, $\pm$ SE

Leaf production of lettuce plants grown in saline soils applied with bamboo-based biochar

Salinity stress did not statistically reduce the leaf production of the lettuce plants grown in saline soils applied with biochar ($p > 0.05$) (Fig. 2A).

Leaf chlorophyll content of lettuce plants grown in saline soils applied with bamboo-based biochar

Salt solutions were drenched and biochar was applied prior to SPAD reading measurement. The leaf chlorophyll content (LCC) of the lettuce plants grown in saline soils was comparable ($p > 0.05$) with the control plants during the first and second week of growth after biochar application. However, it was noted that during the last weeks of growth (5-6 weeks after biochar application), the LCC of the lettuce plants planted in saline soils decreased while the non-stressed plants without biochar have higher LCC (Fig. 2B).

DISCUSSION

Length and fresh biomass of lettuce plants grown in saline soils applied with bamboo-based biochar

The comparable length of the lettuce implies that the biochar application can maintain lateral growth even under increasing salinity in the soil. Murtaza *et al.* (2024) reported that biochar incorporation improved significantly the plant height of *Medicago sativa*, *Amaranthus caudatus*, and *Zea mays*, compared to control (without biochar adding) under saline conditions. The role of biochar is not limited to

improving the growth and productivity of plants, but it plays a crucial role in protecting the plants from the abiotic stresses like salinity (Shaaban *et al.*, 2018).

Biochar did not mitigate the negative effects of salinity on the above-ground and whole plant weights of the lettuce plants since, it is evident that with increasing salinity, the fresh weights of the shoot as well as the whole plant were significantly decreasing.

The biochar may have provided a better environment for root growth under salinity stress due to its nutritional and protective benefits such as reduction of salt stress around the roots (adsorption of excess Na^+ ions, and reduction of ionic toxicity), enhancing soil aggregation and nutrient availability and uptake, and buffering osmotic stress. An enhanced root's fresh weight was also shown in *Medicago sativa* and *Amaranthus caudatus* compared to the control group (Murtaza *et al.*, 2024). Biochar applied to salt-affected soils improves the physical, chemical and biological properties of soil in which improves the water holding capacity and reduces the oxidative and osmotic stresses resulting in the promotion of plant growth (Kul *et al.*, 2021).

Leaf production of lettuce plants grown in saline soils applied with bamboo-based biochar

Biochar applications have mitigated the negative effects of salinity stress in leaf production of lettuce possibly due to its promotive effects on leaf growth such as nutrient availability for leaf production and reducing salt-induced leaf damage.

The bamboo-based biochar may have prevented leaf chlorosis, necrosis, and drying which are common in plants grown in saline soils. Hence, the application of biochar maintains leaf growth and healthier leaves which are necessary for the photosynthetic activity of the plants. A similar finding was reported by Kul *et al.* (2021) that biochar was equally effective in ameliorating the effect of saline water irrigation on the number of tomato leaves under salt stress conditions.

Leaf chlorophyll content of lettuce plants grown in saline soils applied with bamboo-based biochar

Biochar has mitigated the negative effects of salinity where the plants produced green and healthy leaves during the initial phase of salinity stress. It denotes that the LCC of the lettuce plants was conserved and the leaf color and appearance of the plants were not negatively affected by salinity because of the application of bamboo-based biochar. It was revealed in the study of Fedeli *et al.* (2024) that the treated lettuce plants showed statistically significant decreases in chlorophyll content at NaCl exposures of 300 mM (-17%) and 400 mM (-47%) but after biochar amendment, chlorophyll content showed a significant increase at the 400 mM (+21%). But, during the last weeks of growth, the LCC of the lettuce plants planted in saline soils decreased. Bagues *et al.* (2024) reported that the decrease in chlorophyll content in salt-stressed plants is a typical symptom of salt stress and has been attributed to the inhibition of chlorophyll synthesis along with the activation of its degradation by the enzyme chlorophyllase.

CONCLUSION

Bamboo-based biochar effectively sustained plant length, root growth, leaf production under salinity stress, while mitigating early chlorophyll loss. However, it was less effective in maintaining shoot and whole plant biomass. These findings revealed bamboo-based biochar's potential as a partial but significant amendment for improving lettuce resilience in saline soils.

RECOMMENDATIONS

Further research studies are needed to evaluate the agronomic and environmental benefits of bamboo biochar in different crops under different stress conditions.

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