Research article

Impact of Biochar Application on Andosol Soil pH and Electrical Conductivity Under *Avena sativa* Cultivation

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Abstract Biochar, a carbon-rich material derived from the pyrolysis of organic matter, has emerged as a promising soil amendment for enhancing soil properties. It has been shown to increase soil pH, boost microbial activity, improve nutrient retention, and enhance water-holding capacity. When applied to acidic soils, biochar neutralizes the pH and improves nutrient availability, creating a more favorable environment for crop growth. However, the effects of biochar vary significantly depending on the soil type, crop species, and biochar application rate. This study explored the impact of biochar application made from branches and twigs on soil pH and electrical conductivity (EC), under *Avena sativa* cultivation. Biochar was applied at rates of 0, 2, 4, and 8 tons per hectare, and soil pH and EC, and plant growth were monitored over two and a half months. The results demonstrated that biochar initially increased soil pH, with higher application rates of 4 and 8 t/ha, reaching mild alkaline levels favorable for leguminous crops. Biochar significantly increased pH and EC, particularly at higher rates, although the effects diminished over time. These findings highlight the potential of biochar as a short-term soil amendment for pH and nutrient enhancement in acidic soils. This study emphasizes the need for periodic applications or combined soil management strategies to sustain soil quality improvements. This study contributes to sustainable agriculture by offering insights into the role of biochar in enhancing soil health and productivity. Further research on the long-term effects of biochar and its interactions with other soil amendments could help optimize its use for sustainable crop production.

Keywords biochar, Andosol, soil pH, electrical conductivity, oat (*Avena sativa*), soil amendment

INTRODUCTION

Soil properties, such as pH and electrical conductivity (EC), are critical indicators of soil health, fertility, and suitability for agricultural production. pH influences nutrient availability, microbial activity, and the solubility of toxic elements, whereas EC is a measure of soil salinity and ion exchange capacity, reflecting the soil's ability to support crop growth (Brady and Weil, 2017). These parameters are particularly important in Andosols, a soil type derived from volcanic ash, known for its high porosity, organic matter content, and variable charge properties (Shoji et al., 1993). Biochar's role as a soil amendment has been widely studied for its capacity to improve soil pH and EC. Its alkaline nature can neutralize soil acidity, creating a more favorable environment for nutrient uptake and microbial activity (Lehmann and Joseph, 2015). Furthermore, the porous structure and high surface area of biochar contribute to its ability to adsorb nutrients and water, thereby improving soil EC and overall fertility (Novak et al., 2012). The application of biochar to Andosols also influences its cation exchange capacity (CEC) and nutrient retention, with the potential to reduce phosphate fixation, which is a significant challenge in these soils (Agegnehu et al., 2016). These improvements are closely tied to the chemical properties of biochar, pyrolysis temperature, and feedstock material. Importantly, understanding the appropriate application rates of biochar is vital for achieving the desired soil enhancements without adverse effects. Over-application can lead to excessive EC, negatively impacting root function, whereas suboptimal rates may fail to provide meaningful improvements in soil properties. The optimal application rates of biochar are influenced by factors such as soil type, initial fertility status, crop requirements, and environmental conditions. In Andosols, studies have demonstrated that moderate application rates, e.g., 5-10 tons/hectare (t/ha), can effectively improve soil pH and nutrient availability while minimizing the risk of negative impacts. Furthermore, application rate optimization ensures cost-effectiveness and long-term sustainability, as excessive rates may lead to financial inefficiencies and ecological disturbances. Therefore, the objective of this study was to assess the effects and optimum application rates of biochar on Andosol soil pH and EC under *Avena sativa* cultivation.

METHODOLOGY

This study was conducted in an agricultural field in Sakura City, Chiba Prefecture, Japan (Fig. 1). A randomized block design was employed to evaluate the effects of biochar application at four treatment levels: 0 t/ha, 2 t/ha, 4 t/ha, and 8 t/ha, referred to as Control, Treatment 1, Treatment 2, and Treatment 3, respectively (Fig. 2). The soil type of this field was Andosol, which had a carbon-to-nitrogen (C/N) ratio of 13:1. Each treatment was replicated three times. The biochar used in this study was locally produced using traditional farmer techniques in a kiln, utilizing branches and twigs discarded from a nearby orchard. The initial pH and carbon content of the biochar used were 10.2 and 53.6%, respectively. No fertilizers were applied during the study, and all treatments relied solely on natural rainfall for irrigation purposes. Soil samples were collected to measure pH and EC, and crop parameters, including root length and height, were assessed. Statistical analysis was performed using R software, employing two-way ANOVA, followed by Tukey's post-hoc test to evaluate the significance of the results.

Fig. 1 Location of the field

Fig. 2 Random block design of the plots

RESULTS AND DISCUSSION

Effect of Biochar Application on Soil pH and EC

The results (Fig. 3) demonstrated that biochar significantly influenced soil pH dynamics, with a dose-dependent effect observed across the experimental treatments. At the time of application (day 0), the soil pH ranged from 6.0 to 6.5 across all treatments, reflecting uniform baseline conditions. By 42 days, a noticeable increase in soil pH was observed in the biochar-amended soils, with higher application rates (Treatments 2 and 3) showing more pronounced alkalinity. The increase in pH can be attributed to the release of alkaline cations, such as calcium (Ca^{2+}), magnesium (Mg^{2+}), potassium (K^{+}), and sodium (Na^{+}), present in biochar. These cations neutralize hydrogen ions (H^{+}) in acidic soils, thereby effectively increasing the pH (Yuan et al., 2011). Beyond 42 days, a decline in pH was observed across all treatments, which stabilized by 73 days. This trend likely reflects the leaching of soluble alkalinity from biochar, microbial oxidation of organic matter, and inherent acidification processes in the soil. However, soils treated with higher biochar rates maintained slightly higher pH levels than those treated with lower rates or the control. This residual effect indicates that biochar's buffering capacity is sustained over time, albeit diminishing gradually (Chintala et al., 2014). These results emphasize the importance of application rate in determining the effectiveness of biochar. In Treatment 3, biochar induced the most substantial and persistent pH increase, followed by Treatments 2, 1, and the control.

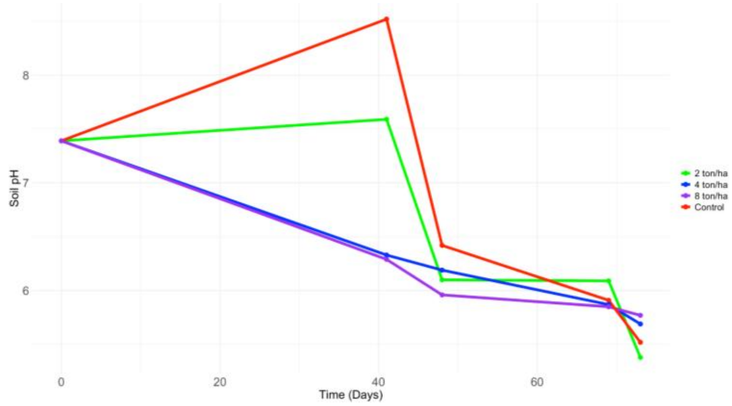

Fig. 3 Change in pH at varying treatments

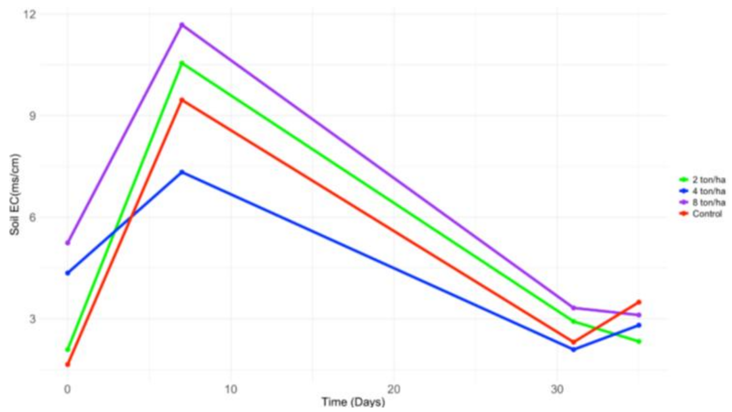

Fig. 4 Change in EC at varying treatments

These findings align with those of previous studies that have demonstrated the dose-dependent effects of biochar on soil pH (Lehmann and Joseph, 2015). While higher rates provide more immediate pH correction, their long-term benefits may depend on soil conditions, biochar stability, and environmental factors. Biochar's ability to raise and buffer soil pH has significant implications for improving acidic soils. By neutralizing acidity, biochar enhances nutrient availability, reduces aluminum toxicity, and fosters favorable conditions for microbial activity and plant growth (Van

Zwieten et al., 2010). Furthermore, the dose-dependent response suggests that while higher rates are more effective, lower rates may offer greater economic and environmental benefits over time.

The results (Fig. 4) indicate that EC increased with biochar application and varied over time. The EC peaked on day 46 for all treatments, with higher biochar application rates (treatment 3) resulting in the highest EC values. This initial spike was attributed to the release of soluble nutrients, such as potassium (K^+), calcium (Ca^{2+}), and magnesium (Mg^{2+}), from the biochar. Over time, the EC decreased significantly by 67 days and stabilized by 71 days, indicating nutrient uptake by plants, leaching, or immobilization within the soil matrix. These findings align with previous studies by Laird et al. (2010), which highlight biochar's nutrient release and subsequent stabilization. Biochar application significantly impacts soil EC due to its inherent properties and nutrient content.

The increase in EC shortly after biochar application demonstrates its role in enhancing short-term nutrient availability, particularly in soils with low fertility. Lehmann et al. (2006) reported that biochar's ash content provides essential nutrients and improves soil chemical properties. Additionally, biochar enhances soil CEC, enabling the retention of cations and reducing nutrient leaching over time (Laird et al., 2010). As biochar decomposes slowly, its effect on EC stabilizes, promoting long-term soil health without the risk of salinity buildup. The stabilization of EC observed in the study suggests biochar's potential as a sustainable amendment that balances immediate nutrient availability with long-term soil fertility. These results are consistent with the findings of Lehmann and Joseph (2009), who highlighted biochar's ability to maintain a steady nutrient supply over extended periods.

Effect of Biochar Application on Crop Height and Root Length

Figure 5 shows *Avena sativa* crop height under varying biochar applications, with no significant differences observed. The consistent height indicates that biochar had a minimal effect on growth, likely due to favorable soil conditions. The C/N ratio of the soil used in this study was 13:1, indicating high soil fertility. Research supports this, suggesting biochar improves soil properties but may not boost crop growth significantly in fertile soils. The benefits of biochar are more pronounced in degraded or nutrient-poor soils. Studies by Jeffery et al. (2011) and Liu et al. (2013) reinforce the context-dependent nature of biochar's effects. Similarly, biochar application at different rates had minimal impact on barley root length, with only a slight increase at the highest rate (Fig.6). The stable root length across treatments may indicate that biochar is not critical for enhancing barley root development in fertile soils. The slight increase at higher application rates suggests that biochar may have a minor positive effect on root growth under certain conditions. Studies on the effects of biochar on root systems support these findings, indicating that the effectiveness of biochar is influenced by soil conditions and crop type. Biochar enhances soil aeration, water retention, and nutrient availability, thereby supporting root growth, primarily in degraded soils. Under such conditions, soil structure and nutrient exchange capacity are improved (Cornelissen et al., 2013). However, in nutrient-rich soils, biochar has a neutral impact on root growth, as plants already have access to adequate resources (Liu et al., 2013; Agegnehu et al., 2015).

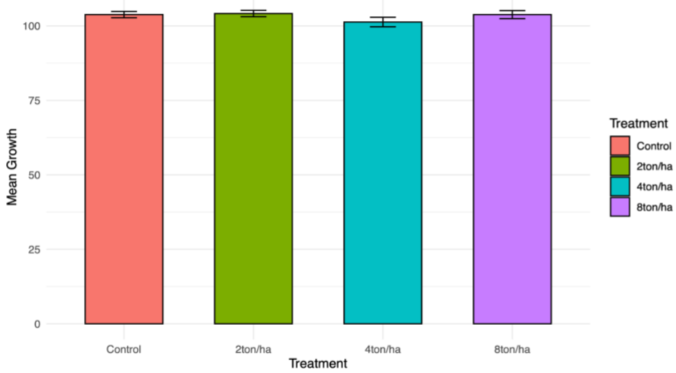

Fig. 5 Plant height at varying treatments

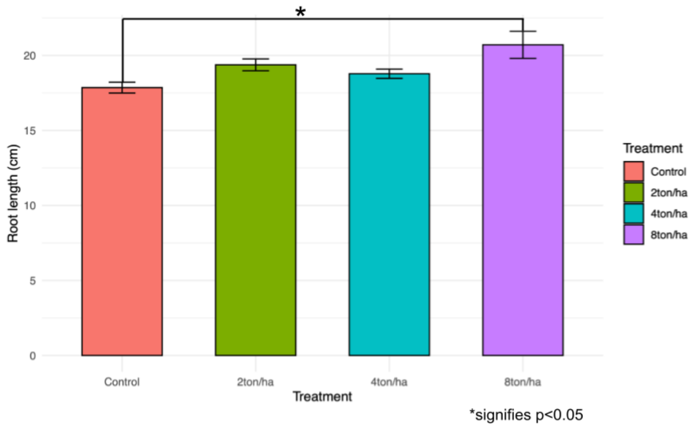

Fig. 6 Root length at varying treatments

CONCLUSION

The findings of this study underscore the significant role of biochar in enhancing soil properties, particularly soil pH and EC, in Andosols under oat (*Avena sativa*) cultivation. Biochar application demonstrated a dose-dependent impact, initially increasing soil pH and EC levels, with higher rates showing more pronounced effects than lower rates. These changes indicate improved nutrient availability and reduced soil acidity, creating favorable conditions for crop growth, particularly in acidic soils. However, the observed decline in pH and stabilization of EC over time highlights the transient nature of these benefits, emphasizing the need for periodic applications or integrated soil management strategies to sustain long-term soil health. The limited influence of biochar on crop height and root length further suggests that its benefits are more pronounced in degraded or nutrient-deficient soils than in inherently fertile conditions. This study provides valuable insights into the potential of biochar as a sustainable soil amendment, offering practical implications for improving soil quality and productivity in acidic soils. Future research should explore the long-term effects of biochar, its interactions with other soil amendments, and its application under diverse soil and crop conditions to optimize its utility for sustainable agriculture.

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REFERENCES

Agegnehu, G., Bass, A.M., Nelson, P.N. and Bird, M.I. 2016. Benefits of biochar, compost, and biochar-compost for soil quality, maize yield and greenhouse gas emissions in a tropical agricultural soil. Science of the Total Environment, 543, 295-306, Retrieved from DOI https://doi.org/10.1016/j.scitotenv.2015.11.054

Chintala, R., Mollinedo, J., Schumacher, T.E., Malo, D.D. and Julson, J.L. 2014. Effect of biochar on chemical properties of acidic soil. Archives of Agronomy and Soil Science, 60-3, 393-404, Retrieved from DOI https://doi.org/10.1080/03650340.2013.789870

Cornelissen, G., Martinsen, V., Shitumbanuma, V., Alling, V., Breedveld, G.D., Rutherford, D.W., Sparrevik, M., Hale, S.E., Obia, A. and Mulder, J. 2013. Biochar effect on maize yield and soil characteristics in five conservation farming sites in Zambia. Agronomy, 3 (2), 256-274, Retrieved from DOI https://doi.org/10.3390/agronomy3020256

Jeffery, S., Verheijen, F.G., van der Velde, M. and Bastos, A.C. 2011. A quantitative review of the effects of biochar application to soils on crop productivity using meta-analysis. Agriculture, Ecosystems and Environment, 144 (1), 175-187, Retrieved from DOI https://doi.org/10.1016/j.agee.2011.08.015

Laird, D., Fleming, P., Wang, B., Horton, B. and Karlen, D. 2010. Biochar impact on nutrient leaching from a Midwestern agricultural soil. Goederma, 158 (3-4), 436-442, Retrieved from DOI https://doi.org/10.1016/j.geoderma.2010.05.012

Lehmann, J., Gaunt, J. and Rondon, M. 2006. Biochar sequestration in terrestrial ecosystem, A review. Mitigation and Adaptation Strategies for Global Change, 11, 403-427, Retrieved from DOI https://doi.org/10.1007/s11027-005-9006-5

Lehmann, J. and Joseph, S. 2009. Biochar for environmental management, An introduction. Biochar for Environmental Management Science and Technology, Earthscans, London, 1-12.

Lehmann, J. and Joseph, S. 2015. Biochar for environmental management. Science, Technology and Implementation 2, Retrieved from DOI https://doi.org/10.4324/9780203762264

Liu, X., Zhang, A., Ji, C., Joseph, S., Bian, R., Li, L. and Pan, G. 2013. Biochar's effect on crop productivity and the dependence on experimental conditions, A meta-analysis of literature data. Plant and Soil, 373, 583-594, Retrieved from DOI 10.1007/s11104-013-1806-x

Novak, J.M., Busscher, W.J., Watts, D.W., Amonette, J.E., Ippolito, J.A., Lima, I.M., M, I., Julia, G., KC., D., Christoph, S., Mohamed, A., Djaafar, R. and Schomberg, H. 2012. Biochars impact on soil-moisture storage in an Ultisols and two Aridisols. Soil Science, 177 (5), 310-320, Retrieved from DOI 10.1097/SS.0b013e31824e5593

Shoji, S., Nanzyo, M. and Dahlgren, R.A. 1993. Volcanic ash soils: Genesis, properties and utilization. Developments in Soil Science 21, 288. Elsevier.

Van Zwieten, L., Kimber, S., Morris, S., Chan, K.Y., Downie, A., Rust, J. and Cowie, A. 2010. Effects of biochar from slow pyrolysis of papermill waste on agronomic performance and soil fertility. Plant and Soil, 327 (1), 235-246, Retrieved from DOI https://doi.org/10.1007/s11104-009-0050-x

Weil, R.R. and Brady, N.C. 2017. The nature and properties of soils. 15th edition, Pearson, New York.

Yuan, J.H., Xu, R.K. and Zhang, H. 2011. The forms of alkalis in the biochar produced from crop residues at different temperatures. Bioresource technology, 102 (3), 3488-3497, Retrieved from DOI https://doi.org/10.1016/j.biortech.2010.11.018