PANAMGEO CHILE 2024
17th PAN-AMERICAN CONFERENCE ON SOIL MECHANICS AND GEOTECHNICAL ENGINEERING | 2nd LATIN-AMERICAN REGIONAL CONFERENCE OF IAEG
LA SERENA • CHILE / NOVEMBER 12 - 16, 2024

Proceedings of the 17th Pan-American Conference on Soil Mechanics and Geotechnical Engineering (XVII PCSMGE), and 2nd Latin-American Regional Conference of the International Association for Engineering Geology and the Environment (IAEG), La Serena Chile, 2024.

Influence of Biochar Addition on Compaction Parameters of Soil

Influência da Adição de Biocarvão nos Parâmetros de Compactação do Solo

Jéssica Pelinsom Marques & Valéria Guimarães Silvestre Rodrigues
Department of Geotechnical Engineering, São Carlos School of Engineering, University of São Paulo, Brazil, jessica.pelinsom@gmail.com

Carlos Manoel Pedro Vaz
Embrapa Instrumentation, Brazil

ABSTRACT: There has been a growing interest on using biochar in environmental geotechnical applications, particularly in compacted soil liners for waste disposal. Previous studies have demonstrated that incorporating biochar derived from urban pruning waste to a clayey soil from Vale do Ribeira (São Paulo, Brazil) increased its capacity to adsorb potentially toxic metals. However, further investigation is needed to understand the effects of biochar on the soil's geotechnical properties. This study aims to assess the influence of adding 2.5% and 5.0% (w/w) of pruning waste biochar to the clayey soil on compaction parameters. Standard Proctor tests showed that biochar reduced the maximum dry density of the soil (from 1.560 g cm^{-3} for the unamended soil to 1.478 g cm^{-3} for the mixture with 5.0% biochar) and increased the optimum moisture content (22.7% for the unamended soil, 26.1% for the mixture with 2.5% biochar, 24.9% for the mixture with 5.0% biochar). These effects can be attributed to the porous structure and lower density of the biochar compared to the soil. The results highlight the importance of adjusting the biochar proportions to achieve the desired geotechnical properties, as they will influence the performance of the mixtures as liners.

KEYWORDS: Standard Proctor, Maximum dry density, Pruning waste, Soil liner

1 INTRODUCTION

Biochar is a solid carbonaceous material generated from the pyrolysis of various feedstocks. When biomass is heated to high temperatures (300 to 1000°C) in a closed reactor in the absence or very limited presence of oxygen, three products are generated: a liquid (bio-oil), a gas (syngas), and a solid (biochar) (Downie, Crosk & Munroe 2009). Different feedstocks can be used to produce biochar, including waste materials and by-products such as straw, leaves, husks, municipal solid waste, animal manure, and effluent treatment sludges (Ahmad et al. 2014; Mishra et al. 2023). Biochar differs from charcoal and similar materials primarily in its application. The primary application of biochar is soil improvement, rather than heating or energy production (Lehman & Joseph 2009).

The application of biochar to soil can increase its organic matter and nutrient contents while reducing acidity (Ahmad et al. 2014; Nascimento et al. 2023). The high stability of biochar can decrease CO_2 emissions to the atmosphere (Downie, Crosky & Munroe 2009; Yadav et al. 2023). Regarding biota, the pores in biochar provide a suitable habitat for microorganisms, protecting them and providing carbon, nutrients, and energy (Nascimento et al. 2023). Biochar also influences the texture, structure, porosity, and consistency of soils, and affects aggregation, shrinkage and swelling dynamics, permeability, cation exchange capacity, and soil response to temperature variations (Downie, Crosky & Munroe 2009; Lu et al. 2023; Wang et al. 2023).

Over the past decade, extensive research has been conducted on using biochar to enhance agricultural soils (Cooper et al. 2020; Zhang et al. 2020; Ghassemi-Golezani et al. 2023), remediate contaminated areas (Lima et al. 2022; Wei et al. 2024; Meng et al. 2023), and mitigate climate change (Hougaard et al. 2024).

Recently, there has been a growing interest in its application in environmental geotechnics, particularly in compacted soil liners for waste disposal. Veena et al. (2023) reported that the use of 10% rice husk biochar or wood chip biochar is efficient in partially replacing bentonite in sand-bentonite mixtures used as liners. Chen et al. (2022) studied the effects of adding peanut husk biochar to compacted clayey soil on performance as landfill covers in different climatic scenarios. The application of biochar reduced the number of pores larger than 20 µm, making the cover more efficient against infiltration. Biochar also helped prevent cracks and extreme dry conditions.

In this study, we investigated urban pruning waste biochar pyrolyzed at 500°C. Urban pruning waste consists of leaves, branches, and roots generated during tree pruning operations in the cities. It is generated in large volumes and has high potential for utilization. However, it is still poorly managed and ends up in landfills, which generate problems to the environment and unnecessary costs to municipalities.

Previous studies (Marques 2013, Marques et al. 2023) have shown that incorporating this biochar into clayey soil from Ribeira Valley (São Paulo, Brazil) increased its capacity to adsorb potentially toxic metals such as Pb, Cd, and Zn, which is an important property for attenuating contamination at hazardous solid waste disposal sites. However, further investigation is needed to understand the effects of biochar on the soil's geotechnical properties.

Thus, this study aims to assess the influence of adding 2.5% and 5.0% (w/w) of pruning waste biochar to the soil on compaction parameters. This article contributes to the study of soil-biochar mixtures as liners. It is a promising alternative for utilizing urban pruning waste as well as for protecting the environment against contamination in waste disposal areas.

2 METHODS

The soil used in this study (see Figure 1a) is a non-contaminated composite sample, representative of Ribeira Valley, specifically from the municipalities of Eldorado and Jacupiranga (São Paulo, Brazil). The sample was prepared and characterized by Marques et al. (2022). It is a silty soil (22.1% clay, 48.1% silt, and 29.7% sand), acidic (pH 4.8) with the fine fraction predominantly composed of kaolinite.

The biochar (see Figure 1b) was obtained from the pyrolysis of urban pruning waste at 500°C, without oxygen, with 5 hours at peak temperature. In the laboratory, the biochar was disaggregated, sieved through a 2 mm opening sieve, and homogenized. The production and preparation procedures of biochar were described by Moraes (2022). The material has a pH of 10.0, 67.3% carbon, 16.3% ash content, and a cation exchange capacity of 69.0 cmol$_c$ kg^{-1} (Moraes 2022).

Mixtures with 2.5% and 5.0% of biochar in the soil (w/w) were then prepared (Figures 1c and 1d). These proportions were chosen based on the literature on biochar-soil mixtures (Sudhakar et al. 2017; Penido et al. 2019; Luo et al. 2020; Yang et al. 2023; Yadav & Bag 2023), as well as on biochar characterization results from Moraes et al. (2021). Soil and biochar were mixed using a concrete mixer and homogenized using the elongated pile method.

The samples of soil (without biochar), soil with 2.5% biochar, and soil with 5.0% biochar were subjected to Standard Proctor Compaction Tests, conducted according to the method described by Brazilian Standard 7182/2016 "Soil: Compaction Test" from the Brazilian Association of Technical Standards (ABNT 2016).

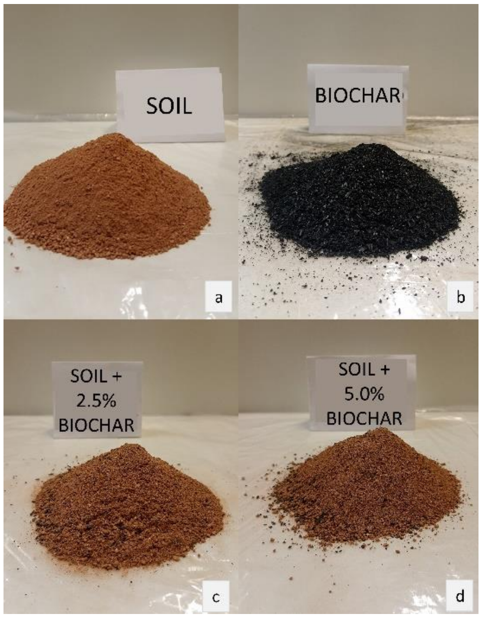

Figure 1. Soil sample (a), pruning waste biochar (b), mixture of soil with 2.5% biochar (c), and mixture of soil with 5% biochar (d).

3 RESULTS

Figure 2 presents the compaction curves of the soil and the mixtures, while Table 1 shows the compaction parameters of each sample, including the maximum dry density (ρ_{dmax}), the optimum moisture content (w_{opt}), and the void ratio (e). The addition of biochar decreased the dry density. For the same moisture content, the higher the proportion of biochar in the mixture, the lower the dry density, except for the point at around 23% moisture content, where the mixture with 5.0% biochar had a slightly higher dry density than the other mixture.

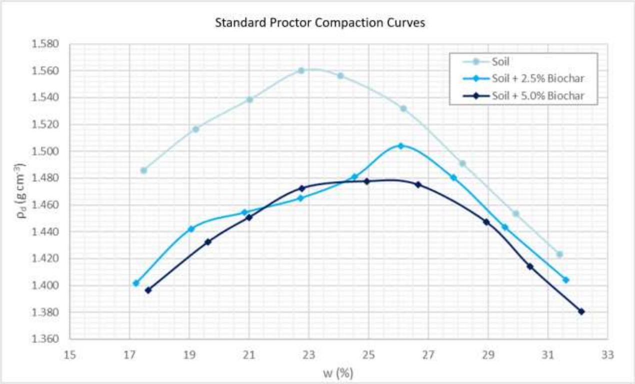

Figure 2. Standard Proctor Compaction curves for the soil, the mixture of soil with 2.5% biochar and the mixture of soil with 5.0% biochar.

Table 1. Standard Proctor compaction parameters of the soil, the mixture of soil with 2.5% biochar, and the mixture of soil with 5.0% biochar.

Parameter	*Soil*	*Soil + 2.5% Biochar*	*Soil + 5.0% Biochar*
ρ_{dmax} (g cm^{-3})	1.560	1.504	1.478
w_{opt} (%)	22.7	26.1	24.9
e	0.699	0.762	0.793

Biochar reduced ρ_{dmax} of the soil, with values of 1.560 g cm^{-3} for the soil, 1.504 g cm^{-3} for the mixture with 2.5% biochar, and 1.478 g cm^{-3} for the mixture with 5.0% biochar. The w_{opt} was higher for the mixtures (26.1% for the mixture with 2.5% biochar and 24.9% for the mixture with 5.0% biochar) than for the soil (22.7%). The void ratio of the compacted specimens increased with the addition of biochar (0.699, 0.762, and 0.793 for the soil, the mixture with 2.5% biochar, and the mixture with 5% biochar, respectively).

Such an effect on soil compaction curves due to the addition of biochar has been reported in the literature for biochar from different feedstocks. For example, Kumar et al. (2019) added 5% peanut husk biochar to a sandy-silty soil in India and observed an increase in w_{opt} from 16.7% to 17.2% and a decrease in ρ_{dmax} from 1.73 g cm^{-3} to 1.60 g cm^{-3}. The addition of sawdust biochar in the same proportion increased w_{opt} to 19.8% and decreased ρ_{dmax} to 1.56 g cm^{-3}. Similar results were reported by Sudhakar et al. (2017) studying mixtures of a silt soil from India with 20% sugarcane bagasse biochar, by Ganesan et al. (2020) studying the addition of 5% and 10% of cedar wood biochar in a sand clay, and by Yadav & Bag (2023), who investigated the mixture of bamboo biochar in a clayey soil in proportions up to 5%.

The decrease in ρ_{dmax} may be related to the replacement of heavier soil particles by lighter biochar particles, while the increase in w_{opt} may be associated with a greater water retention capacity of biochar compared to the soil.

4 CONCLUSIONS

The addition of pruning waste biochar to the soil decreased maximum dry bulk density and increased optimum moisture content. These findings underscore the significance of adjusting the proportions of biochar to attain the targeted geotechnical properties, as they will impact the performance of the mixtures as liners. Further research will focus on examining the effects of pruning waste biochar on other parameters, such as permeability and strength.

5 ACKNOWLEDGEMENTS

The authors are grateful to the National Council for Scientific and Technological Development (CNPq) for providing a PhD scholarship (140124/2019-5) and Research Productivity Fellowship (310989/2020-5).

6 REFERENCES

Gibson R.E. and Henkel D.J. 1954. Influence of duration of tests at constant rate of strain on measured “drained” strength. *Géotechnique* 4 (1), 6-15.

Terzaghi K. 1936. The shearing resistance of saturated soils. *Proc. 1st Int. Conf. Soil Mech.*, Cambridge, Mass., 1, 54-56.

Ahmad, M.; Rajapaksha, A.U.; Lim, J. E.; Zhang, M.; Bolan, N.; Mohan, D.; Vithanage, M.; Lee, S. S.; Ok, Y. S. 2014. Biochar as a sorbent for contaminant management in soil and water: A review. *Chemosphere* 99, 19-33. https://doi.org/10.1016/j.chemosphere.2013.10.071

Associação Brasileira De Normas Técnicas (ABNT). NBR 7182. Solo: Ensaio de compactação. Rio de Janeiro, 1986.

Chen, Z.; Kamchoom, V.; Apriyono, A.; Chen, R.; Chen, C. 2022. Laboratory study of water infiltration and evaporation in biochar-amended landfill covers under extreme climate. *Waste Management*, 153, 323-334. https://doi.org/10.1016/j.wasman.2022.09.015

Cooper, J.; Greewberg, I.; Ludwig, B.; Hippich, L.; Fisher D.; Glaser, B.; Kaiser, M. 2020. Effect of biochar and compost on soil porperties and organic matter in aggregate size fractions under field conditions. *Agriculture, Ecosystems and Environment* 295. https://doi.org/10.1016/j.agee.2020.106882

Downie, A.; Crosky, A.; Munroe, P. 2009. *Physical Properties Of Biochar*. In: Lehmann, J; Joseph, S. 2009. Biochar for Environmental management: Science and Technology. London: Earthscan, 2009. p13-30.

Ganesan, S. P.; Bordoloi, S.; Ni, J.; Garg, A.; Sekharan, A.2020. Exploring implication of variation in biochar production on geotechnical properties of soil. *Biomass Conversion and Biorefinary*. https://doi.org/10.1007/s13399-020-00847-2

Ghassemi-Golezani, K.; Rahimzadeh, S.; Farhangi-Abriz, S. 2023. Utilization of biochar in rainfed farming systems: A meta-analysis. *Bioresource Technology Reports*, 22, 101436. https://doi.org/10.1016/j.biteb.2023.101436

Hougaard, I. 2024. Enacting biochar as a climate solution in Denmark. *Environmental Science and Policy* 152, 103651. https://doi.org/10.1016/j.envsci.2023.103651

Kumar, H.; Ganesan, S. P.; Bordoloi, S.; Sreedeep, S.; Lin, P.; Mei, G.; Garg, A.; Sarmah, A. K. 2019. Erodibility assessment of compacted biochar amended soil for geoenvironmental applications. *Science of Total Environment* 672, 698 – 707.

Lehmann, J; Joseph, S. 2009. *Biochar for Environmental Management: An Introduction*. In: Lehmann, J; Joseph, S. 2009. Biochar for Environmental management: Science and Technology. London: Earthscan, 2009. p1-9.

Lima, J. Z. 2022. *Avaliação da sorção e pós-sorção de contaminantes provenientes de resíduos de mineração: turfa, composto e biocarvão*. 2022. 300 p. Phd thesis, University of São Paulo and University of Aveiro, São Carlos, SP.

Lu, Y.; Gu, K.; Shen, Z.; Tang, C.; Shi, B.; Zhou, Q. 2023. Biochar implications for the engineering properties of soils: A review. *Science of the Total Environment*, 888, 164185. https://doi.org/10.1016/j.scitotenv.2023.164185

Luo, M.; Lin, H.; He, Y.; Zhang, Y. 2020. The influence of corncob-based biochar on remediation of arsenic and cádmium in yellow soil and cinnamon soil. *Science of the Total Environment* 717, 137014. https://doi.org/10.1016/j.scitotenv.2020.137014

Marques, J. P. *Misturas de Solo com Biocarvão de Resíduos de Poda para Retenção de Pb, Cd e Zn em Barreiras de Proteção Ambiental*. 2023. 260p. Phd thesis, University of São Paulo, São Carlos, SP.

Marques, J. P.; Lima, J. Z.; Vaz, C. M. P.; Rodrigues, V. G. S. 2023. Adsorção de Cd em Misturas de Solo com Biocarvão de Resíduos de Poda Urbana. *Proceedings of X Brazilian Congress of Environmental Geotecnics and IX Brazilian Congress of Geosynthetics*. Salvador, BA, Brazil.

Marques, J. P.; Vaz, C. M. P.; Sígolo, J. B.; Rodrigues, V. G. S. 2022. Soils of the Ribeira Valley (Brazil) as Environmental Protection Barriers: Characterization and Adsorption of Lead and Cadmium. *Sustainability* 14, 5135. https://doi.org/10.3390/su14095135

Meng, Z.; Huang, S.; Wu, J.; Lin, Z. 2023. Competitive adsorption and immobilization of Cd, Ni, and Cu by biochar in unsaturated soils under single-, binary-, and ternary-metal systems. *Journal of Hazardous Materials* 452, 131106. https://doi.org/10.1016/j.jhazmat.2023.131106

Mishra, S. R.; Chandra, R.; Kaila, J.; Darshi, S. 2017. Kinects and Isotherm studies for the adsorption of metal ions onto two soil types. *Environmental Technology & Innovation* 7, 87-101. https://doi.org/10.1016/j.eti.2016.12.006

Moraes, T. T. 2022. Caracterização de biocarvão de resíduos de poda e análise da sorção de Cd e Pb. MSc. Dissertation. University of São Paulo, São Carlos, SP.

Moraes, T. T. 2021. Characterization Of Pruning Waste-Based Biochar And Adsorption Analysis Of Cd And Pb Elements. *Proceedings of 1ª Conferencia Regional Sudamericana de IAEG y 2° Congreso Argentino de Geología Aplicada a la Ingenieria y al Ambiente*.

Nascimento, I. V.; Freglente, L. G.; Pereira, A. P. A.; Nascimento, C. D. V.; Mota, J. C. A.; Ferreira, O. P.; Sousa, H. H. F.; Silva, D. D. G.; Simões, A. G. S.; Souza Filho, A. G.; Costa, M. C. G. 2023. Biochar as a carbonaceous material to enhance soil quality in drylands ecosystems: A review. *Environmental Research*, 233, 116489. https://doi.org/10.1016/j.envres.2023.116489

Penido, E. S.; Martins, G. C.; Mendes, T. B. M.; Melo, L. C. A.; Guimarães, I. R.; Guilherme, L. R. G. 2019. Combining biochar and sewage sludge for immobilization of heavy metals in mining soils. *Ecotoxicology and Environmental Safety* 172, 326-333. https://doi.org/10.1016/j.ecoenv.2019.01.110

Sudhakar, A.; Remya, N.; Varghese, G. K. 2017. Estimation of effect of sugarcane bagasse biochar amendment in landfill soil cover on geotechnical properties and landfill gas emission. Environmental *Quality Management* 27, 33-39. https://doi.org/10.1002/tqem.21528

Veena, V.; Cyrus, S.; Abraham, B. M.; Jose, B. T. 2023. Effect of partial replacement of bentonite with biochar in liner soils. *Biomass Conversion and Biorefinery*, 13, 2079–2087. https://doi.org/10.1007/s13399-021-01319-x

Wang, L.; Luo, P.; Jiang, C.; Shen, J.; Liu, F.; Xiao, R.; Wu, J. 2023. Distinct effects of biochar addition on soil macropore characteristics at different depths in a double-rice paddy field. *Science of the Total Environment* 857, 159368. http://dx.doi.org/10.1016/j.scitotenv.2022.159368

Wei, Z.; Wei, Y.; Liu, Y.; Niu, S.; Xu, Y.; Park, J.; Wang, J. J. 2024. Biochar-based materials as remediation strategy in petroleum hydrocarbon-contaminated soil and water: Performances, mechanisms, and environmental impact. *Journal of Environmental Sciences* 138, 350–372. https://doi.org/10.1016/j.jes.2023.04.008

Yadav, S.; Bag, R. 2023. Effect of Bamboo biochar on strength and water retention properties of low plastic clay and silty sand. *Scientific Reports*, 13, 6201. https://doi.org/10.1038/s41598-023-33466-8

Yadav, S. K.; Bhandari, S.; Bhatta, D.; Poudel, A.; Bhattarai, S.; Yadav, P.; Ghimire, N.; Paudel, P.; Paudel, P.; Shrestha, J.; Oli, B. 2023. Biochar application: A sustainable approach to improve soil health. *Journal of Agriculture and Food Research* 11, 100498. https://doi.org/10.1016/j.jafr.2023.100498

Yang, K.; Wang, X.; Cheng, H.; Tao, S. 2023. Effects of physical aging processes on the bioavailability of heavy metals in contaminated site soil amended with chicken manure and wheat straw biochars. *Environmental Pollution*, 324, 121414. https://doi.org/10.1016/j.envpol.2023.121414

Zhang, Q.; Song, Y.; Wu, Z.; Yan, X.;Gunina, A.; Kuzyakov, Y.; Xiong, Z. 2020. Effects of six-year biochar amendment on soil aggregation, crop growth, and nitrogen and phosphorus use efficiencies in a rice-wheat rotation. *Journal of Cleaner Production* 2, 42, 118435.

INTERNATIONAL SOCIETY FOR SOIL MECHANICS AND GEOTECHNICAL ENGINEERING

The paper was published in the proceedings of the 17th Pan-American Conference on Soil Mechanics and Geotechnical Engineering (XVII PCSMGE) and was edited by Gonzalo Montalva, Daniel Pollak, Claudio Roman and Luis Valenzuela. The conference was held from November 12th to November 16th 2024 in Chile.