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Evaluation of Physicochemical Parameters in Sandy Soils After Applying Biochar as an Organic Amendment

Alex Huamán De La Cruz[1,3]†, Gina Luna-Canchari[2], Nicole Mendoza-Soto[2], Daniel Alvarez Tolentino[3], Ronald Jacobi Lorenzo[4], Armando Calcina Colqui[4], Geovany Vilchez Casas[4], Julio Mariños Alfaro[3] and Roger Aguilar Rojas[3]
[1]Facultad de Derecho, Universidad Tecnológica del Perú, San Agustín de Cajas 12007, Huancayo 12001, Peru
[2]Escuela Profesional de Ingeniería Ambiental, Universidad Peruana Unión, Lima, Peru
[3]Escuela Profesional de Ingeniería Ambiental, Universidad Nacional Intercultural de la Selva Central Juan Santos Atahualpa, Jr. Los Cedros N°141, Chanchamayo, Perú
[4]Escuela Profesional de Ingeniería Civil, Universidad Nacional Intercultural de la Selva Central Juan Santos Atahualpa, Jr. Los Cedros N°141, Chanchamayo, Perú
†Corresponding author: Alex Huamán De La Cruz; alebut2@hotmail.com

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ABSTRACT

Sandy soils are not suitable for agriculture because they do not retain nutrients, and water drains quickly. The biochar applied to these soils provides nutrients, improves their fertility, and favors crop yields. Thus, this work aimed to evaluate the effect of the application of pine biochar and the pruning of green areas obtained by slow pyrolysis on the physicochemical attributes of sandy soil. For this purpose, a greenhouse experiment was conducted in fifteen pots randomly divided into three groups (five replicas) of treatment depending on the dose of biochar: 0% (0 g/pot, T1 control treatment), 10% (100 g/pot, T2), and 25% (250 g/pot, T3) calculated according to the volume of the soil. Likewise, 05 seeds of turnip (*Brassica rapa* subsp. *rapa*) were placed in each pot, where their germination and growth were monitored. Application of biochar reported an increase in organic matter, porosity, pH, electrical conductivity, cation exchange capacity, NO_3^-, K, and Mg (without significant differences) and a reduction in bulk density, P, and Ca (without significant differences). These behaviors were higher in T3, followed by T2, compared to T1. Similarly, T3 (68%, 7.5 ± 0.9 cm) showed a higher number of turnip germinations and growth compared to T2 (48%, 7 ± 0.6 cm) and T1 (28% 6 ± 0.4 cm). The biochar applied improved the attributes of the sandy soil, strengthening it against possible erosion and promoting the preservation of terrestrial ecosystems.

INTRODUCTION

Land degradation is a problem that is growing at alarming rates, threatening land productivity and fertility, as well as food security, sustainable development, and healthy ecosystems in many countries around the world (Jie et al. 2002). The Intergovernmental Science-policy Platform on Biodiversity and Ecosystem Services (IPBES) indicates that only a quarter of the world's land is free from anthropogenic impact and that by 2050 this will be reduced to one-tenth (IPBES 2018). Likewise, the United Nations (UN) maintains that every year 24000 million tons of fertile soil are lost as a result of desertification, which puts at risk the well-being of 3200 million people (ONU 2019). In Latin America, Brazil and Honduras show the highest deforestation, while Mexico, Argentina, Bolivia, Chile, and Peru have the highest desertification (Ontiveros 2014).

In Peru, desertification is classified according to its geographical regions. In the Sierra, due to overgrazing, water and wind erosion and pollution, on the coast by salinization, and the jungle mainly by water erosion (Eguren & Marapi 2015). Peru faces significant soil degradation challenges due to erosion in the Andes, deforestation in the Amazon, overgrazing in highland pastures, and unsustainable agricultural practices like monoculture and excessive chemical use (Tito et al. 2022). Mining activities contribute to soil contamination and erosion, while climate change exacerbates these issues with extreme weather events (Bech et al. 2017). Additionally, irrigation-induced salinization and rapid urbanization further degrade soil quality, complicating efforts to maintain soil health. For instance, the National Forest and Wildlife Service (SERFOR) identified 8.2 million degraded hectares in Peru, with 2.2 million referring to the Sierra, 519,000 in the Jungle, and 149,000 in the Coast (Andina 2021). Among the main problems of soil degradation in Peru are the loss of vegetation cover and biodiversity, burning of pastures and forest fires, reduction of ecosystem services, overgrazing, poor agricultural practices, inadequate water use, change of land use (overuse), erosion, etc. (Andina 2021). Soil degradation occurs when it loses or is altered its chemical, physical, ecological, and biological properties as a result of natural or anthropogenic disturbances (population growth, industrialization, and climate change) (FAO 2015).

Soil degradation processes include erosion, nutrient, and organic matter depletion, loss of organic carbon, desertification, acidification, and pollution (Samec et al. 2023).

Sandy soils are prone to erosion, especially in areas with minimal vegetation cover or where the wind is strong, which degrades soil quality over time (Flumignan et al. 2023). Much of Peru's sandy soils are found along the coastal regions, particularly in the desert areas, which is a major agricultural hub, producing a variety of high-value crops such as asparagus, avocados, grapes, and various fruits and vegetables for domestic consumption and export (Olarte et al. 2023). Thus, this degradation could be reversed if sustainable management practices and the use of appropriate technologies are put into practice.

Biochar is a carbon-rich material, a highly porous product that can be obtained from the carbonization (thermal decomposition) of organic materials through the process of pyrolysis (combustion in the absence of oxygen) with temperatures below 700^{o}C. Its application is considered as a promising soil amendment in for several reasons, such as i) soil health improvement because it enhances soil structure, increases nutrient retention, and boosts microbial activity (Yadav et al. 2023), ii) carbon sequestration due to that reduces greenhouse gas emissions and long-term carbon storage (Zhang et al. 2023), iii) environmental benefits because reduces pollution and water quality improvements (Oni et al. 2019), iv) sustainable agriculture due to that enhanced crop yields and reuse agricultural and forestry residues (Liu et al. 2023), and v) climate resilience because improve drought resistance and extreme weather conditions (Lehmann et al. 2021). Furthermore, due to its high specific surface, high porosity, and strong adsorption capacity, biochar as an organic amendment can remedy soils contaminated by different pesticides (Brassard et al. 2019, Pan et al. 2022) and metals (Haider et al. 2022, Xiong et al. 2024). In plants, biochar improves the biological nitrogen fixation processes by stimulating bacterial nitrification rates. Likewise increases the availability of C, Ca, Mg, K, and P to plants. Biochar-added modified soil microbial habitats and directly affect microbial metabolisms, which together induce changes in microbial community and activity (Zhu et al. 2017).

In addition, recent studies reported that the application of biochar in soils helped to minimize the absorption of metals, thus reducing the toxicity of the metal in different plants such for example wheat (*Triticum aestivum* L.) (Rehman et al. 2020), alfalfa (*Medicago sativa* L.) (Zhang et al. 2019), and lettuce (*Lactuca sativa* L.) (Vannini et al. 2021, Rivera et al. 2022).

Avoiding, reducing, and reversing the problem of contaminated and degraded soils will protect biological diversity and ecosystem services important for life on Earth and ensure human well-being. Therefore, the objective of this work was to determine the effect of the application of biochar on the physicochemical properties of sandy soils and to evaluate their germination and growth of turnips.

MATERIALS AND METHODS

Soil Sampling and Characterization

The potting experiments were conducted under greenhouse

Table 1: Characterization of physicochemical properties of soil used in biochar experiments.

Parameter	Value
Bulk density (B. D.)	2.20 g.cm^{-3}
Real density (R.D)	2.74 g.cm^{-3}
Porosity (PO)	19.87%
pH	7.77
Electrical conductivity (EC)	726 uS.cm^{-1}
Cation Exchange Capacity (CIC)	0.9 meq.100g^{-1}
Organic matter (OM)	(3.23%)
Texture	Sandy loam
Nitrate (NO_3)	1.40 mg.L^{-1}
Potasium (K)	4.5 mg.L^{-1}
Phosphorus (P)	1.10 mg.L^{-1}
Calcium (Ca)	165 mg.L^{-1}
Magnesium ((Mg)	20 mg.Lv1
Color	Wet: Dark Brown Dry: Yellowish Brown

conditions using soils sampled within the plant's facilities of the Universidad Peruana Unión (11º59'24" S, 76º50'29" O), Lurigancho-Chosica, Lima (Perú). The soils were obtained by sampling an area of 25 m^2 at 30 cm depth, applying the methodology of patterns with uniform distribution described in the "Guide for Soil Sampling" of the Ministry of the Environment (MINAM) (MINAM 2014). In total, 25 subsamples were collected (1 kg per m^2), which were gathered, homogenized, sieved (Size 1.18 mm with ASTM-E-11 specifications), and quartered to obtain 25 representative samples of 1 kg. One of the samples was randomly characterized as physicochemical (Table 1), presenting a sandy loam texture.

Production and Characterization of Biochar

A pyrolytic furnace of 20 kg capacity was designed and manufactured with two metal cylinders (Fig. 1). An external one (70 cm in height and 58 cm in diameter) produces the biochar with perforations to release volatile gases and energy. An internal one (40 cm in height and 38 cm in diameter) that allowed to feed the residual biomass and increase the temperature of pyrolysis and perforations to regulate the aeration and collect the ashes through the sieving. It is important to mention that the system had a hermetic lid with a chimney (10 cm height and 5 cm height) that allowed the moderate entry and exit of oxygen.

Plant biomass (branches, trunks, and leaves mainly of the pine tree, plant remains, and grasses) corresponding to the pruning of green areas and gardens of the District of Chaclacayo, Lima (Peru) was used as raw material (RM). This RM was subjected to the process of slow pyrolysis in the pyrolytic furnace, starting with a temperature of 0^oC to 200^oC (first stage for evaporation of moisture and light volatiles) with a heating rate of 5 $^oC.s^{-1}$ to reach 450 ^oC (the second stage where hemicellulose and cellulose were devolatilized and decomposed) and with a residence time of 45 min.

Plant biomass (branches, trunks, and leaves mainly of the pine tree, plant remains, and grasses) corresponding to the pruning of green areas and gardens of the District of Chaclacayo, Lima (Peru) was used as raw material (RM). This RM was subjected to the process of slow pyrolysis in the pyrolytic furnace, starting with a temperature of 200^oC with a heating rate of $5^oC.s^{-1}$ to reach 450^oC and with a residence time of 45 min.

The biochar obtained was transferred to the laboratory, after which it was crushed using a mortar and sieved to obtain particles smaller than 2 mm (ASTM-E-11 specifications) (Fig. 2) before its use as an organic amendment. From a total of 12.5 kg of biomass, 4.85 kg (38.8% yield) of biochar was obtained.

Application of Biochar Pots with Turnip Seeds (*Brassica rapa* subsp. *rapa*)

To experiment was carried out in fifteen pots, where was added 1 kg of soil, which were divided into five pots (five repetitions) in three treatments: control treatment (T1) had a concentration of 0% (0 g of biochar), treatment two (T2) had a concentration of 10% (0.1 kg of biochar) and treatment three (T3) was 25% (0.25 kg of biochar). Likewise, 05 seeds of turnip (*Brassica rapa* subsp. *rapa*) were placed

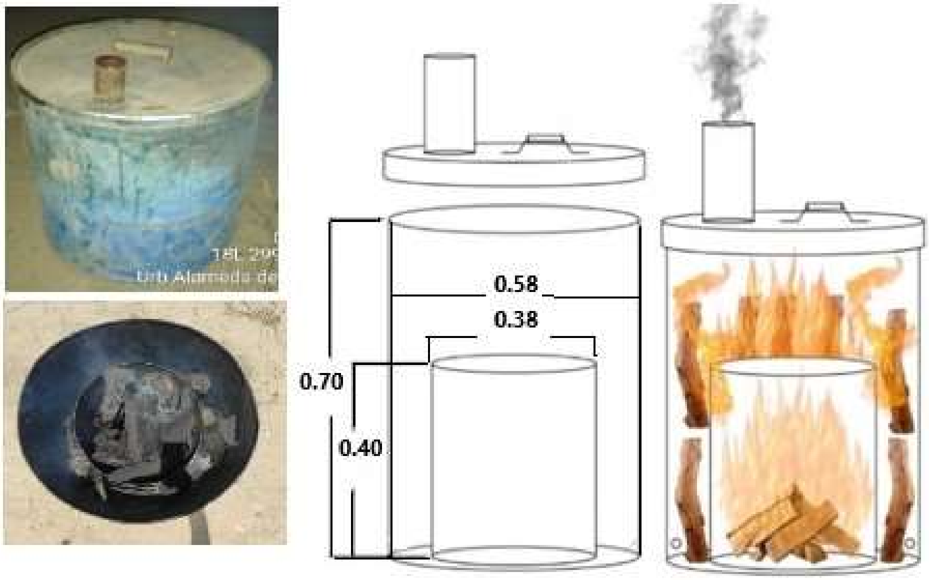

Fig. 1: Desing and use of pyrolytic furnace to produce biochar.

Fig. 2: Crushing and sieving of biochar produced.

Table 2: Physicochemical parameters to be evaluated.

Parameter	Unity	Methodology	Ideal ranges	References
Bulk density (BD)	$g.cm^{-3}$	Cylinder	Low: ≤0.7 Ideal: 0.7-0.8 High: 09-1.2 ≥1.2	(Reyes 2001)
Real density (DR)	$g.cm^{-3}$	Pycnometer	Around 2.65 g,cm^{-3} *Always minor to BD	(Volverás-Mambuscay et al. 2020)
Porosity (P)	%	Relation between RD and BD	Very low: 30-35 Low: 35-40 Medium: 40-45 High: 45-55 Very high: 55-60	(Reyes 2001)
pH		Potentiometer	Low: < 5 Medium: 5-6 Optimal: 6-7 High: >7	(Meléndez & Molina 2001)
Electrical conductivity (EC)	$\mu s.cm^{-1}$	Potentiometer	Non-saline: 0-2 $dS.m^{-1}$ Slightly saline: 2-4 $dS.m^{-1}$ Moderately saline: 4-8 $dS.m^{-1}$ Strongly saline: 8-16 $dS.m^{-1}$ Very strong saline: >16 $dS.m^{-1}$ *1000$\mu S.cm^{-1}$ = 1 $dS.m^{-1}$	(Gallart 2017)
Cation exchange capacity (CIC)	$meq.100g^{-1}$	Vacuum pump	Very low: <5 $cmol.Kg^{-1}$ Low: 5-10 Moderately: 10-15 High: 15-20 Very high: >20	(Ortega 1995)
Texture		Bouyoucos	Ideal: loam Good: Sandy loam Acceptable: Approaching or within loamy loam, clay loam, or sandy loam Regular: Approaching or inside silty, clayey, or sandy	(Salinas & García 1979)
Organic matter	%	Titrimetric	Low: <2 Medium: 2-5 Óptimal: 5-10 High:>10	(Meléndez & Molina 2001)
Nitrate (NO_3)	$mg.L^{-1}$	Photometry	Optimal: 2 $mg.kg^{-1}$ - 8 $mq.kg^{-1}$	HORIBA (AOAC 2023)

Table Cont....

Parameter	Unity	Methodology	Ideal ranges	References
Potassium (K)	mg.L^{-1}	Photometry	Very low: <0.10 Low: 0.10 – 0.20 Moderate: 0.21-0.30 High: 0.31-0.40 Very high: >0.40	(Ortega 1995)
Phosphorus (P)	mg.L^{-1}	Photometry	Low: <12 mg.L^{-1} Medium:12-20 mg.L^{-} Óptimal: 20-50 mg.L^{-1} High: >50 mg.L^{-}	(Meléndez & Molina 2001)
Magnesium (Mg)	mg.L^{-1}	Photometry	Low: <1 Medium: 1-3 Óptimal:6-3 High: > 6 *cmol/L =10 mmol.L^{-} 1mmool/L = 1ppm ÷ (24.3) 1ppm = 1mg.L^{-1}	(Meléndez & Molina 2001)
Calcium (Ca)	mg.L^{-1}	Photometry	Low: <4 cmol.L^{-1} Medium: 4-6 cmol.L^{-1} Óptimal:15-6 cmol.L^{-1} High: >15 cmol.L^{-1} *cmol/L =10 mmol.L^{-1} 1mmol.L^{-} = 1ppm ÷ (40) 1ppm = 1mg.L^{-1}	(Meléndez & Molina 2001)

in each pot and irrigated with 250 mL of water every two days.

Germination and stem height were monitored every 10 days in the three treatments for 40 days.

Physicochemical Parameters Evaluated

The physicochemical parameters measured at the beginning and end of the experiments, their units, the methodology used, and ideal ranges for the physicochemical properties of soil are presented in Table 2.

Statistical Analysis

The data obtained was subjected to the normality test. Subsequently, the data were submitted to the ANOVA analysis of variance and the Tukey multiple comparison tests (p-value < 0.05) to see differences between the treatments. All statistical treatments were carried out in the free software RStudio (R Team Core 2019) version 4.2.6.

RESULTS AND DISCUSSION

Physicochemical Characterization

Fig. 3 shows the characterization of physical parameters (Bulk Density, organic matter, Porosity, pH, Electrical Conductivity, and Cation Exchange Capacity) measured in the treatments: T1 (0% biochar, control treatment), T2 (10% biochar), and T3 (25% biochar).

Bulk Density (BD) shows that there is a significant difference ($p<0.05$) between treatments (Fig. 3a). The T3 treatment presented the lowest bulk density with 1.82 ± 0.01 g.cm^{-3}, while the control treatment obtained the highest bulk density with (2.22 ± 0.06 g.cm^{-3}), showing to be higher by 18.0%. Likewise, it is observed that the addition of biochar to the soil decreases the bulk density by increasing the dose of biochar. Delaye et al. (2020) reported reduced bulk density by adding biochar in soils collected at different soil depths (0-5 cm, 5-10 cm, 10-20 cm, and 20-30 cm). Li et al. (2023) reported a soil bulk density decreasing from 1.30 to 1.10 μg.cm^{-3} when was added more corn straw biochar on light sierom soil (0-20 cm). Likewise, the authors reported a reduction of soil thermal conductivity and soil thermal diffusivity but no effects on the soil thermal capacity with the increase of biochar amendment rate. Singh et al. (2022) found a significant reduction in the bulk density of soils with biochar compared to control soils, with greater emphasis on greenhouse studies (62%) than laboratory studies (30%) and field studies (23%). Although the ideal range (0.7- 0.8 g.cm^{-3}) of BD was not reached, a reduction in BD could be observed with the increase in the amount of biochar, which could perhaps be achieved if working with for example, 50% dose (500 g biochar) (Reyes 2001). Agbede & Adekiya (2020), after applying biochar of maize on sandy soil, found a significantly improved grain yield and soil chemical properties (reduction bulk density, penetration resistance, and increased porosity).

The organic matter (O.M.) shows significant differences ($p<0.05$) between the treatments evaluated (Fig. 3b). The highest concentration of O.M. was found in T3 (24%) with an increase of 1044% followed by T2 (13.3%), with an increase of 578%, both compared to the T1 control treatment (2.3%). It is observed that with an increase in biochar, the amount of MO increases. Biochar has the potential to sequester carbon in the soil, mainly in soils that lose organic matter (Rebolledo et al. 2016). Oses (2013) argues that this happens because Biochar is an amendment with a high content of Organic Matter, and when incorporated into the soil can have positive effects on physicochemical parameters, specifically MO. Likewise, Fiallos-Ortega et al. (2015) reported higher MO content after the addition of Biochar to the soil. Based on the classification of Meléndez and Molina (2001), the organic matter in the control treatment (T1, 2.13%) was at the intermediate level (2-5%), and after adding the biochar, the T2 (13.3%) and T3 (24%) began to present a high level of MO (>10%).

Porosity (Fig. 3c) showed differences ($p>0.05$) between the three treatments (T1, T2, and T3). An increase in porosity is observed when biochar is added to treatments. T3 presented the highest porosity of 23.2%, followed by T2 with 21.4%, and finally T1 with 19.8%. Baiamonte et al. (2019) found that biochar applied to desert sandy soil from the United Arab Emirates significantly increased soil porosity and the amount of storage pores. Likewise, this behavior of increased porosity and reduction in the BD is in agreement with works previously published in the scientific literature (Toková et al. 2020, Chang et al. 2021, Singh et al. 2022). According to the classification of Reyes (2001), the porosity of T2 and T3 found are within the very low level (30%-35%). However, increases of 20% (T3) and 8% (T2) were achieved compared to the T1 control treatment. Singh et al. (2022) found higher porosity (31% to 66%) when biochar is prepared at higher temperatures (>500^{o}C), while at lower pyrolytic temperatures (<500^{o}C), it has a greater effect on biological diversity, some that were not measured in this work. Based on this, our very low porosity could be related to the low pyrolytic temperature used (450^{o}C).

The pH measured showed differences ($p>0.05$) between the three treatments (Fig. 3d). pH is an indicator of soil quality because it affects soil function and nutrient availability for plants, pesticide yield, and decomposition of organic matter (Penn & Camberato 2019). There is an increase in pH in T3 (8.05) of 3.6% and 2.3% in T2 (7.95) compared to T1 (7.77) when biochar is added. Lima et al. (2018) applied biochar of coffee residues on sandy soil and found an increase in pH in the function of the doses. Similar findings of pH increase were reported when the percentage of biochar types was increased on different types of soils (Toková et al. 2020, Chang et al. 2021, Singh et al. 2022, Xiong et al. 2024). An optimal pH range varies from 6 to 7 (Meléndez & Molina 2001). Here, the pH varies from 7.77 to 7.95, which is characterized as high (>7). However, this slightly alkaline scale is also considered suitable for growing any plant and can immobilize metals in the soil.

Regarding Electrical Conductivity (EC), statistical differences ($p>0.05$) were found between treatments (Fig. 3e). Fig. 3(e) shows an increase in EC with increasing biochar dose, i.e., T2 increased by 74% and T3 by 154% concerning T1, respectively. Kane et al. (2021) indicated that the increase in EC differs depending on the pyrolysis temperature, catalyst used, raw material, and heating rate. For instance, Singh et al. (2022), after doing review work, found an increase in EC of 78% when used as raw material herbaceous, 55% in fine-textured soils, and 51% in biochar prepared at low temperatures (<500^{o}C), all compared to the control group. Thus, the increase in EC in the soil could be related to the fact that pine and garden pruning debris were used as raw materials, which were subjected to a slow pyrolysis of low temperature (450^{o}C) to obtain the biochar. Likewise, all the results are in the category "Non-saline" (Table 2) considered of good quality for agricultural productivity, these results are positive since the low concentration of EC allows the soil not to store salts that could interfere with productivity. This event may be because biochar does not contain high concentrations of salts, unlike synthetic fertilizers.

Fig. 3(f) shows that the values of the Cation Exchange Capacity (CEC) present differences ($p>0.05$) between the treatments. Likewise, an increase in CEC was observed in T2 treatment (1.3 ± 0.6 meq.100g^{-1}) and T3 (1.9 ± 1.3 meq.100g^{-1}) compared to T1 (0.9 ± 0.5 meq.100g^{-1}). This shows that the application of biochar contributes to increasing the ability of sandy soil to retain cations (Ca, Mg, Na, etc.). Despite showing a growing trend, the concentration of all treatments was less than 5 meq.100g^{-1} is considered a "very low" CEC for agricultural soil (Ortega 1995). However, it is important to note that the chemical properties require more time under study to obtain significant results. Rebolledo et al. (2016) argued that the increase in CEC is probably due to the high negative surface charge, high charge density, and high specific surface area of the Biochar. Chinchajoy (2021) also presented an increase in CEC in treatments with the application of biochar in the soil, which he mentions is related to the oxidation of aromatic carbon and the formation of negatively charged carboxyl.

Fig. 4 shows the chemical parameters of Nitrate (NO_3^-), potassium (K), phosphorus (P), magnesium (Mg), and Calcium measured in the three treatments: control T1 (0% biochar), T2 (10% biochar), T3 (25% biochar) applied in sandy soils.

Fig. 4(a) shows significant differences ($p<0.05$) between treatments for nitrate (NO_3), with a higher value in T3 (7.6 ± 2.7 mg.kg^{-1}), followed by T2 (4.3 ± 2.1 mg.kg^{-1}), and

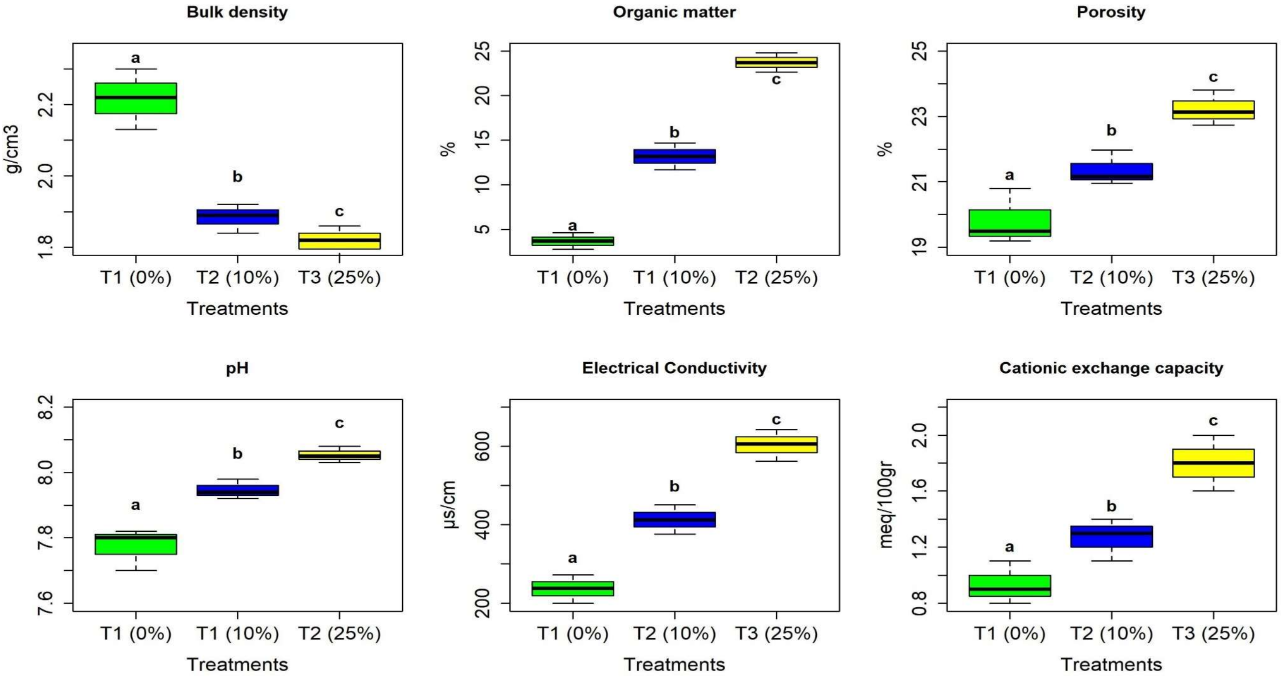

Fig. 3: Physical parameters: (a) Bulk density; (b) Organic matter; (c) Porosity; (d) pH; (e) Electrical conductivity; and (f) Cationic exchange capacity.

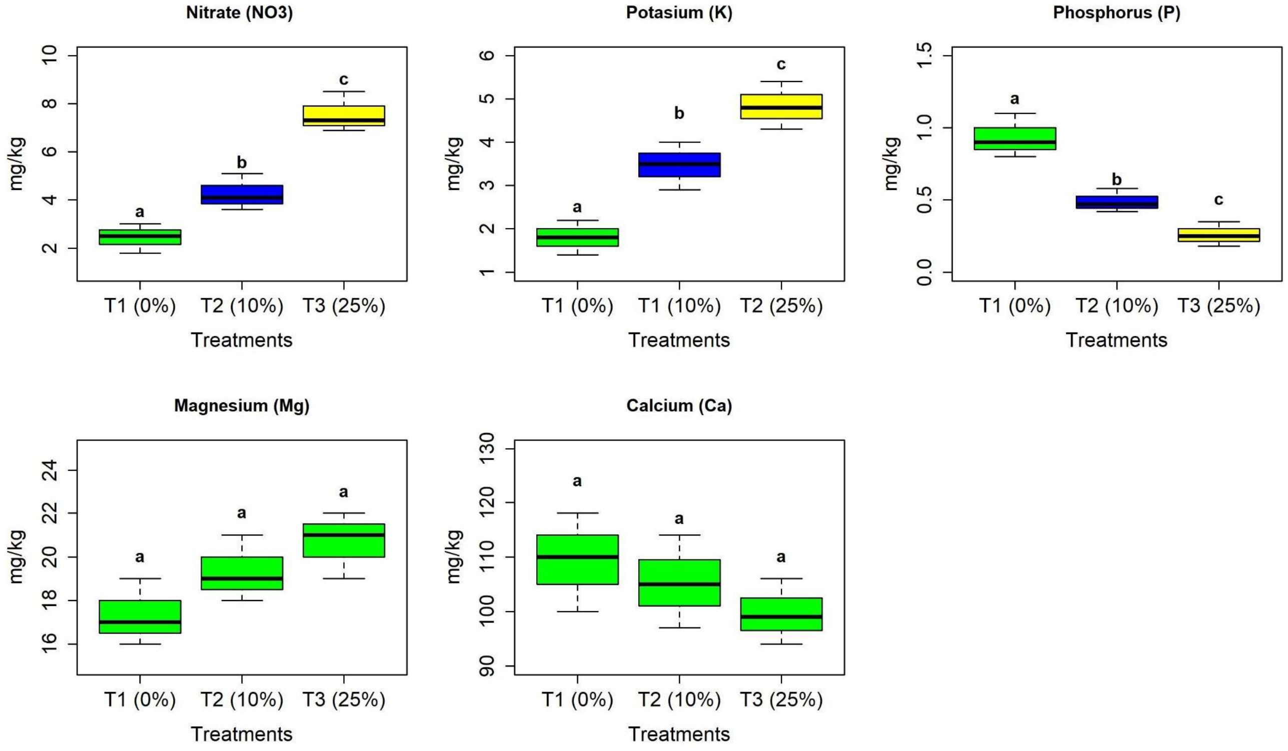

Fig. 4: Result of chemical parameters: (a) nitrate; (b) Potassium (K); (c) Phosphorus (P); (d) Magnesium (Mg); and (e) Calcium (Ca).

T1 (2.4 ± 1.3 mg.kg^{-1}). From Fig. 4(a), it is observed that the addition of biochar increased the amount of nitrate in T2 (79%) and T3 (216%) compared to T1. Hu et al. (Hu et al. 2023) reported an increase of 4.7% to 32.3% when adding biochar concentrations between 1% to 4% on cropland. Our results were higher probably because higher concentrations of biochar were added to the soil. Nitrate measures the amount of nitrogen (N) available in the soil that can be immediately absorbed by plants (Horiba 2015). Nitrogen in the soil is a complex parameter. It is involved in a whole cycle and is essential for plant growth and ecosystem health (Dong et al. 2022). A higher percentage of nitrogen is found in the atmosphere, which plants cannot capture without microbial help; for that reason, the percentage of MO in the soil is vital to determining the availability of nitrogen (Anas et al. 2020). Pacheco-Avila et al. (2002) mention that the degradation of MO releases Ammonium (NH_4), part of this compound is used by plants, and the rest is transformed into nitrites (NO_2), the same that are oxidized to nitrates (NO_3), a compound that serves as fertilizer for plants. The addition of biochar can improve N recycling in agricultural soil-plant systems, reduce N_2O emissions, control N leaching, and increase microbial activity and crop productivity (Gul & Whalen 2016, Liao et al. 2020). According to Wilson (2017), our values (4.3 to 7.6 $mg.L^{-1}$) are within the optimal range (2 $mg.L^{-1}$ to 8 $mg.L^{-1}$) for cropland.

The potassium result (K) is presented in Fig. 4b, where the treatments showed a significant difference ($p>0.05$). An increase in K in T2 (3.47 ± 1.73 $mg.L^{-1}$) and T3 (4.83 ± 2.39 $mg.L^{-1}$) was noted concerning the T1 control treatment (1.80 ± 0.90 $mg.L^{-1}$). Doulgeris et al. (2023) and Farrar et al. (2022) reported that an increase in the proportion of biochar above the soil increased available K. Likewise, Farrar et al. (2022) argue that the addition of biochar causes less K to be leached, causing more K to be retained, which could explain the increase in K when higher concentrations of biochar is applied.

Fig. 4(c) shows significant differences ($p>0.05$) between the three treatments, with a reduction in phosphorus (P) by 47% for T2 (0.49 ± 0.25 $mg.L^{-1}$) and 72% for T3 (0.26 ± 0.14 $mg.L^{-1}$) compared to control treatment T1 (0.93 ± 0.47 $mg.L^{-1}$). P is a vital element for plant growth; its reduction in soils indicates soil degradation and environmental pollution (Xu et al. 2019). The availability of P is a function of the pH level of the soil (optimal range between 6.5 to 7.5), showing a high affinity for Al, Fe, and Ca, with which it can form insoluble precipitates dependent on the acidity of the soil. For instance, Penn and Camberato (2019) indicate that phosphate solubility is affected at a pH greater than 6.5. Likewise, Chang et al. (2021) argued that P becomes insoluble at pH less than 6.5, while at higher values, it becomes soluble. Thus, the reduction of available P observed in the soil added with biochar could be related to the increase in pH (7.95 to 8.05) (Fig. 3c) and the formation of precipitates with calcium.

For Magnesium (Mg), the behavior of the results between the treatments did not show significant differences ($p>0.05$), but there was a slight increase of 11.5% in T2 (19.3 ± 9.5 $mg.L^{-1}$) and 19.3% for T3 (20.7 ± 8.4 $mg.L^{-1}$) compared to T1 (17.3 ± 8.6 $mg.L^{-1}$) (Fig. 4d). These meetings show that the application of Biochar had a positive change on the Mg parameter. Arévalo (2020) reported an increase of 24% (from 1.04 to 1.29 $meq.100mL^{-1}$) when adding 2.5 kg pine biochar above ground. A greater increase in Mg is probably related to the greater amount of biochar added. Likewise, Wu et al. (2020) reported an increase in Mg (control = 12.9 $mg.kg^{-1}$) of 24.5% (16.2 $mg.kg^{-1}$), 65.7% (21.5 $mg.kg^{-1}$), and 24.2% (16.12 $mg.kg^{-1}$) when straw, rice, and corn biochar were added, respectively.

Fig. 4(e) shows a reduction in calcium (Ca) concentration of 3.7% in T2 (105 $mg.kg^{-1}$) and 8.7% for T3 (100 $mg.kg^{-1}$) compared to T1 (109 $mg.kg^{-1}$). However, there was no significant difference ($p<0.05$) between treatments. Ca is an essential component of soil and plants and is key in regulating the acidity, structure, and function of ecosystems (Luo et al. 2023). Arévalo (2020) reported a Ca reduction of 15% and 21% in two 2x2 m soil plots when 2.5 kg of biochar was added as an organic amendment. Wu et al. (2020) found a reduction of Ca by 0.6% when corn biochar was added, .26% with straw biochar, and 48% when wheat biochar was applied. These findings corroborate the report by Singh et al. (2022), who indicate that the effect of biochar on chemical properties is dependent on the raw material used.

*

Effect of Biochar on Turnip Germination

Germination and height were measured every 10 days in the three treatments for 40 days (Table 3). Table 3 shows that the addition of biochar significantly increased ($p>0.05$) the germination of seeds of T3 (68% germinated) and T2 (48% germinated) concerning T1 (28% germinated). It was also noted that 02 seeds took more than 20 days to germinate in T1, which could be related to the physicochemical characteristics of the control soil. About the height of the stems was observed a greater growth in treatments T1 and T2 without significant difference between these, but if compared to T1. Therefore, it could be attributed that higher germination of seeds is related to a higher dose (% biochar) added. Tammeorg et al. (2014) reported a similar encounter, where a greater number of turnip seeds germinated when biochar was added compared to the control treatment. Murtaza et al. (2023) reported that the addition of biochar on sandy soil caused the growth of corn to increase as a response to the increase in the rate of photosynthesis, reduction of bulk density, moisture retention, and the relationship between plant water and soil. Thus, the addition of biochar

Table 3: Germination and growing of turnip.

Treatment	Day	Germinated plants	Stem height [cm]
T1 (n = 25)	10	01	1
	20	04	3.5
	30	02	4
	40	0	6 ± 0.4
Total		07 a	
T2 (n = 25)	10	5	2
	20	7	4
	30	0	6
	40	0	7
Total		12 b	7 ± 0.6 a
T3 (n = 25)	10	9	2.2
	20	8	4.5
	30	0	6.3
	40	0	7.5
Total		17 c	7.5 ± 0.9 a

could control poor germination and plant growth resulting from poor soil attributes (Furtado et al. 2016). Likewise, an increase in crop productivity after applying biochar was reported in leguminous crops (21.2%), corn (14.3%), and wheat (8.0%) (Zhang et al. 2022). It is important to note that this type of work is influenced by different factors and interactions between, for example, the type of soil, raw material to produce biochar, pyrolysis method, and dose to be added, which must still be studied more extensively.

The application of biochar based on pine and remains of tree pruning on sandy loam soil improved the physicochemical parameters of the soil through the increase of porosity, organic matter, CEC, and K, stabilized the pH, electrical conductivity, there was a slight increase in Mg and maintained the Ca. The physicochemical parameters showed a greater increase (T3 followed by T2) when higher doses (25% and 10%) were added of biochar, compared to T1 (0% control). The sandy soil became ideal for plant development. The seeds germinated in greater quantity and volume in T2. Therefore, it is inferred that the higher the dose of biochar the results are more favorable, without detracting from the results obtained in T2 since a large part of its parameters fall into the quality range.

Biochar offers practical benefits for farmers by enhancing soil fertility, improving water retention, and boosting crop yields, particularly in degraded soils. It helps sequester carbon, supporting climate change mitigation efforts. For policymakers, promoting biochar use aligns with sustainable agriculture goals, reducing the need for chemical fertilizers and addressing soil degradation. Integrating biochar into agricultural policies can lead to long-term environmental and economic benefits, making farming more resilient and sustainable.

As a recommendation, for sandy soils, apply biochar at 5-10 tons per hectare, mixing it into the top 15-20 cm along with compost or manure. Incorporate it during land preparation or post-harvest, and use cover crops and drip irrigation to enhance its benefits. Regularly test soil and monitor crop performance to adjust application practices for optimal results.

CONCLUSIONS

The application of biochar based on pine and remains of tree pruning on sandy loam soil improved the physicochemical parameters of the soil through the increase of porosity, organic matter, CEC, and K, stabilized the pH, electrical conductivity, there was a slight increase in Mg and maintained the Ca. The physicochemical parameters showed a greater increase (T3 followed by T2) when higher doses (25% and 10%) were added of biochar, compared to T1 (0% control). The sandy soil became ideal for plant development. The seeds germinated in greater quantity and volume in T2. Therefore, it is inferred that the higher the dose of biochar the results are more favorable, without detracting from the results obtained in T2 since a large part of its parameters fall into the quality range. Finally, it is concluded that the biochar used as an organic amendment contributes significantly to the improvement of the physicochemical parameters of the soil, positively impacting the environment.

Future research on biochar should focus on long-term impact studies and examine the effects of biochar on soil health, crop productivity, and carbon sequestration over extended periods. Likewise, to explore how different biochar types and feedstocks affect the soil properties and plant growth.

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REFERENCES

Agbede, T.M. and Adekiya, A.O., 2020. Influence of biochar on soil physicochemical properties, erosion potential, and maize (Zea mays L.) grain yield under sandy soil condition. *Communications in Soil Science and Plant Analysis*, 51, pp.2559–2568.

Anas, M., Liao, F., Verma, K.K., Sarwar, M.A., Mahmood, A., Chen, Z.L., et al., 2020. Fate of nitrogen in agriculture and environment: Agronomic, eco-physiological and molecular approaches to improve nitrogen use efficiency. *Biological Research*, 53, pp.1–20.

Andina, 2021. Serfor identifica 8.2 millones de hectáreas degradadas para restaurar en el Perú. *Agencia Peruana de Noticias*. Retrieved 25

August 2023, from https://andina.pe/agencia/noticia-serfor-identifica-82-millones-hectareas-degradadas-para-restaurar-el-peru-833166.aspx.

AOAC, 2023. Nitrogen. *Official Methods of Analysis of AOAC INTERNATIONAL*, Oxford University Press, pp.12–21.

Arévalo, N.M., 2020. *Assessment of Soil Quality Through the Application of Pine Needle Biochar (Pinus Patula) in the Machángara - Saucay Basin*. Salesian Polytechnic University, Cuenca Campus. Pp.1–112.

Baiamonte, G., Crescimanno, G., Parrino, F. and De Pasquale, C., 2019. Effect of biochar on the physical and structural properties of a sandy soil. *CATENA*, 175, pp.294–303.

Bech, J., Roca, N. and Tume, P., 2017. *Hazardous Element Accumulation in Soils and Native Plants in Areas Affected by Mining Activities in South America*. *In: Assessment, Restoration, and Reclamation of Mining Influenced Soils*. Elsevier Inc., pp.419–461.

Brassard, P., Godbout, S., Lévesque, V., Palacios, J.H., RaghavanV. and Ahmed, A., 2019. Biochar for soil amendment. In: Char and Carbon Materials Derived from Biomass, Elsevier, pp. 109–146.

Chang, Y., Rossi, L., Zotarelli, L., Gao, B., Shahid, M.A. and Sarkhosh, A., 2021. Biochar improves soil physical characteristics and strengthens root architecture in Muscadine grape (Vitis rotundifolia L.). *Chemical and Biological Technologies in Agriculture*, 8, pp.1–11.

Chinchajoy, J.A.B., 2021. *Effect of Biochar Addition as a Soil Amendment on Microorganisms Related to the Carbon Cycle* Universidad de la Salle, pp.1–49.

Delaye, L.A.M., Ullé, J.Á. and Andriulo, A.E., 2020. Biochar application in degraded soil under sweet potato production effect on edaphic properties. *Ciencia del Suelo*, 38, pp. 162–173.

Dong, J., Cui, X., Niu, H., Zhang, J., Zhu, C., Li, L. and Zhang, X., 2022. Effects of nitrogen addition on plant properties and microbiomes under high phosphorus addition level in the Alpine Steppe. *Frontiers in Plant Science*, 13, p.1–11.

Doulgeris, C., Kypritidou, Z., Kinigopoulou, V. and Hatzigiannakis, E., 2023. Simulation of potassium availability in the application of biochar in agricultural soil. *Agronomy*, 13, p.784.

Eguren, F. and Marapi, R., 2015. The soils in Peru: A fundamental resource for creating and sustaining life. *La Revista Agraria*, 170, p.1–16.

FAO, 2015. Soils Are Endangered, But the Degradation Can Be Rolled Back. Food and Agriculture Organization of the United Nations. Retrieved 23 August 2023, fromhttps://www.fao.org/news/story/en/item/357059/icode/.

Farrar, M.B., Wallace, H.M., Xu, C.-Y., Joseph, S., Nguyen, T.T.N., Dunn, P.K. and Smith, R., 2022. Biochar compound fertilisers increase plant potassium uptake 2 years after application without additional organic fertiliser. *Environmental Science and Pollution Research*, 29, p.7170–7184.

Fiallos-Ortega, L.R., Flores-Mancheno, G., Duchi-Duchi, N., Flores-Mancheno, I., Baño-Ayala, D. and Estrada-Orozco, L., 2015. Soil ecological restoration applying biochar (charcoal) and its effects on the Medicago sativa production. *Rev Cien Agri*, 12, p.13–20.

Flumignan, D.L., Gomes, L.D., Motomiya, A.V.A., Oliveira, G.Q. De and Vieira Filho, P.S., 2023. Soil cover is strategic to remedy erosion in sandy soils. *Engenharia Agrícola*, 43, p.1–2.

Furtado, G. de F., Chaves, L.H.G., de Sousa, J.R.M., Arriel, N.H.C., Xavier, D.A. and de Lima, G.S., 2016. Soil chemical properties, growth and production of sunflower under fertilization with biochar and NPK. *Australian Journal of Crop Science*, 10, p.418–424.

Gallart, F., 2017. *The Electrical Conductivity of Soil as an Indicator of Soil Use Capacity in the Northern Area of the Albufera Natural Park in Valencia*. Universitat Politecnica de Valencia, p.1–34.

Gul, S. and Whalen, J.K., 2016. Biochemical cycling of nitrogen and phosphorus in biochar-amended soils. *Soil Biology and Biochemistry*, 103, p.1–15.

Haider, F.U., Wang, X., Farooq, M., Hussain, S., Cheema, S.A., Ain, N. ul, and Zhang, L., 2022. Biochar application for the remediation of trace metals in contaminated soils: Implications for stress tolerance and crop production. *Ecotoxicology and Environmental Safety*, 230, p.113165.

Horiba, M. 2015. Soil nitrate measurement for determination of plant-available nitrogen. *ASPLM,* 6, pp.2–3.

Hu, T., Wei, J., Du, L., Chen, J. and Zhang, J., 2023. The effect of biochar on nitrogen availability and bacterial community in farmland. *Annals of Microbiology*, 73, p.1–11.

IPBES, 2018. Press Release: Global Soil Degradation Worsens and Is Now "Critical," Threatening the Well-being of 3.2 Billion People. Science and Policy for People and Nature.. Retrieved 24 August 2023, from https://www.ipbes.net/news/comunicado-de-prensa-la-degradación-del-suelo-nivel-mundial-empeora-y-ahora-es-crítica-poniendo.

Jie, C., Jing-zhang, C., Man-zhi, T. and Zi-tong, G., 2002. Soil degradation: A global problem endangering sustainable development. *Journal of Geographical Sciences*, 12, p.243–252.

Kane, S., Ulrich, R., Harrington, A., Stadie, N.P. and Ryan, C., 2021. Physical and chemical mechanisms that influence the electrical conductivity of lignin-derived biochar. *Carbon Trends*, 5, p.100088.

Lehmann, J., Cowie, A., Masiello, C.A., Kammann, C., Woolf, D., Amonette, J.E. and Smith, R., 2021. Biochar in climate change mitigation. *Nature Geoscience*, 14, p.883–892.

Li, Y.Q., Li, L.J., Zhao, B.W., Zhao, Y., Zhang, X., Dong, X. and Wang, Y., 2023. Effects of corn straw biochar, soil bulk density and soil water content on thermal properties of a light sierozem soil. *Nature Environment and Pollution Technology*, 22, p.895–903.

Liao, J., Liu, X., Hu, A., Song, H., Chen, X. and Zhang, Z., 2020. Effects of biochar-based controlled release nitrogen fertilizer on nitrogen-use efficiency of oilseed rape (Brassica napus L.). *Scientific Reports*, 10, p.1–14.

Lima, J.R. de Moraes Silva, W., de Medeiros, E.V., Duda, G.P., Corrêa, M.M., Martins Filho, A.P. and Pereira, F., 2018. Effect of biochar on physicochemical properties of a sandy soil and maize growth in a greenhouse experiment. *Geoderma*, 319, p.14–23.

Liu, Z., Ju, X., Zheng, L. and Yu, F., 2023. The Bright Future of Biochar in Sustainable Agriculture: A Bibliometric Analysis. *Journal of Soil Science and Plant Nutrition*, 23, p.5036–5047.

Luo, Y., Shi, C., Yang, S., Liu, Y., Zhao, S. and Zhang, C., 2023. Characteristics of soil calcium content distribution in Karst dry-hot valley and its influencing factors. *Water*, 15, p.1119.

Meléndez, G. and Molina, E., 2001. Soil fertility and crop nutrition management in Costa Rica. *Plos One,* 715, pp.102134–102148

MINAM, 2014. *Guide for Soil Sampling*. MINAM p.72.

Murtaza, G., Ahmed, Z., Eldin, S.M., Ali, B., Bawazeer, S., Usman, M. and Zhang, L., 2023. Biochar-Soil-Plant interactions: A cross talk for sustainable agriculture under changing climate. *Frontiers in Environmental Science*, 11, p.1–16.

Olarte, D.L., Aguilar-Bardales, Z. and Calderón-Cahuana, D.L., 2023. Estimation of the soil-water characteristic curve in sandy soils using the filter paper method. *TECNIA*, 33, p.42–51.

Oni, B.A., Oziegbe, O. and Olawole, O.O., 2019. Significance of biochar application to the environment and economy. *Annals of Agricultural Sciences*, 64, p.222–236.

Ontiveros, R., 2014. *Methodological Guide, Climate Change and Soil Degradation in Latin America*. EuroClima, pp.1–192.

ONU, 2019. Around 24 Billion Tons of Fertile Soil Are Lost Each Year Due to Desertification. United Nations. Retrieved 24 August 2024, from https://news.un.org/es/story/2019/06/1457861.

Ortega, D., 1995. *Soils of Colombia: Origin, Evolution, Classification, Distribution, and Use*. *In: Agrológica*. Colombia, p.632.

Oses, A.O., 2013. *Effects of Biochar Application in the Hierarchical Aggregation Model of a Forest Soil Under Oceanic Conditions*. Springer, 96p.

Pacheco-Avila, J., Pat-Canul, R. and Cabrera-Sansores, A., 2002. Analysis of the nitrogen cycle in the environment in relation to groundwater and its effect on living beings. *Ingeniería*, 6, pp.73–81.

Pan, L., Mao, L., Zhang, H., Wang, P., Wu, C., Xie, J. and et al., 2022. Modified biochar as a more promising amendment agent for remediation of pesticide-contaminated soils: Modification methods, mechanisms, applications, and future perspectives. *Applied Sciences (Switzerland)*, 12, p.651.

Penn, C. and Camberato, J., 2019. A critical review of soil chemical processes that control how soil pH affects phosphorus availability to plants. *Agriculture*, 9, p.120.

R Team Core, 2019. *A Language and Environment for Statistical Computing*. R Foundation for Statistical Computing.

Rebolledo, A.E., López, G.P. and Moreno, C.H., 2016. Biocarbón (biochar) I: Naturaleza, historia, fabricación y uso en el suelo. *Terra Latinoamericana*, 34, pp.367–382.

Rehman, M.Z. ur, Zafar, M., Waris, A.A., Rizwan, M., Ali, S. and Sabir, M., 2020. Residual effects of frequently available organic amendments on cadmium bioavailability and accumulation in wheat. *Chemosphere*, 244, p.125548.

Reyes, M.L., 2001. Soil degradation in Sonora: The problem of erosion in soils used for livestock. *Región y sociedad*, 13, pp.1–25.

Rivera, J., Reyes, J., Cuervo, J., Martínez-Cordón, M. and Zamudio, A., 2022. Effect of biochar amendments on the growth and development of "Vera" crisp lettuce in four soils contaminated with cadmium. *Chilean Journal of Agricultural Research*, 82, pp.244–255.

Salinas, J.G. and García, R., 1979. *Analytical Methods for Acid Soils and Plants*. Colombia Publication, p.62

Samec, P., Kučera, A. and Tomášová, G., 2023. *Forest Degradation Under Global Change, Sustainable Development*, Oxford Publications, pp.1–62.

Singh, H., Northup, B.K., Rice, C.W. and Prasad, P.V.V., 2022. Biochar applications influence soil physical and chemical properties, microbial diversity, and crop productivity: A meta-analysis. *Biochar*, 4, pp.1–17.

Tammeorg, P., Simojoki, A., Mäkelä, P., Stoddard, F.L., Alakukku, L. and Helenius, J., 2014. Biochar application to a fertile sandy clay loam in boreal conditions: effects on soil properties and yield formation of wheat, turnip rape, and faba bean. *Plant and Soil*, 374, pp.89–107.

Tito, R., Salinas, N., Cosio, E.G., Boza Espinoza, T.E., Muñiz, J.G. and Aragón, S.., 2022. Secondary forests in Peru: differential provision of ecosystem services compared to other post-deforestation forest transitions. *Ecology and Society*, 27, art.12.

Toková, L., Igaz, D., Horák, J. and Aydin, E., 2020. Effect of biochar application and re-application on soil bulk density, porosity, saturated hydraulic conductivity, water content and soil water availability in a silty loam haplic luvisol. *Agronomy*, 10, p.1005.

Vannini, A., Bianchi, E., Avi, D., Damaggio, N., Di Lella, L. and Nannoni, F., 2021. Biochar amendment reduces the availability of Pb in the soil and its uptake in lettuce. *Toxics*, 9, p.268.

Volverás-Mambuscay, B., Campo-Quesada, J.M., Merchancano-Rosero, J.D. and López-Rendón, J.F., 2020. Physical properties of soil in the Wachado planting system in Nariño, Colombia.*Agronomía Mesoamericana*, 31, pp.743–760.

Wu, C., Hou, Y., Bie, Y., Chen, X., Dong, Y. and Lin, L., 2020. Effects of biochar on soil water-soluble sodium, calcium, magnesium and soil enzyme activity of peach seedlings. *IOP Conference Series: Earth and Environmental Science*, 446, p.032007.

Xiong, M., Dai, G.Q., Sun, R.G. and Zhao, Z., 2024. Passivation effect of corn vinasse biochar on heavy metal lead in paddy soil of Pb-Zn mining area. *Nature Environment and Pollution Technology*, 23, pp.419–426.

Xu, M., Wu, J., Yang, G., Zhang, X., Peng, H., Yu, X. and et al., 2019. Biochar addition to soil highly increases P retention and decreases the risk of phosphate contamination of waters. *Environmental Chemistry Letters*, 17, pp.533–541.

Yadav, S.P.S., Bhandari, S., Bhatta, D., Poudel, A., Bhattarai, S. and Yadav, P. 2023. Biochar application: A sustainable approach to improve soil health. *Journal of Agriculture and Food Research*, 11, p.100498.

Zhang, F., Liu, M., Li, Y., Che, Y. and Xiao, Y., 2019. Effects of arbuscular mycorrhizal fungi, biochar and cadmium on the yield and element uptake of Medicago sativa. *Science of the Total Environment*, 655, pp.1150–1158.

Zhang, L., Wu, Z., Zhou, J., Zhou, L., Lu, Y. and Xiang, Y., 2022. Meta-analysis of the response of the productivity of different crops to parameters and processes in soil nitrogen cycle under biochar addition. *Agronomy*, 12, p.1857.

Zhang, T., Tang, Y., Li, H., Hu, W., Cheng, J. and Lee, X., 2023. A bibliometric review of biochar for soil carbon sequestration and mitigation from 2001 to 2020. *Ecotoxicology and Environmental Safety*, 264, p.115438.

Zhu, X., Chen, B., Zhu, L. and Xing, B., 2017. Effects and mechanisms of biochar-microbe interactions in soil improvement and pollution remediation: A review. *Environmental Pollution*, 227, pp.98–115.