J. Trop. Resour. Sustain. Sci. 12 (2024): 28-35
https://doi.org/10.47253/jtrss.v12i1.1362

Journal of Tropical Resources and Sustainable Science

journal homepage: jtrss.org

Review on The Impacts of Biochar and Soil Organic Matter (SOM) Habitation toward the Soil Physico-Chemical Properties Conjugating with Maize *(Zea mays)* Growth Performance

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Received 02 September 2023
Accepted 06 November 2023
Online 30 June 2024

Keywords:
Biochar, soil organic matter, soil physioco-chemical, maize

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Abstract

This study studies the complex relationships between maize growth, soil organic matter, and soil physical-chemical properties, with an emphasis on biochar. It examines how soil organic matter affects pH, bulk density, Cation Exchange Capacity (CEC), porosity, and nutrient levels. Biochar and soil organic matter increase soil pH by decomposing organic anions. With biochar, increasing soil organic matter concentration reduces bulk density, improving soil structure, porosity, and water retention. By increasing Cation Exchange Capacity (CEC), biochar and soil organic matter improve soil nutrient retention and delivery, which is essential for soil fertility. As a soil organic matter component, biochar provides macro and micronutrients, boosting soil production. The study also highlights the importance of soil porosity in plant growth, with sandy soils having high porosity and leaching susceptibility and soil organic matter. However, loam soils, made of sand, clay, and silt, have a balanced porosity and soil organic matter concentration that makes them ideal for agriculture. These data show how organic matter, and biochar, affect maize growth and soil physico-chemical properties. This finding has major implications for protecting the environment and sustainable agriculture.

1. INTRODUCTION

Zea mays, or maize, stands as a vital agricultural commodity not only in Malaysia but also on a worldwide scale, ranking closely alongside paddy and wheat crops (Jalal et al., 2020). The value of it goes beyond food for humans, as it is necessary for Malaysian livestock feed (Nor et al., 2019). However, to accommodate the population's demand, the increasing demand for maize has necessitated the implementation of multiple cropping strategies and the extensive application of chemical fertilizers (Habibi et al., 2019; Zhou et al., 2014). Unfortunately, poor oversight has led to a significant deterioration of the physico-chemical characteristics of the soil and maize growth and production (Vilakazi et al., 2022; Melkamu et al., 2019). Furthermore, excessive fertilizer application resulted in soil acidity, which is now a major problem affecting maize yield (Bai et al., 2020). The loss of soil organic matter has resulted in a severe degradation of the physico-chemical properties of the soil, which has led to a decline in soil fertility and maize growth performance (Turner et al., 2016; Campitelli et al., 2008). To mitigate this scenario, organic addition such as biochar is advocated as a potential method of improving soil physico-chemical characteristics and maize productivity (Sisouvanh et al., 2021; Yu et al., 2022). According to Maharjan et al. (2021), the use of biochar improves soil physico-chemical characteristics and nutrient availability in maize production. Organic matter in the soil has also been shown to help preserve soil fertility (Medina-Méndez et al., 2019).

Soil organic matter is described as organic matter in the soil obtained from plant and animal leftovers in various phases of decomposition, and it plays an important role in maximizing yield production (Adugna, 2016). Organic matter, together with the cooperation of biochar has been found to be strongly related to the biological, chemical, and physical aspects of soil (Angelopoulou et al., 2021). Addressing these variables, the goal of this research is to analyze and support sustainable agricultural methods in maize production, with a particular emphasis on alleviating soil degradation issues and maximizing maize productivity through the incorporation of biochar.

2. RESULT AND DISCUSSION

2.1. Soil pH balancing by biochar

Soil pH is described as the measurement of soil alkalinity and acidity (Seifu et al., 2014). It is one of the soils physico-chemical characteristics that are essential for plant as well as soil health (Liu et al., 2020). Extremely low soil pH, which indicates acidity, may inhibit nutrient

eISSN Number: 2462-2389

mobility and absorption by soil and plants, as well as microbial activity and plant growth (Machodo et al., 2021; Maharajan et al., 2021). Acidic soil is associated with a high concentration of aluminum (Al), which significantly limits plant growth (Su et al., 2022; Zhang et al., 2022; Jiang et al., 2021).

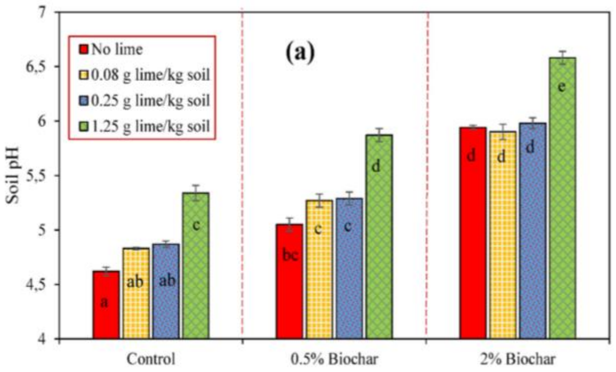

Figure 1: Figure shows the increase rate of biochar application significantly increase soil pH reading to optimum range (Pandit et al., 2018)

Aluminum toxicity is significantly related to soil acidification, which causes a global decline in maize production (Kong et al., 2021; Fu et al., 2020).

However, studies have shown that biochar can decrease soil aluminum content and significantly increase soil pH to the optimal range, with the rate of increase depending on the amount of biochar applied (Rogovska et al., 2014). Studies on the impacts of varying biochar application rates on maize production have revealed that when the biochar application rate increases, soil pH values rise and change from acidic to neutral (Pandi et al., 2018) (Fig. 1). A significant impact is shown by these findings ($P < 0.001$). According to Pandit et al. (2018), biochar helps the soil's organic matter and nitrogen mineralize, which in turn balances the pH of the soil (Calamai et al., 2020). Biochar can be used to neutralize the pH of maize crop soil, resulting in increased maize production (Masud et al., 2020). According to research, the addition of biochar to crop production soil pH can be raised to the optimal range of 5.0 to 7.0, a conducive range for healthy maize growth (Musharrof et al., 2021; Pen et al., 2018). According to science, biochar improves soil by correcting the pH to its suitable range (Singh et al., 2022; Chen et al., 2020; Zhang et al., 2019). This amendment repairs acidic soil by displacing aluminum and cations such as potassium, sodium, magnesium, and calcium from soil exchange sites, elevating soil pH and base saturation (Zuo et al., 2023). According to research, altering soil pH with biochar resulted in significant improvements in other soil physico-chemical parameters (Singh et al., 2022; Yunfeng et al., 2013).

Accordingly, plant materials addition to soil, such as wheat straw, legume residues, and wheat straw, can reduce acidity and improve pH levels (Sulaiman et al., 2023). Welen et al. (2019) found that lucerne chaff significantly improved in pH, ranging from pH 4.3 to pH 5.7. Furthermore, Yunfeng et al. (2013) found that the addition of plant residues affects soil-surface interactions, specifically, ligand exchange involving iron hydroxyl and aluminium hydroxyl oxides. Chickpeas, canola, and wheat are examples of organic matter that raises pH levels when applied; chickpeas have the greatest pH values (Gao et al., 2021). Furthermore, the addition of crop residues causes aluminium and other cations, such as potassium (K), sodium (Na), magnesium (Mg), and calcium (Ca), to be displaced from their exchange sites. This raises the pH of the soil and its base saturation (Khan et al., 2021). It is noteworthy that plant materials' characteristics can also impact pH alterations (Yunfeng et al., 2013).

2.2. Bulk density reduction by biochar

Bulk density can be defined as a soil compaction indicator (Dörner, 2002). Soil bulk density is determined by dividing the weight of dry soil by its total volume, which includes both soil particles and pores (Correa et al., 2019; Chaudhari et al., 2021).

Biochar's high porosity has been successfully demonstrated as a soil conditioning agent, proportionally reducing soil bulk density (Bell et al., 2022; Chen et al., 2020; Yu et al., 2019; Rogovska et al., 2014). Higher biochar application rates ($100\, Mg\, ha^{-1}$) result in high reduction of soil bulk density (1.48 $g\, cm^{-3}$) (Fig. 2). in maize productivity, which is consistent with previous research (Rogovska et al., 2014). Findings supported by Yue et al., (2023) proved that soil bulk density able to reduce with biochar application by approximately 1.34 to 22.82%. Therefore, a number of successful research studies have proven that biochar significantly affects soil bulk density and maize development. (Mayhew, 2021; Sakin et al., 2011). The significant amount of carbon of biochar encourages the formation of stable soil organic matter, improving soil structure and nutrient retention (Mustapha et al., 2022). Biochar incorporation has been proven to improve soil physico-chemical parameters, including an approximate decrease in bulk density of approximately 1-23% and an increase in the percentage of large pores of approximately 0.7-12% (Ma, 2020). Yue (2023) conveyed similar data, demonstrating a significant decline in soil bulk density following biochar application, with reductions ranging from 1.34% to 22.82% over a three-year research period.

Organic matter on the other hand plays a pivotal role in soil physical properties, and has a strong relationship with bulk density (Blanco and Jasa, 2019). A higher organic matter content is known to reduce soil bulk density increasing soil volume relative to its bulk density (Gui et al., 2021). This is facilitated by organic matter's ability to enhance soil water-holding capacity (Bhadha et al., 2017). Research has strongly demonstrated a substantial relationship between organic matter and bulk density (Sakin et al., 2011). Furthermore, research has observed that the quantity of organic matter significantly influences soil bulk density across various soil horizons in podzolic soils (Nelson et al., 2021). Other research proved that with an addition of 1% organic matter can decrease bulk density by 0.007 g/cm3 (Piaszczyk et al., 2019). Mouazen et al., (2002) demonstrated that organic matter inside the soil can be enhanced by the process of decomposition of dead animals and plant residues, coupled with the activity of organisms such as earthworms, which enriches the topsoil with organic matter (Marzi et al., 2019). Research significantly indicates that the presence of organic matter enhances soil pore spaces, enhancing soil porosity, and mitigating soil compaction and bulk density (Canrodi et al., 2020)

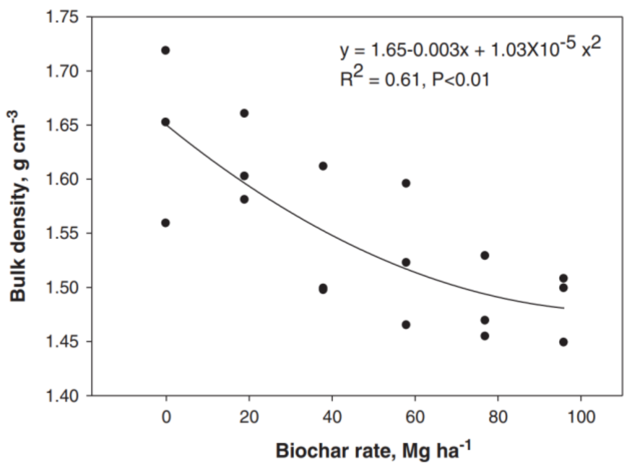

Figure 2: The reading of soil bulk density is decreasing as the biochar application is increasing (Rogovska et al., 2014)

2.3. Cation Exchange Capacity (CEC) optimization by biochar

Cation Exchange Capacity (CEC) is a term used to indicate the amount of negative ions inside the soil to facilitate the absorption of cations such as magnesium, potassium, and calcium by plants (Hutasuhut et al., 2023; Tripathi et al., 2021; Nakhli et al., 2017). A study conducted by Yue et al., (2023) proven that the cooperation of different rates of biochar (0, 30, 75, and 175 $t\ hm^{-2}$) for subsequently three years showed an increase in Cation Exchange Capacity (CEC) compared to control treatment at 0 $t\ hm^{-2}$ application (B0) (Table 1).

Table 1: Cation Exchange Capacity (CEC) in sulfate saline soils amended with biochar at various rates from 2014 to 2016 (Yue et al., 2023)

Treatments	**CEC** $cmol\ kg^{-1}$		
	2014	**2015**	**2016**
B0	7.76b	7.42b	9.67a
B30	8.37ab	7.87b	10.65a
B75	8.69ab	8.91ab	11.14a
B175	10.13a	10.13a	11.90a

Findings indicate that the application of biochar to maize soils is able to increase the Cation Exchange Capacity (CEC) and positively affect the availability of soil nutrients to maize plants (Glaser et al., 2019; Pandit et al., 2021). In simple words, the higher the CEC, the more fertile the soil. This is explained by Siltecho et al., (2021) that the oxidation process of biochar is able to promote high Cation Exchange Capacity (CEC) that allows numerous nutrient and soil organic compound absorption. The finding has proven that the application of biochar is a significant method in solving soil and maize nutrient depletion (Nakhli et al., 2017). High Cation Exchange Capacity (CEC) in soil is able to stimulate both soil and maize fertility and leads to optimum maize production (Yue et al., 2023; Kebede et al., 2019). Cation Exchange Capacity (CEC), commonly known as CEC, is a term used to define the number of negative ions in soil that facilitate plants' absorption cations including magnesium, potassium, and calcium (Hutasuhut et al., 2023; Tripathi et al., 2021). Yue et al. (2023) discovered that applying varying rates of biochar (0, 30, 75, and 175 $t\ hm^{-2}$) over three years resulted in an increase in CEC as compared to the control treatment at 0 $t\ hm^{-2}$ application (B0).

Studies highlight the strong relationship between soil organic matter content and the enhancement of soil (Mouzakis et al., 2019). According to another research, soil organic matter contributes significantly to the topsoil's Cation Exchange Capacity (CEC), with an average depth of less than 30 cm, accounting for up to 35–50% of the total (Solly et al., 2020). Additionally, studies show that the addition of organic matter increases its potential for exchange since these organic components contain humic materials (SM et al., 2016). Particularly at a pH of 7, carboxyl group dissociation is the cause of this increase in Cation Exchange Capacity (CEC) in the presence of organic matter (Tomczyk et al., 2020). Organic matter's many functional groups—such as alkyl, carboxyl, and hydroxyl groups—which carry charges are responsible for its significant contribution to Cation Exchange Capacity (CEC) (Wang et al., 2020). On the other hand, Cation Exchange Capacity (CEC) measurements in tropical soils show that oxidized minerals such as iron, manganese, and aluminium are commonly abundant (Lorandi and Reinaldo, 2012).

2.4. Soil Nutrient Content Level with Biochar Application

The presence of soil nutrients is strongly related to the amount of nutrients contained within the soil and is

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characterized by its association with soil fertility (Begriche et al., 2013). Nutrients in the soil are essential for maize growth and development, which eventually results in the highest crop production. Moreover, several factors, including soil acidity, texture, structure, mineral composition, and soil moisture, can have an influence on soil nutrient levels (Lemus et al., 2021). Biochar has been shown to have a significant impact on soil fertility (Eilin, 2012; Grant, 2017; Banwart, 2015; Douglas, 2016; Lehmann, 2015). According to Hossain et al. (2020), the utilization of biochar results in the retention of approximately 65-95% of nitrogen and sulfur, as well as 20-75% of phosphorus, within the soil. Research by Khadim et al. (2022) (Fig. 3) indicates that introducing biochar to the soil boosts soil nitrogen levels and maximizes maize yield. According to similar research, soil nitrogen, phosphorus, and potassium levels increase as biochar application increases (Pandit et al., 2018).

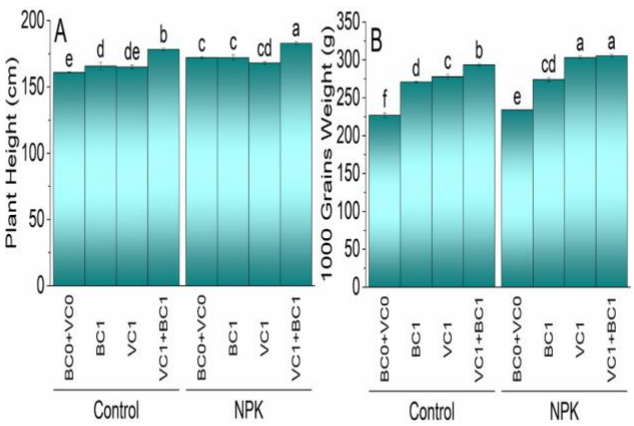

Fig 3. Figure indicates the application of biochar (bc) stimulate maize production and enhance soil nutrient concentration (Khadam et al., 2022)

Researchers have also indicated great deal on soil fertility, which is certainly the most important factor impacted by organic matter (Eilin, 2012; Grant, 2017; Banwart, 2015; Douglas, 2016; Lehmann, 2015). Because it acts as a long-term retention of nutrients and a source of plant nutrients through active decomposition, organic matter is essential to preserving this fertility (Diacono, 2011). Organic matter plays a more significant function in soils that do not receive external fertilization because it contains a multitude of macro- and micronutrients that are vital for plant growth (Pető et al., 2020). Furthermore, it has been demonstrated that adding organic matter to soil increases its availability of phosphorus (Xiao et al., 2021), but removing organic matter from the soil is associated with a corresponding reduction in its sulphur content (Khadka et al., 2016). The benefits of organic matter also extend to the preservation and availability of iron.

Research has shown that plants with higher levels of organic matter have a lower propensity to chlorosis and a more readily available type of iron (Thorp et al., 2021). In addition, a healthy microbial population is fostered by the presence of organic matter, which is essential for transforming iron into a form that is more plant-friendly (Uhlig and Blankenburg, 2019). Furthermore, organic matter is crucial for providing bound micronutrients including zinc, iron, manganese, and copper that can be chelated to increase plant availability (Fageria, 2012). Moreover, the importance of organic matter in soil is further demonstrated by its relationships with a wide range of living things, such as nematodes, fungi, bacteria, and earthworms. These organisms actively participate in the processes that break down organic matter and convert it into nutrients, which affects the amount of nutrients in the soil. They work as a biological nutrient cycle to produce a complex soil food web (Murphy et al., 2015). Finally, the relationship that exists between the amount of hot water-soluble boron in soil and organic matter highlights the function of organic matter as the main source of easily available boron storage, which is essential for plant nutrition (Khurana et al., 2022).

2.4. Enhancing soil porosity and Alleviating Water Stress through biochar Cooperation

Soil porosity is the percentage of pores in the total volume of the soil that is positioned between soil organic matter and mineral particles that can store either water or air (Rima et al., 2023; Sun et al., 2023). Due to its dual role as a fertility indicator and regulator of numerous soil activities, soil porosity is important for maize growth and development (Ramesh et al., 2019; Luong et al., 2015). It has been demonstrated that low soil porosity beyond 0.10 m^3 m^{-3} adversely impacts both maize growth and production (Gleiciane et al., 2020).

Nonetheless, a number of studies have demonstrated that the application of biochar is a mitigating technique to improve the condition of the soil and increase maize production (Rogovska et al., 2011; Bell et al., 201; Salem et al., 2015). Analogous research suggests that utilizing biochar can mitigate many physico-chemical constraints, such as water stress (Pandit et al., 2018). Supporting research has proven that the volumetric water content of the soil may elevate by up to 22.82% as the dosage of incorporated biochar induced into the soil is increased (Yue et al., 2023) (Fig 4). Based on the result obtained in (Fig 4), it shows that the volumetric water content of B150 reached a maximum of 0.55 cm3 cm−3 at a matric potential of 6 kPa. This represents an increase of 11.99% and 7.72%, respectively when compared to B0. This result is consistent with the observation that implementing biochar in the soil increases its volumetric soil content by 0.74–11.99% when compared to soil that does not have biochar treatment (Yue et al., 2023; Liang et al., 2020).

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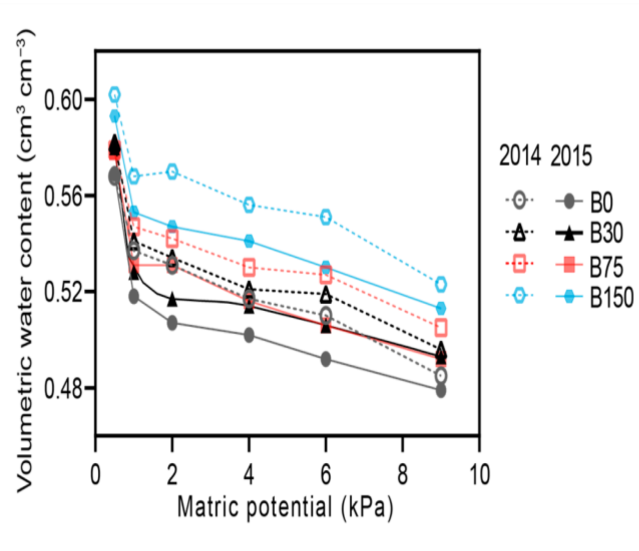

Fig 4. Water retention curve under the low suctions in the soils amended with various biochar range of application. B0= Control (No biochar cooperation), B30= $30\ t\ hm^{-2}$, B75= $75\ t\ hm^{-2}$, and B150=150 $t\ hm^{-2}$. (Yue et al., 2023).

Soil organic matter on the other hand is essential for improving soil porosity and structure, which in turn improves the overall quality of the soil (Readyhough et al., 2021). However, studies have shown that a higher aggregate density and a more constrained range in the aggregate size distribution are frequently brought about by an increase in the soil organic matter content of soils (Rondon et al., 2021). Soil organic matter has a substantial correlation with the percentage of soil porosity and is intimately related to soil permeability (Marín and Rivera, 2022).

Sandy soils, known for their large porosity, which ranges from 33% (at a density of 1.78 g/cm³) to 47% (with a density of 1.40 g/cm³), are prone to increased nitrogen leaching from the soil (Nisa et al., 2023; Campos et al., 2019). As a result, reduced soil organic matter concentration and thus poorer soil quality are associated with sandy soils (Minhal et al., 2020). On the other hand, loam soil is thought to be high-quality soil that supports healthy plant growth because of its 40–60% soil organic matter content, 1.33 g/cm³ density, 50% pore spaces, and sufficient water retention (Zaffar and Sheng, 2015; Eluozo, 2013).

CONCLUSION

To sum up, this study highlights how important it is to use sustainable farming methods, particularly adding organic amendments like biochar and soil organic matter, to improve soil quality and maximize maize yield. Because of its significant effect on soil pH management, biochar and soil organic matter play vital parts in reducing soil acidification, which is a significant threat to maize productivity. Both biochar and soil organic matter improve a variety of soil physico-chemical characteristics, including pH, and replaces toxic components such as aluminum to create a healthy soil environment that is favorable to maize growth. Additionally, the implementation of biochar improves soil structure and nutrient retention by decreasing bulk density and increasing porosity. This helps maize plants expand their roots and become more nutrient-available. The study also shows that biochar increases the soil's Cation Exchange Capacity (CEC), which increases maize's accessibility to vital nutrients and eventually improves soil

ACKNOWLEDGEMENT

The author would like to express higher gratitude to the Ministry of Higher Education of Malaysia for sponsoring this research under the Fundamental Research Grant Scheme (FGRS) (Ref:FGRS/1/2023/STG02/UITM/02/4), Faculty of Plantation and Agrotechnology, UiTM, Jasin branch, Melaka, Malaysia.

REFERENCES

Adugna G. (2016). A review on Impact of Compost On Soil Properties, Water Use and Crop Productivity. *Academic Research J, 4*(3). Affected by Organic Residues. *Soil Science Society of America Journal*, *40*(3), 389-394.

Angelopoulou, T., Balafoutis, A. T., Zalidis, G. C., & Bochtis, D. (2020). From laboratory to proximal sensing spectroscopy for soil organic carbon estimation—a review. Sustainability, 12(2), 443. https://doi.org/10.3390/su12020443

Bai, Y., Chang, Y., Hussain, M., Lu, B., Zhang, J., Song, X., … & Pei, D. (2020). Soil chemical and microbiological properties are changed by long-term chemical fertilizers that limit ecosystem functioning. Microorganisms, 8(5), 694. https://doi.org/10.3390/microorganisms8050694

Banwart SA, B. H. (2015). The global challenge for soil carbon. *Soil carbon : Science, Management and Policy for multiple beneits*, 1-9.

Bell, M. J., & Worrall, F. (2011). Charcoal addition to soils in NE England: a carbon sink with environmental co-benefits?. *Science of the Total Environment*, *409*(9), 1704-1714.

Blanco-Canqui, H. and Jasa, P. J. (2019). Do grass and legume cover crops improve soil properties in the long term?. Soil Science Society of America Journal, 83(4), 1181-1187. https://doi.org/10.2136/sssaj2019.02.0055

Calamai, A., Chiaramonti, D., Casini, D., Masoni, A., & Palchetti, E. (2020). Short-term effects of organic amendments on soil properties and maize (zea maize l.) growth. Agriculture, 10(5), 158. https://doi.org/10.3390/agriculture10050158

Campos, T., Chaer, G. M., Leles, P. d. S., Silva, M., & Santos, F. M. (2019). Leaching of heavy metals in soils conditioned with biosolids from sewage sludge. Floresta Ambient, 26(spe1). https://doi.org/10.1590/2179-8087.039918

Chen, H., Yang, X., Wang, H., Sarkar, B., Shaheen, S. M., Gielen, G., … & Rinklebe, J. (2020). Animal carcass- and wood-derived biochars improved nutrient bioavailability, enzyme activity, and plant growth in metal-phthalic acid ester co-contaminated soils: a trial for reclamation and improvement of degraded soils. Journal of Environmental Management, 261, 110246. https://doi.org/10.1016/j.jenvman.2020.110246

Chowaniak, M., Głąb, T., Klima, K., Niemiec, M., Zaleski, T., & Zuzek, D. K. (2020). Effect of tillage and crop management on runoff, soil erosion and organic carbon loss. Soil Use and Management, 36(4), 581-593. https://doi.org/10.1111/sum.12606

Conradi, É., Gonçalves, A. C., Seidel, E. P., Ziemer, G. L., Zimmermann, J., Oliveira, V. H. D. d., … & Zeni, C. D. (2020). Effects of liming on soil physical attributes: a review. Journal of Agricultural Science, 12(10), 278. https://doi.org/10.5539/jas.v12n10p278

Correa, J., Postma, J., Watt, M., & Wojciechowski, T. (2019). Soil compaction and the architectural plasticity of root systems. Journal of Experimental Botany, 70(21), 6019-6034. https://doi.org/10.1093/jxb/erz383

Dörner, J., Bravo, S., Stoorvogel, M., Dec, D., Valle, S. R. M. d., Clunes, J., … & Zúñiga, F. (2022). Short-term effects of compaction on soil mechanical properties and pore functions of an andisol. Soil and Tillage Research, 221, 105396. https://doi.org/10.1016/j.still.2022.105396

Douglas Richardson, N. C. (2016). Soil Fertility and Management. *International Encyclopedia of Geography: People, the Earth, Environment and Technology*, 1-10.

E. Sakin, A. D. (2011). Bulk Density Of Harran Plain Soils In Relation To Other Soil Properties. *African Journal of Agricultural Research Vol. 6(7)*, 1750-1757.

Eilin Walsh, K. P. (2012). The influence of added organic matter on soil physical, chemical, and biological properties: a small-scale and short-time experiment using straw. *Archives of Agronomy and Soil Science, 58*, 1-6.

Eluozo, S. N. (2013). Predictive model to monitor the rate of bulk density in fine and coarse soil formation influenced variation of porosity in coastal area of Port Harcourt. *American Journal of Engineering Science and Technology Research*, *1*(8), 115-127.

Fu, Z., Jiang, X., Li, W., Lai, S., Zhuang, J., Yao, S., … & Xia, T. (2020). Proanthocyanidin–aluminum complexes improve aluminum resistance and detoxification of camellia sinensis. Journal of Agricultural and Food Chemistry, 68(30), 7861-7869. https://doi.org/10.1021/acs.jafc.0c01689

Gao, S., He, P., Lin, T. S., Liu, H., Guo, B., Lin, H., … & Jiang, L. (2021). Consecutive soybean (glycine max) planting and covering improve acidified tea garden soil. Plos One, 16(7), e0254502. https://doi.org/10.1371/journal.pone.0254502

Glaser, B. and Lehr, V. (2019). Biochar effects on phosphorus availability in agricultural soils: a meta-analysis. Scientific Reports, 9(1). https://doi.org/10.1038/s41598-019-45693-z
Gleiciane, F., Raimundo, Rosilene Oliveira Mesquita, Marques, S., & Mota, A. (2020). Gas exchanges and growth of maize as affected by aeration porosity and soil compaction. *Revista Ciencia Agronomica* 51(3):20196834.

Grant, C. A. (2017). Soil fertility and management. *The International Encyclopedia of Geography : People, the Earth, Environment and Technology*, 1-10.

Gui, Y., Zhang, Q., Qin, X., & Wang, J. (2021). Influence of organic matter content on engineering properties of clays. Advances in Civil Engineering, 2021, 1-11. https://doi.org/10.1155/2021/6654121

Habibi, L. N., Komariah, K., Ariyanto, D. P., Syamsiyah, J., & Tanaka, T. S. (2019). Estimation of soil organic matter on paddy field using remote sensing method. *SAINS TANAH-Journal of Soil Science and Agroclimatology*, *16*(2), 159-168.

Haque, A. N. A., Uddin, M. K., Sulaiman, M. F., Amin, A. M., Hossain, M., Aziz, A. A., & Mosharrof, M. (2021). Impact of organic amendment with alternate wetting and drying irrigation on rice yield, water use efficiency and physicochemical properties of soil. *Agronomy*, *11*(8), 1529.

Hossain, Z., Bahar, M., Sarkar, B., Donne, S. W., Ok, Y. S., Palansooriya, K. N., … & Bolan, N. (2020). Biochar and its importance on nutrient dynamics in soil and plant. Biochar, 2(4), 379-420. https://doi.org/10.1007/s42773-020-00065-z

Hutasuhut, M. A., Febriani, H., & Widiarti, L. (2023). Soil quality in organic agricultural land: study of chemical analysis and soil microbiology. BIOLINK (Jurnal Biologi Lingkungan Industri Kesehatan), 9(2), 209-218. https://doi.org/10.31289/biolink.v9i2.8178

Jalal, A., Azeem, K., Teixeira Filho, M. C. M., & Khan, A. (2020). Enhancing soil properties and maize yield through organic and inorganic nitrogen and diazotrophic bacteria. *Sustainable crop production. London: IntechOpen*, 165-178.

Jehangir H. Bhadha, J. M. (2017). Raising Soil Organic Matter Content to Improve Water Holding Capacity. *UF/IFAS*, 1-5.
Johannes Lehmann, M. K. (2015). The contentious nature of soil organic matter. *Nature*, 60-68.

Johannes Lehmann, M. K. (2015). The contentious nature of soil organic matter. *Nature*, 60-68.

Kalkhoran, S.S.; Pannell, D.J.; Thamo, T.; White, B.; Polyakov, M. Soil acidity, lime application, nitrogen fertility, and greenhouse gas emissions: Optimizing their joint economic management. *Agric. Syst.*: 176, 102684

Kebede, B. A., Molla, E., Selassie, Y. G., Belay, H. T., & Bayu, T. (2022). Effects of different dose of nitrogen and lime on soil properties and maize (zea mays l.) on acidic nitisols of northwestern ethiopia. Journal of Agriculture and Natural Resources, 5(1), 213-227. https://doi.org/10.3126/janr.v5i1.50758

Khadka, D. (2016). Assessment of Relationship between Soil Organic Matter and Macronutrients, Western Nepal. *Journal of Biological Pharmaceutical And Chemical Research*, 4-12.

Khan, R., Farooque, A. A., Brown, H. C. P., Zaman, Q., Acharya, B., Abbas, F., … & McKenzie-Gopsill, A. (2021). The role of cover crop types and residue incorporation in improving soil chemical properties. Agronomy, 11(10), 2091. https://doi.org/10.3390/agronomy11102091

Khurana, M., Singh, J., Chhabra, V., Singh, T., & Tarkha, A. (2022). Boron in soil plant system and its significance in indian agriculture. Ecology, Environment and Conservation, 946-956. https://doi.org/10.53550/eec.2022.v28i02.057

Kong, W., Pan, H., Li, X., Huang, R., Ma, Q., & Nian, H. (2021). Identification of an atp-binding cassette transporter implicated in aluminum tolerance in wild soybean (glycine soja). International Journal of Molecular Sciences, 22(24), 13264. https://doi.org/10.3390/ijms222413264

Liang, J., Wei, D., Yin, D., Zhou, B., Ding, J., Wang, W., … & Gu, J. (2020). Investigations of the effect of the amount of biochar on soil porosity and aggregation and crop yields on fertilized black soil in northern china. Plos One, 15(11), e0238883. https://doi.org/10.1371/journal.pone.0238883 ska, N.,

Laird, D. A., Rathke, S. J., & Karlen, D. L. (2014). Biochar impact on Midwestern Mollisols and maize nutrient availability. *Geoderma*, *230*, 340-347.

Liu, D., Feng, Z., Zhu, H., Yu, L., Yang, K., Shen, Y., … & Guo, W. (2020). Effects of corn straw biochar application on soybean growth and alkaline soil properties. BioResources, 15(1), 1463-1481. https://doi.org/10.15376/biores.15.1.1463-1481

Liu, R., Pan, Y., Bao, H., Shen, L., Jiang, Y., Tu, H. J., … & Huang, W. (2020). Variations in soil physico-chemical properties along slope position gradient in secondary vegetation of the hilly region, guilin, southwest china. Sustainability, 12(4), 1303. https://doi.org/10.3390/su12041303

Lorandi, R. (2012). Evaluation of Cation Exchange Capacity (CEC) in Tropical Soils Using Four Different Analytical Methods. *Journal of Agricultural Science;* 4(6), 278-290.

Luong, J., Mercatoris, B., & Destain, M. F. (2015). Measurement of the open porosity of agricultural soils with acoustic waves. *EGUGA*, 5292.

Ma, R., Guan, S., Dou, S., Wang, D., Xie, S., & Ndzelu, B. S. (2020). Different rates of biochar application change 15n retention in soil and 15n utilization by maize. Soil Use and Management, 36(4), 773-782. https://doi.org/10.1111/sum.12649

Mariangela Diacono, F. M. (2011). Long-Term Effects of Organic Amendments on Soil Fertility. *Sustainable Agriculture Volume 2*, 761-786.

eISSN Number: 2462-2389

Marín, J. A. E. and Rivera, D. (2022). Generation of soil maps permeability, case study in two cantons of loja province, ecuador. *Research Square*.

Marzi, M., Shahbazi, K., Kharazi, N., & Rezaei, M. (2019). The influence of organic amendment source on carbon and nitrogen mineralization in different soils. Journal of Soil Science and Plant Nutrition, 20(1), 177-191. https://doi.org/10.1007/s42729-019-00116-w

Masud, M. M., Baquy, M. A., Akhter, S., Sen, R., Barman, A., & Khatun, M. (2020). Liming effects of poultry litter derived biochar on soil acidity amelioration and maize growth. Ecotoxicology and Environmental Safety, 202, 110865. https://doi.org/10.1016/j.ecoenv.2020.110865

Mayhew-Hammond, S. (2021). The effectiveness of tillage radish® to improve the growing medium for trees. https://doi.org/10.32920/ryerson.14652762

Medina-Méndez, J., Volke-Haller, V., Cortés-Flores, J. I., Galvis-Spínola, A., & Santiago-Cruz, M. d. J. (2019). Soil organic matter and grain yield of rainfed maize in luvisols of campeche, Mexico. *Agricultural Sciences,* 10(12), 1602-1613.

Melkamu, D., Melese, A., & Tena, W. (2019). Effects of soil conservation practice and crop rotation on selected soil physicochemical properties: the case of dembecha district, northwestern ethiopia. *Applied and Environmental Soil Science*;1-14.

Minhal, F., Maas, A., Hanudin, E., & Sudira, P. (2020). Improvement of the chemical properties and buffering capacity of coastal sandy soil as affected by clays and organic by-product application. Soil and Water Research, 15(2), 93-100.

Mosharrof, M., Uddin, M. K., Sulaiman, M. F., Mia, S., Shamsuzzaman, S. M., & Haque, A. N. A. (2021). Combined application of rice husk biochar and lime increases phosphorus availability and maize yield in an acidic soil. *Agriculture*, *11*(8), 793.

Muche, M., Molla, E., Mohammed, S., Esubalew, S., & Hassen, A. (2022). Evaluating slow pyrolysis of parthenium hysterophorus biochar: perspectives to acidic soil amelioration and growth of selected wheat (Triticum aestivum) varieties. The Scientific World Journal, 2022, 1-13. https://doi.org/10.1155/2022/8181742

Murphy, B. W. (2015). Impact of soil organic matter on soil properties : a review with emphasis on Australian soils. *Soil Research*, 605-635.

Mustapha, Y., Muhammad, I., & Alhassan, I. (2022). Use of biochar for enhance carbon sequestration to mitigate climate change and growth of maize in sudan savanna zone of nigeria. Brazilian Journal of Science, 1(12), 63-75. https://doi.org/10.14295/bjs.v1i12.207

Nelson, L., Sanborn, P., Cade-Menun, B. J., Walker, I. J., & Lian, O. B. (2021). Pedological trends and implications for forest productivity in a holocene soil chronosequence, Calvert Island, British Columbia, Canada. Canadian Journal of Soil Science, 101(4), 654-672. https://doi.org/10.1139/cjss-2021-0033

Nikiforos Meimaroglou, a. C. (2019). Cation Exchange Capacity (CEC), Texture, Consistency and Organic Matter In Soil Assessment For Earth Construction: The Case Of Earth Mortars. *Construction and Building Materials Volume 221*, 27-39.

Nisa, K., Rusdi, M., & Indra, I. (2023). Bulk density and soil porosity in the patchouli development area of aceh barat, indonesia. IOP Conference Series: Earth and Environmental Science, 1183(1), 012029. https://doi.org/10.1088/1755-1315/1183/1/012029

Nor, N. A. A. M., Rabu, M. R., Adnan, M. A., & Rosali, M. H. (2019). An overview of the grain corn industry in Malaysia. *FFTC Agricultural Policy Platform (FFTC-AP).*

Pandit, N. R., Mulder, J., Hale, S. E., Martinsen, V., Schmidt, H. P., & Cornelissen, G. (2018). Biochar improves maize growth by alleviation of nutrient stress in a moderately acidic low-input Nepalese soil. *Science of the Total Environment*, *625*, 1380-1389.

Pető, J., Hüvely, A., Vojnich, V. J., & Cserni, I. (2020). Investigation of the relationship between soil organic matter and magnesium content. Gradus, 7(1), 53-56. https://doi.org/10.47833/2020.1.agr.013

Piaszczyk, W., Lasota, J., & Błońska, E. (2019). Effect of organic matter released from deadwood at different decomposition stages on physical properties of forest soil. Forests, 11(1), 24. https://doi.org/10.3390/f11010024

Ramesh, T., Bolan, N., Kirkham, M. B., Hasintha Wijesekara, Manjaiah Kanchikerimath, Cherukumalli Srinivasa Rao, S. Sandeep, Jörg Rinklebe, Yong Sik Ok, Choudhury, B. U., Wang, H., Tang, C., Wang, X., Song, Z., & Freeman, O. W. (2019). Soil organic carbon dynamics: Impact of land use changes and management practices: A review. *Advances in Agronomy*, 1–107. https://doi.org/10.1016/bs.agron.2019.02.001

Readyhough, T. J., Neher, D. A., & Andrews, T. (2021). Organic amendments alter soil hydrology and belowground microbiome of tomato (*Solanum lycopersicum*). Microorganisms, 9(8), 1561. https://doi.org/10.3390/microorganisms9081561

Rondon, T., Hernández, R. M., & Guzmán, M. (2021). Soil organic carbon, physical fractions of the macro-organic matter, and soil stability relationship in lacustrine soils under banana crop. Plos One, 16(7), e0254121. https://doi.org/10.1371/journal.pone.0254121

Salem, H. M., Valero, C., Miguel Ángel Muñoz-García, & Luis Leopoldo Silva. (2015, January 31). Short-term effects of four tillage practices on soil physical properties, soil water potential, and maize yield. *Geoderma* 237-238: 60-70.

Seifu, Y., Hiremath, S. S., Tola, S., & Wako, A. (2022). Investigation of soil physiochemical properties effects on soil compaction for a long year tilled farmland. Applied and Environmental Soil Science, 2022, 1-9. https://doi.org/10.1155/2022/8626200

Seyyed Ali Akbar Nakhli, M. D. (2017). Application of Zeolites for Sustainable Agriculture: a Review on Water and Nutrient Retention. *Water Air Soil Pollut*, 463-497.

Siltecho, S., Suvannang, N., Kaiphoem, J., Medeiros, É. V. d., Lima, J. R. d. S., Prakongkep, N., … & Hammecker, C. (2021). Characterization of pterocarpus macrocarpus (pradoo wood) biochar and its effect on the retention properties of sandy soils in northeast thailand. Soil Use and Management, 38(2), 1293-1306. https://doi.org/10.1111/sum.12774

Singh, H., Northup, B. K., Rice, C. W., & Prasad, P. (2022). Biochar applications influence soil physical and chemical properties, microbial diversity, and crop productivity: a meta-analysis. Biochar, 4(1). https://doi.org/10.1007/s42773-022-00138-1

Sisouvanh, P., Trelo-ges, V., Ayutthaya, S. I. N., Pierret, A., Nunan, N., Silvera, N., … & Hartmann, C. (2021). Can organic amendments improve soil physical characteristics and increase maize performances in contrasting soil water regimes?. Agriculture, 11(2), 132. https://doi.org/10.3390/agriculture11020132

Solly, E. F., Weber, V., Zimmermann, S., Walthert, L., Hagedorn, F., & Schmidt, M. W. (2020). A critical evaluation of the relationship between the effective cation exchange capacity and soil organic carbon content in swiss forest soils. Frontiers in Forests and Global Change, 3. https://doi.org/10.3389/ffgc.2020.00098

Su, L., Lv, A., Wen, W., Fan, N., Li, J., Gao, L., … & An, Y. (2022). msmyb741 is involved in alfalfa resistance to aluminum stress by regulating flavonoid biosynthesis. The Plant Journal, 112(3), 756-771. https://doi.org/10.1111/tpj.15977

Sulaiman, S., Navaranjan, N., Hernandez-Ramirez, G., & Sulaiman, Z. (2023). Plant residues ameliorate ph of agricultural acid soil in a laboratory incubation: a meta-analysis. Journal of Plant Nutrition and Soil Science, 186(3), 330-338. https://doi.org/10.1002/jpln.202200332

Sun, Q., Sun, W., Zhao, Z., Jiang, W., Zhang, P., Sun, X., & Xue, Q. (2023). Soil Compaction and Maize Root Distribution under Subsoiling Tillage in a Wheat–Maize Double Cropping System. *Agronomy*, *13*(2), 394–394. https://doi.org/10.3390/agronomy13020394

Thorp, T., Barnett, A., Civolani, C., Spinelli, R., Lallu, N., & Burdon, J. (2021). Iron chelate applications improve productivity and fruit quality at harvest and during cold storage of actinidia chinensis var. chinensis (‘hort16a’) kiwifruit growing in high-ph calcareous soils. European Journal of Horticultural Science, 86(6), 609-619. https://doi.org/10.17660/ejhs.2021/86.6.4

eISSN Number: 2462-2389

Tomczyk, A., Sokołowska, Z., & Boguta, P. (2020). Biochar physicochemical properties: pyrolysis temperature and feedstock kind effects. Reviews in Environmental Science and Bio/Technology, 19(1), 191-215. https://doi.org/10.1007/s11157-020-09523-3

Tripathi, P. K., Mishra, U., Sirothia, P., & Singh, R. (2021). Characterization and classification of soils of northern hills zone of chhattisgarh, madhya pradesh. International Journal of Agricultural Sciences, 17(AAEBSSD), 147-149. https://doi.org/10.15740/has/ijas/17-aaebssd/147-149

Turner, K. G., Anderson, S., Gonzales-Chang, M., Costanza, R., Courville, S., Dalgaard, T., ... & Wratten, S. (2016). A review of methods, data, and models to assess changes in the value of ecosystem services from land degradation and restoration. *Ecological Modelling*, *319*, 190-207.

Uhlig, D. and Blanckenburg, F. v. (2019). How slow rock weathering balances nutrient loss during fast forest floor turnover in montane, temperate forest ecosystems. Frontiers in Earth Science, 7. https://doi.org/10.3389/feart.2019.00159

Vilakazi, B. S., Zengeni, R., & Mafongoya, P. (2022). Selected Soil Physicochemical Properties under Different Tillage Practices and N Fertilizer Application in Maize Mono-Cropping. *Agriculture*, *12*(10), 1738.

Wang, L., O'Connor, D., Rinklebe, J., Ok, Y. S., Tsang, D. C., Shen, Z., … & Hou, D. (2020). Biochar aging: mechanisms, physicochemical changes, assessment, and implications for field applications. Environmental Science &Amp; Technology, 54(23), 14797-14814. https://doi.org/10.1021/acs.est.0c04033

Welten, B., Ledgard, S., Judge, A., Sprosen, M. S., McGowan, A. W., & Dexter, M. (2019). Efficacy of different temperate pasture species to reduce nitrogen leaching from cattle urine applied in different seasons: a soil lysimeter study. Soil Use and Management, 35(4), 653-663. https://doi.org/10.1111/sum.12512

Xiao-hu, Y., Kong, Y., Guo, E., Chen, X., & Li, L. (2021). Organic acid regulation of inorganic phosphorus release from mollisols with different organic matter contents. Soil Use and Management, 38(1), 576-583. https://doi.org/10.1111/sum.12710

Yu, L., Wen, Y., Luo, X., Xiang, Y., Yuan, X., Pang, S., … & Li, X. (2022). Effects of biogas residues on dissipation of difenoconazole in paddy sediment system under field conditions. Frontiers in Environmental Science, 10. https://doi.org/10.3389/fenvs.2022.814438

Yu, X. and Lu, S. (2019). Reconfiguration of macropore networks in a silty loam soil following biochar addition identified by x-ray microtomography and network analyses. European Journal of Soil Science, 70(3), 591-603. https://doi.org/10.1111/ejss.12773

Yue, Y., Lin, Q., Li, G., Zhao, X., & Chen, H. (2023). Biochar Amends Saline Soil and Enhances Maize Growth: Three-Year Field Experiment Findings. *Agronomy*, *13*(4), 1111.

Yunfeng Wang, Caixian Tang, Jianjun Wu, Xingmei Liu, Jianming Xu. (2013). Impact of organic matter addition on pH change. *Journal of Soil Sediment* (13).

Zaffar, M., & Sheng-Gao, L. U. (2015). Pore size distribution of clayey soils and its correlation with soil organic matter. *Pedosphere*, *25*(2), 240-249.

Zhang, M., Riaz, M., Zhang, L., El-Desouki, Z., & Jiang, C. (2019). Biochar induces changes to basic soil properties and bacterial communities of different soils to varying degrees at 25 mm rainfall: more effective on acidic soils. Frontiers in Microbiology, 10. https://doi.org/10.3389/fmicb.2019.01321

Zhang, N., Ma, Z., Dong, L., Ni, H., Sun, B., & Liang, Y. (2022). Soil ph filters the association patterns of aluminum-tolerant microorganisms in rice paddies. mSystems, 7(1). https://doi.org/10.1128/msystems.01022-21

Zhou, W., Lv, T. F., Chen, Y., Westby, A. P., & Ren, W. J. (2014). Soil physicochemical and biological properties of paddy-upland rotation: a review

eISSN Number: 2462-2389