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Biochar An Emerging Potential Nutrient Source In Horticulture And Urban Farming Industry

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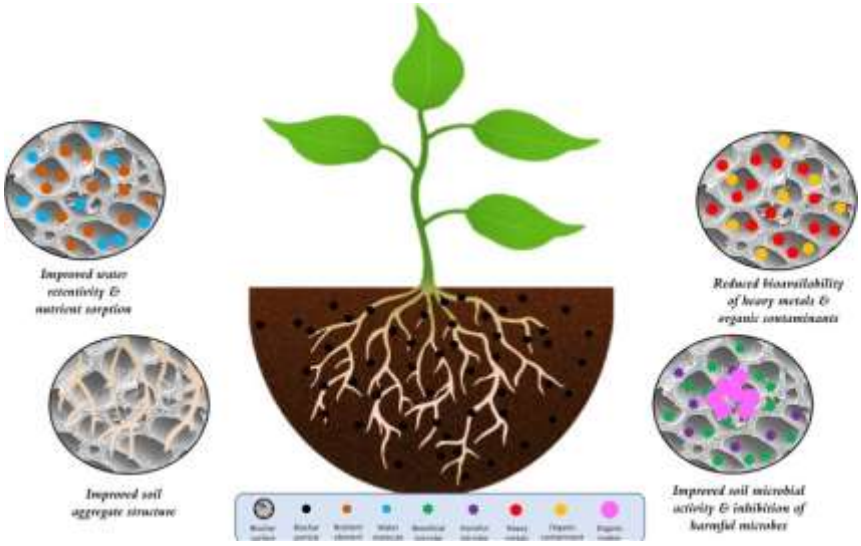
Abstract: The properties of biochar and its impact on soil health and natural ecosystems are mainly influenced by the origin of the feedstock, the time it remains in the soil, and the conditions during pyrolysis. Using biochar as an adsorbent can help eliminate both organic and inorganic soil pollutants. A nutrient-rich increase created from biomass, biochar is growing increasingly popular as a soil add to to increase crop yields and store carbon. The possibilities to generate biochar and its potential benefits have been determined for this Portuguese region, showing how agricultural application may effectively result in several environmental, economic, and social advantages. Additionally, biochar could improve sure biological, chemical, and physical properties of soil and substrate. But there are disadvantages to applying biochar in addition. As an example, applying biochar increased the pH to a level that plant growth was greatly impeded which may have concealed potential advantages. The most recent study on bio char's use for sustainable horticulture has been collected in this review. Increasing horticultural productivity of crops and promoting durability to major abiotic and biotic obstacles are two examples of how biochar works in this regard. Significant holes and possible routes for utilising biochar technology are also discussed.

Index Terms – Biochar, Nutrient, Industry

I. Introduction

Biochar is extensively studied and utilized for enhancing soil and as an absorbent. Its production is an environmentally sustainable process (Elkhlifi et al., 2023). Biochar is designed for use in soil applications and environmental management to enhance soil fertility. It also serves as a valuable amendment in composting by reducing nitrogen levels and improving the composting process and its quality. Additionally, biochar is utilized in soilless cultivation, particularly in peat-based growing media, where peat is commonly used(Amery et al., 2021) Addressing both immediate and long-term challenges, biochar plays a crucial role in creating a sustainable future and contributing valuable products to the economic model. Researchers enhance soil quality and agricultural sustainability by using biochar. Key soil factors that influence nutrient availability, moisture retention, and overall quality include texture(Allohverdi et al., 2021).Biochar used in its untreated form has been shown to improve soil health and plant yields, but recent research indicates that modifying biochar both physically and chemically enhances its effectiveness. Increasing yields without relying on fertilizers remains a challenge for modern sustainable agricultural practices(Royet al., 2021).
For agricultural purposes Currently United States and china used biochar. They focus on generally crop yield or economic assessment and effects on microbiota.
Generally generated through advanced pyrolysis procedures, biochar is a high-carbon residue having a fine grain. The process generates a combination of gases, liquids, and solids. Through the procedure of pyrolysis, biomass is transformed into the product known as biochar (Malabadi et al., 2023).In environmental management, biochar serves an important part in decreasing greenhouse gas emissions, particularly the sequestration of CO2 and CH4 and the release of N2O, which reduces the ozone layer. In addition, biochar substances produced through thermochemical methods have a variety of intriguing

characteristics that make them great for creative incorporation in coatings, nanomaterials, and bio-composites in addition to being utilised as soil drugs and solid fuel (Kolkar et al., 2023).



II. BIOCHAR

Pyrolysis involves heating biomass with little to no air, resulting in the production of biochar. This biochar can be applied to soil or used for environmental management. When used in agriculture, biochar can enhance soil fertility and aid in carbon retention. Additionally, it helps reduce nitrogen losses (Debode et al., 2021). Biochar has been reported as a component in soilless cultivation using peat-based growing substrates. Although peat is commonly used in growing media, it raises concerns due to its environmental impact, including damage to peatlands and greenhouse gas emissions from its extraction. Therefore, substituting part of the peat with biochar is becoming more appealing. Biochar's exceptional structural stability, along with its ability to retain water and air, makes it an essential addition for these growing substrates(Tender et al., 2021).

2.1 Types of Biochar

The diverse properties of biochar are due to the various types of biomass used in its production and assessment in the literature. In order to facilitate the assessment of biochar characteristics, this research categorises six varieties of biochar based on the primary biomass type utilised in their manufacturing (Aller et al, 2016).

- Lignin rich biochar– that has a high lignin concentration, such as sawdust, wood, tree parts, etc.
- Cellulose rich biochar– such as grasses, straws, grains, etc., where cellulose serves as the primary structural component
- Shell biochar–made from components like husks and shells that shield nuts.
- Waste biochar–produced by pyrolyzing biological waste such as compost or bio solids.
- Algae biochar –made from both freshwater and marine algae.
- Black carbon–made from biomass that was not covered in the previous sections.

III. BIOCHAR PRODUCTION

Gasification, hydrothermal carbonization, torrefaction, pyrolysis arecarbonization techniques commonly used to produce biochar from variety of raw materials. Increase the yield of biochar, slow pyrolysis is a thermal conversion technique that is follow up at temperature between 300°C and 800°C. Low heating rates and long residence time are the characteristic of the process of atmospheric pressure (Alves et al., 2022).In this procedure big particle sizes are preferred for producing biochar. The cracking reactions decrease the quantity of bio oil and raise the production of biochar. Pyrolysis have very attractive benefits for optimising the yield of biofuel because of its high heating rates and brief residence duration (Lourinho et al., 2022).

The gasification process is produced syngas and contrast to pyrolysis is carried out in the presence of oxidising agent.Because of these biochar is seen as by-products and yields are poor (Nobre et al., 2022). For producing biochar torrefaction, pyrolysis and gasification is newly developed methods. In this process long Polysaccharide chains are depolymerized , which removes oxygen, carbon dioxide and moisture. This process is referred to as mild pyrolysis because these process is carried out at medium heating rate(Alves etal., 2022). The higher product yields torrefaction is not thought to be a promising method for producing biochar. As a result torrefaction Is frequently employed as a biomass pre-treatment method to increase densify feedstock, brittleness and remove moisture (Lourinho et al., 2022).

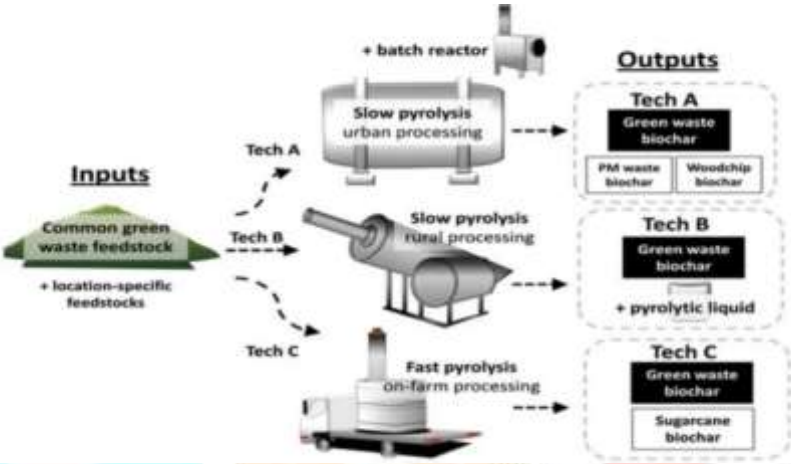
Hydrothermal Carbonization (HTC), also known as wet pyrolysis or torrefaction, occurs in a wet environment, unlike pyrolysis and torrefaction which happen in dry conditions. This process is performed over several hours in a biomass-water mixture at temperatures ranging from 180°C to 300°C under autogenous pressure. HTC produces significant biochar yields similar to pyrolysis and generates a liquid fraction that includes a blend of bio-oil and water, along with a gas phase mainly composed of CO_2.(Bruno Gracia 2022). HTC has attracted significant interest because it can produce biochar without the energy-intensive drying step required for traditional pyrolysis, leading to reduced operating costs. Additionally, HTC can minimize the leaching of salts and minerals from feed stocks with moisture levels above 75%, resulting in bio chars with lower ash content (Catarina Nobre 2022) .

The best method for producing biochar is slow pyrolysis. With the right combination of low temperatures, slow heating ratesand extended residence times, the method can be used with nearly any biomass feedstock to produce stable carbonaceous solid materials (Bruna Rijo 2022).It is important to note that the aforementioned processes—pyrolysis, torrefaction, and HTC in particular—produce additional valuable products. In order to achieve circularity and, as a result, greater sustainability in the manufacture of biochar, it is imperative that the application of these by-products be addressed (Goncalo Lourinho, Caterina Nobre 2022).

Raw material	Production condition	Components	Reference
Corn cob	Slow pyrolysis	Carbon, Nitrogen, Potassium	(Allohverdi et al., 2021)
Corn stover	Slow pyrolysis	Carbon, Nitrogen, Sulphur, phosphorus	(Mohanty et al., 2021)
Rice straw	Fast pyrolysis	Carbon, Oxygen	(Roy et al., 2021)
Rice husk	Co pyrolysis	Carbon, Nitrogen, Hydrogen	(Mohanty et al., 2021)
Peanut hull	Slow pyrolysis	Carbon, Nitrogen, Potassium, Sulphur	(Misra et al., 2021)

Biochar can be produced using various methods, each affecting the properties of the final product. Pyrolysis, a thermochemical process that occurs in an oxygen-deprived environment, usually produces charcoal, syngas, and bio oil (Mohanty et al., 2021). The process is carried out with an inert gas (usually nitrogen) present in special equipment. Both rapid and gradual pyrolysis can be performedout in this kind of reactor. Materials used in the pyrolysis process are shown in the diagram as both input and output (Misra et al., 2021).

The terms "slow" and "fast" pyrolysis relate to the process's heating rate. When pyrolysis is to be classified as rapid or slow depends on the heating rate. Fast pyrolysis takes place in a few seconds to minutes, and slow pyrolysis happens in minutes to hours. The natural polymers in biomass go through several changes when it is pyrolyzed. At various temperatures, these organically produced polymers may fragment, cross-link, and then break away (Allohverdi et al., 2021). Biochar is produced at a slower rate than bio-oil and syngas under slow pyrolysis. For a quick pyrolysis process, the opposite is typically true likewise. There is evidence that these two processes can be utilised to regulate specific surface areas and pore volume, though it appears that other factors have a bigger impact. It is notable that the properties of biochar may not always be identical, even similar production processes (Mohanty et al., 2021). Temperature has an important effect on two factors: pH and surface area. The removing of different chemical groups from the surface of biochar at varying temperatures, including carboxyl, carbonyl, and hydroxyl groups,



affects pH. Biochar derived from animal waste seems to be subject to the same restrictions of mineral attributes and organic carbon content as feedstock (Misra et al., 2021).

IV. APPLICATION

Applying biochar as a soil add to was demonstrated in multiple studies to improve soil fertility and crop yields while additionally enhancing the physical and hydrological attributes, water content, and efficiency of water use. Improving agricultural residues, composts, and decomposed manures with biochar improves the efficiency of nutrient use (Rijo et al., 2022). The kind of farming system, labour availability, and power tools available all have an important effect on the methods employed for application soil. Portugal has uncommonly low soil carbon levels. In order to achieve particular objectives, "tailor-made" biochars can be produced for specific crops and soil types (Nobre et al., 2022).Even with these advantages, the economic and environmental performance of biochar generated by biomass wastes will influence whether or not it's feasible to use it for use in agriculture later on. Farmers are not as possible to make investments as other potential customers and tend to be risk cautious, thus there are limitations. In addition, the effects of biochar are still extremely volatile (Alves et al., 2022).

CO_2 emissions are currently responsible for 60% of the global warming effect, consequently novel approaches to regulate the levels of CO_2 in the atmosphere are needed. Retaining significant quantities of carbon over a long period of time—from years to thousands of years—is a fascinating property of biochar. Since it contains CO_2 absorbed by the vegetable feedstock used in its production, biochar is especially beneficial for storing carbon (Lourinho et al., 2022).

When used in wastewater maintenance and water disinfection processes, biochars can be regarded as a novel, inexpensive substitute for business activated carbon. The macroporous surface structure of biochars explains their considerable adsorption abilities for pollutants found in real wastewaters, as demonstrated by batch adsorption studies. For this purpose, these materials are capable of treating complicated wastewaters without leading to early pore-clogging. Interest in researching biochars as novel methods of remediation has grown as a result of the reduced cost and land application history, as well as the requirement for removing fresh pollutants (Gracia et al., 2022).

V. BIOCHAR AS A NUTRIENT SOURCE

- Biochar potential for use as fertilizer
- The chemical composition and availability of nutrients in biochars
- Microorganisms, fertility and Biochar
- Biochar's effect on the ecosystem of microorganisms
- Biochar's effects on microbial activity
- It's impacts on microorganisms functional ecology.

VI. ADVANTAGE OF BIOCHAR IN HORTICULTURE

6.1 In horticultural crops, biochar improves better seed germination

Plant density and initial crop growth strength are affected by seed germination, becoming an essential step in agricultural cultivation that produces the best possible yield and margins of profit (Zulfiqar et al., 2022). The effects of biochar on germination can range from inhibitory to stimulating, depending on factors such as the type of feedstock, pyrolysis temperature, quantity used, and crop species. In general, low biochar dosages have more advantageous effects than big ones. By enhancing or altering the porosity and water-holding capacity of soils or growing media, BC may encourage the growth of seeds by enhancing the accessibility of water. Biochar salts and phytotoxins (Nazir et al., 2022). Affect germination of seeds adversely by causing osmotic stress. By releasing karakins, or germination hormones, Biochar stimulates the germination of seeds.Incorporating biochar into the soil enhances its physical and chemical properties, which in turn supports seed germination.(Ferrante et al., 2022).

6.2 Horticultural crop roots grow faster while biochar is applied to enhance crop water and nutrient relationships

Water absorption and availability, along with the amount of dissolved solutes present, define plant water relationships including turgor potential, osmotic potential, and water potential. In addition, the use or addition of inorganic or organic solutes can alter water-nutrient relations in plants (Chen et al., 2022).Comparative water content and consumption of water effectiveness also increased in tomato plants grown under deficiency and partial root-zone drying irrigation when BC was added. Despite the results mentioned above, more research is required to determine whether applying BC affects the factors regulating plant-water relations (Nazir et al., 2022).

6.3 Horticultural crop growth, yield, and quality of the product are all improved by biochar

The development and growth of plants are dependent on the condition of the original starting materials, such as seeds or propagules, the accessibility of water and nutrients in the soil, the absorption of water and nutrients, and photosynthesis in the presence of the required quantities of light and temperature (Chen et al., 2022). When applied to soil or growing medium at the right amount, biochar improves seedling growth, blocks certain phytohormones, and boosts the production of photosynthetic pigments and photosynthesis. Exogenous production BC treatment, thus, has been demonstrated in studies to enhance yield and development in plants growing in both stressed and non-stressed environments (Nazir et al., 2022). A. Zeriumbet in reaction to BC produced solely of wheat straw and in combined with compost (Darras et al., 2022).

6.4 Biochar use for greater stress tolerance

Environmental factors such as drought, salinity, heavy metals, extreme temperatures, and acidic conditions can negatively impact plant growth and productivity. These factors additionally represent a risk to global food security and the sustainability of agriculture as an entire sector. In order to raise agricultural productivity in both yield and quality, biochar supplementation is an efficient and reasonably priced method of management (Ferrante et al., 2022).

6.5 Biochar increasesplants resistance to illness

Incorporating biochar can boost a plant's disease resistance and overall resilience. Even at low concentrations, biochar can reduce the presence of disease-causing organisms, leading to improved plant resistance and increased crop yields.(Nazir et al., 2022).

VII. ADVANTAGE OF BIOCHAR

- Natural fertiliser named biochar improves soil nutrients and prevents it from evaporating. Because biochar keeps nutrients that are soluble in the soil, it's able to maintain the good health of the soil. Biochar can be used for soil enrichment because of its porous nature, which allows it to retain water and nutrients which are soluble in it. Several advantages for soil health are widely recognised for biochar. Therefore, it may reduce soil acidity, limit depletion of nutrients, improve water quality, and need less irrigation and fertiliser(Chalannavar et al., 2023).
- Since it is porous, biochar helps microbial populations in the soil by providing nutrients and conserving water during severe weather.In the end, burning biomass emits lesser greenhouse gases into the atmosphere since it is a stable product that may stay in the soil for many years (Malabadi et al., 2023).
- Since biochar has an average porosity, it helps the soil absorb more water. It helps soil in the growth of plants and vegetables in this manner. While there is some atmospheric carbon produced during the transformation of biomass into biochar, there is not as much as during biomass burning. Biochar thus acts as a carbon sink in soil (Acharya et al., 2023).
- Using biochar in the soil enhances agricultural tolerance and boosts production. Its hydrophilic nature allows biochar to absorb and retain moisture from the environment.This indicates that in regions where water scarcity is common, it can be used as a soil material. The preservation of phosphate and nitrogen, two elements vital to plant growth, leads to more nutritious plants that use a proportionately smaller amount of fertiliser (Kolkar et al., 2023).
- Biochar's capacity to decrease soil acidity, which is a barrier to crop output, is one of its primary advantages. Biochar is a valuable method for enhancing crop yield and diversity in areas with severely degraded soils, limited organic resources, inadequate water supply, and insufficient chemical fertilizers (Mudigoudra et al., 2023).
- It enhances also the quality and quantity of water by preserving nutrients and agricultural chemicals in the soil to be utilised by plants and crops. More nutrients stay in the soil as compared to escaping into groundwater and producing pollution (Malabadi et al., 2023).
- For hundreds to thousands of years, carbon can be stored in soils utilising biochar carbon, that's resistant to decay. While decreasing water and nutrient losses, biochar may used for agriculture and substrates, save money(Kolkar et al., 2023).
- Sustainable biochar techniques can produce fuel using oil and gas food that remains, enriching soil and providing clean, renewable energy. The system could grow "carbon negative" if biochar is used as a soil enhancer and buried (Acharya et al., 2023).
- The coproduction of biochar and bioenergy may reduce global climate change by providing as a replacement to the consumption of fossil fuels and depositing carbon in stable soil carbon pools. Reducing nitrous oxide emissions might be beneficial (Chalannavar et al., 2023).

VIII. DISADVANTAGE OF BIOCHAR

- By utilising fossil fuel opposed to Worm activity decreases whenever biochar is put in to the soil, which is essential to soil production. While biochar improves the output of agriculture, it further absorbs nutrients, which leaves growing plants with an absence of these nutrients.
- The frequent application of biochar compresses the soil, which reduces productivity in agriculture.
- Biochar also have an effect on pesticides application, that reduces pesticide effectiveness in soil.
- The implementation of biochar can lead to degradation of the soil, making the soil open to adverse weather.
- Like charcoal, biochar is flammable and requires careful handling. Biochars can spontaneously combust and catch fire when exposed to air due to their tendency to self-heat.
- The most significant health risk linked to biochar is dust, that additionally renders using it in the field the most problematic. Breathed biochar nanoparticles might irritate the respiratory tract and damage them.
- The method for applying biochar to the soil is another area of unpredictability, especially in low-tillage or no-till functioning processes.

CONCLUSION

Biochar offers various benefits for enhancing agricultural soils, including water filtration, removal of heavy metals, and environmental clean-up of pharmaceuticals. To tailor its use to specific regions, crop types, climates, and soils, it will be crucial to adjust biochar properties in future applications. When used sustainably, biochar helps maintain soil health and its stability is vital for ensuring crop productivity by improving, maintaining, and preserving soil characteristics. Due to recent advancements in biochar production methods, further research is needed to understand how different raw materials affect biochar's capacity to enhance soil nutrients. Biochar is created through the pyrolysis of biomass and is used to improve soil structure and boost agricultural yields. Its properties make it particularly useful in arid conditions, as it retains soil moisture and may help address soil infertility resulting from climate change. Biochar is characterized by its large surface area and porous structure.

REFERENCES

1) Elkhlifi, Z., Iftikhar, J., Sarraf, M., Ali, B., Saleem, M. H., Ibranshahib, I., ... & Chen, Z. (2023). Potential role of biochar on capturing soil nutrients, carbon sequestration and managing environmental challenges: a review. *Sustainability*, **15**(3), 2527.
2) Amery, F., Debode, J., Ommeslag, S., Visser, R., De Tender, C., & Vandecasteele, B. (2021). Biochar for circular horticulture: Feedstock related effects in soilless cultivation. *Agronomy*, ***11***(4), 629.
3) Sanchez-Monedero, M. A., Cayuela, M. L., Roig, A., Jindo, K., Mondini, C., & Bolan, N. J. B. T. (2018). Role of biochar as an additive in organic waste composting. *Bioresource Technology*, **247**, 1155-1164.
4) Allohverdi, T., Mohanty, A. K., Roy, P., & Misra, M. (2021). A review on current status of biochar uses in agriculture. *Molecules*, **26**(18), 5584.
5) Alling, V., Hale, S. E., Martinsen, V., Mulder, J., Smebye, A., Breedveld, G. D., & Cornelissen, G. (2014). The role of biochar in retaining nutrients in amended tropical soils. *Journal of Plant Nutrition and Soil Science*, **177**(5), 671-680.
6) Cha, J. S., Park, S. H., Jung, S. C., Ryu, C., Jeon, J. K., Shin, M. C., & Park, Y. K. (2016). Production and utilization of biochar: A review. Journal of Industrial and *Engineering Chemistry*, **40**, 1-15.
7) Ding Yang, D. Y., Liu YunGuo, L. Y., Liu ShaoBo, L. S., Li ZhongWu, L. Z., Tan XiaoFei, T. X., Huang XiXian, H. X., ... & Zheng BoHong, Z. B. (2016). Biochar to improve soil fertility. A review.
8) Atkinson, C. J., Fitzgerald, J. D., & Hipps, N. A. (2010). Potential mechanisms for achieving agricultural benefits from biochar application to temperate soils: a review. *Plant and soil*, ***337***, 1-18.

9) Garcia, B., Alves, O., Rijo, B., Lourinho, G., & Nobre, C. (2022). Biochar: production, applications, and market prospects in Portugal. *Environments*, **9**(8), 95.
10) Verheijen, F., Jeffery, S., Bastos, A. C., Van der Velde, M., & Diafas, I. (2010). Biochar application to soils. A critical scientific review of effects on soil properties, processes, and functions. EUR, **24099**(162), 2183-2207.
11) Schmidt, H. P., & Wilson, K. (2012). 55 uses of biochar. *Ithaka Journal*, **1**(2012), 286-289.
12) Aller, M. F. (2016). Biochar properties: Transport, fate, and impact. Critical reviews in environmental science and technology, **46**(14-15), 1183-1296.
13) Tenic, E., Ghogare, R., & Dhingra, A. (2020). Biochar—a panacea for agriculture or just carbon?. *Horticulturae*, **6**(3), 37.
14) Zulfiqar, F., Moosa, A., Nazir, M. M., Ferrante, A., Ashraf, M., Nafees, M., ... & Siddique, K. H. (2022). Biochar: An emerging recipe for designing sustainable horticulture under climate change scenarios. *Frontiers in Plant Science*, **13**, 1018646.
15) Agegnehu, G., Srivastava, A. K., & Bird, M. I. (2017). The role of biochar and biochar-compost in improving soil quality and crop performance: A review. *Applied soilecology*, **119**, 156-170.
16) Malabadi, R. B., Kolkar, K. P., Chalannavar, R. K., Acharya, M., & Mudigoudra, B. S. (2023). Industrial Cannabis sativa: Hemp-Biochar-Applications and Disadvantages. World Journal of Advanced Research and Reviews, **20**(01), 371-383.
17) Jing, Y., Zhang, Y., Han, I., Wang, P., Mei, Q., & Huang, Y. (2020). Effects of different straw biochars on soil organic carbon, nitrogen, available phosphorus, and enzyme activity in paddy soil. *Scientific Reports*, **10**(1), 8837.
18) Yang, K., Jiang, Y., Yang, J., & Lin, D. (2018). Correlations and adsorption mechanisms of aromatic compounds on biochars produced from various biomass at 700 C. *Environmental pollution*, **233**, 64-70.
19) Agegnehu, G., Srivastava, A. K., & Bird, M. I. (2017). The role of biochar and biochar-compost in improving soil quality and crop performance: A review. *Applied soil ecology*, **119**, 156-170.
20) Huang, M., Yang, L., Qin, H., Jiang, L., & Zou, Y. (2014). Fertilizer nitrogen uptake by rice increased by biochar application. *Biology and fertility of soils*, **50**, 997-1000.
21) Brtnicky, M., Hammerschmiedt, T., Elbl, J., Kintl, A., Skulcova, L., Radziemska, M., ... & Holatko, J. (2021). The potential of biochar made from agricultural residues to increase soil fertility and microbial activity: impacts on soils with varying sand content. *Agronomy*, ***11***(6), 1174.
22) Guo, X. X., Liu, H. T., & Zhang, J. (2020). The role of biochar in organic waste composting and soil improvement: A review. *Waste Management*, **102,** 884-899.
23) Cha, J. S., Park, S. H., Jung, S. C., Ryu, C., Jeon, J. K., Shin, M. C., & Park, Y. K. (2016). Production and utilization of biochar: A review. *Journal of Industrial* and Engineering Chemistry, ***40***, 1-15.
24) Li, X., Wang, T., Chang, S. X., Jiang, X., & Song, Y. (2020). Biochar increases soil microbial biomass but has variable effects on microbial diversity: A meta-analysis. *Science of the Total Environment*, ***749***, 141593.
25) Zhang, Q., Zhang, D., Lu, W., Khan, M. U., Xu, H., Yi, W., ... & Zou, R. (2020). Production of high-density polyethylene biocomposites from rice husk biochar: Effects of varying pyrolysis temperature. *Science of the total environment*, **738**, 139910.
26) Yu, H., Zou, W., Chen, J., Chen, H., Yu, Z., Huang, J., ... & Gao, B. (2019). Biochar amendment improves crop production in problem soils: A review. *Journal of environmental management*, ***232***, 8-21.
27) Kookana, R. S., Sarmah, A. K., Van Zwieten, L., Krull, E., & Singh, B. (2011). Biochar application to soil: agronomic and environmental benefits and unintended consequences. *Advances in agronomy*, ***112,*** 103-143.
28) Annabi, M., Le Bissonnais, Y., Le Villio-Poitrenaud, M., & Houot, S. (2011). Improvement of soil aggregate stability by repeated applications of organic amendments to a cultivated silty loam soil. *Agriculture, Ecosystems & Environment*, ***144***(1), 382-389.
29) Bartoli, M., Giorcelli, M., Jagdale, P., Rovere, M., & Tagliaferro, A. (2020). A review of non-soil biochar applications. *Materials*, ***13***(2), 261.
30) Jeffery, S., Abalos, D., Prodana, M., Bastos, A. C., Van Groenigen, J. W., Hungate, B. A., & Verheijen, F. (2017). Biochar boosts tropical but not temperate crop yields. *Environmental Research Letters*, **12**(5), 053001.