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Effects of Organic Amendments on Soil productivity, its physical and chemical properties: A Review of Compost and Biochar Applications

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ABSTRACT

This article examines the impacts of compost and biochar on soil properties and their potential to enhance soil productivity, particularly in soils of low fertility. Compost contributes to improving soil health by stimulating microbial activity, enriching soils with essential nutrients, and increasing organic matter. These effects enhance soil fertility and accelerate restoration of soil functionality. In addition, compost increases retention of soil moisture and decreases soil bulk density. However, the stability of compost in soil is relatively low, necessitating frequent reapplication of this additive, which may limit its cost-effectiveness and long-term utility. On the other hand, biochar offers a long-term stable carbon rich product through the pyrolysis of plant residues in anaerobic conditions, thereby serves as durable soil amendment. Its incorporation in soils improves soil characteristics by promoting soil aggregation and improving nutrient retention due to its high cation exchange capacity (CEC). Unlike compost, biochar remains longer in the soil, offering more economic applications. The combined application of compost and biochar demonstrate synergistic effects on soil quality than the utilization of either amendment independently. Compost provides readily available nutrients, while biochar increases the retention of these nutrients, thereby reducing their losses via leaching. It is imperative that future research seeks to optimize the methodologies and quantities for the application of these two organic amendments.

Keywords: Soil bulk density; Water holding capacity; CEC; Soil organic matter; Nutrient availability & uptake.

1. Introduction

Availability of nutrients and low soil moisture content are critical factors influencing crop yield in sandy soils (Liu et al., 2012). Additionally, extensive human activities have led to significant degradations in both soil quality and fertility (El-Naggar et al., 2019). Recycling organic waste may be a promising approach to restore or enhance soil fertility (Abbas et al., 2012; Farid et al., 2014; Ding et al., 2016), when properly processed into compost or biochar (Abdelhafez et al., 2017).

The application of compost and biochar considerably improves the physical and chemical characteristics of soils (Farid et al., 2018; Bassouny and Abbas, 2019; De Jesus Duarte et al., 2019), also mitigating the environmental impacts associated with the accumulation of organic waste (Coomes and Miltner, 2016). Compared to compost, biochar possesses relatively high stable organic carbon (Song et al., 2019) that remains in soils for extended periods, ranging from seven years (Giagnoni et al., 2019) to ten years (Kätterer et al., 2019). This stability is attributed mainly to the low availability of carbon to microbial communities, thereby reducing microbial activity (Fiorentino et al., 2019; Li et al., 2019) and contributes to decrease greenhouse gas emissions (Agegnehu et al., 2016; Clark et al., 2019; De Jesus Duarte et al., 2019).

Biochar is a carbon rich product through the pyrolysis of organic carbon in conditions of limited oxygen (Mohamed et al., 2018; Nguyen et al., 2019; Asaad et al., 2022; Lalarukh et al., 2022). Generally, the incorporation of organic materials into soils leads to notable enhancements in soil physical characteristics, including increased aggregate stability, reduced soil bulk density, and increased pore volume (Manivannan et al., 2009). Soil bulk density is the key indicator of how tightly soil particles are tightly compacted, in which soil bulk density exceeding 1.6 Mg m^{-3} possess a diminished ability to retain water and demonstrate elevated resistance to penetration by plant roots (Goadman and Ennos, 1998).

This study aligns with numerous United Nations Sustainable Development Goals (SDGs), including SDG 2 (Zero Hunger), SDG 12 (Responsible Consumption and Production), SDG 13 (Climate Action), and SDG 15 (Life on Land). It achieves these goals by advocating for sustainable soil management techniques, augmenting soil fertility, enhancing crop productivity, and aiding in the mitigation of climate change through the utilization of compost and biochar.

2. Effect of compost on soil bulk density and porosity

The incorporation of compost into soils has been widely recognized for its role in enhancing soil structure by increasing both micro and macro pore spaces (Miglerain et al., 2015). These aggregates have subsequently contributed to reductions in soil bulk density, especially at higher application rates (Brown and Cotton, 2011; Agegnnehu et al., 2016). For example, El Kamar (2008) noted that the application of 24 tons of compost per hectare led to a modest reduction in soil bulk density. Similarly, Wahdry et al. (2009) reported that addition of 29 tons per hectare of compost improved bulk density, total porosity, and saturated water content. Moreover, Blanco-Cancqui (2017) identified a 29–63% enhancement in soil structure and aggregate stability following compost application, with a corresponding decrease in soil bulk density of 0.7–2.3% and an increase in water holding capacity ranging from 34% to 50%. This is a critical factor in soil sustainability.

3. Effect of biochar on soil bulk density and porosity

Blanco-Conqui (2017) elucidated various mechanisms through which the application of biochar contributes to the reduction of soil bulk density. Primarily, biochar possesses a low bulk density of less than 0.6 g cm^{-3} in comparison to soil minerals, which have a bulk density of approximately 1.25 Mg m^{-3}. Consequently, mixing low-density biochar with soil minerals lowers the overall bulk density. In addition, biochar promotes aggregation of soil particles and increases soil porosity, both contribute to reductions in soil bulk density. This occurrence requires long-term monitoring to fully understand these changes. Furthermore, biochar exhibits notably high porosity, and its integration into soil substantially reduces bulk density, a change that can be credited to the increased volume of pore spaces (Mukheijee and Lal, 2013). For instance, biochar applications led to a 14.2% decrease in bulk density in coarse-textured soils, whereas only 9.20% reduction was observed in fine-textured ones (Liu et al., 2016). It is generally observed that biochar application resulted in a linear decrease in soil bulk density (Laird et al., 2010; Liu et al., 2016; Bassouny and Abbas, 2019). This reduction in bulk density can foster better root proliferation and promote plant growth (Atkinson et al., 2010).

In a meta-analysis, Omondi et al. (2016) noted that biochar application resulted in decline in bulk density ranging from 3% and 31% across 22 different soil types, illustrating a consistent pattern of reduced bulk density associated with the application of biochar. In contrast, Pratiwi and Shinogi (2016) found that a high biochar application rate of 50 Mg h^{-1} yielded no significant impact on bulk density.

Conversely, Puhringer (2016) noted a marked decrease in soil bulk density with increasing biochar rates, from 1 to 5 Mg ha^{-1}, where the lowest bulk density was recorded at the highest application rate of biochar (5 Mg ha^{-1}). Likewise, Xiao et al. (2016) reported significant reductions in soil bulk density with application of biochar at rates below 10 Mg ha^{-1}. Higher doses also, affected significantly soil bulk density as demonstrated by Berihun et al. (2017) who found significant decreases in bulk density at application rates of 12 and 18 Mg ha^{-1}, in which the highest effects were observed at the highest application rate, i.e. 18 Mg ha^{-1}.

4. Water holding capacity as affected by the soil application of organic amendments

Soil's water holding capacity (WHC) is defined as the maximum volume of water that soil can retain against gravitational forces. Soils with high WHC significantly need less frequent irrigation for the optimal growth of crops and vegetation, which is particularly beneficial for sustainable agriculture. A soil type that possesses a high capacity for water retention can considerably reduce the frequency of irrigation required. This advantageous characteristic is crucial for sustainable agricultural practices and plays significant roles in ensuring more consistent and adequate moisture availability for crops. Mixing soils with organic amendments, such as biochar, may enhance WHC by increasing soil porosity while improving soil structure. This, in turn, increases higher water retention and agricultural resilience under water-limited conditions.

4.1 Effect of compost on water holding capacity

Incorporation of compost into soils significantly enhances soil structure and increases water holding capacity through stimulating the activity of soil microorganisms, including bacterial slimes and fungal hyphae, specifically their byproducts increase aggregation of soil particles (Askin and Aygun, 2018). Numerous studies have indicated that the levels of organic matter present in the soil influence its water holding capacity, field capacity, and availability of water. For instance, Webery et al. (2003) found that incorporation of compost into soils led to a decrease in water loss while concurrently improving soil moisture retention and availability. Similarly, Brown and Cotton (2011) ascertained that compost application significantly contributes to the improvement of soil water holding capacity, especially in coarse textured soils. They further found that addition of compost affects the rates of soil infiltration, further contributing to efficient water utilization.

4.2 Effect of biochar on water holding capacity

Biochar exhibits a distinguishable higher porous structure and larger surface area than other organic amendments, allowing it to absorb more water on its surfaces. Furthermore, its stability enhances long-term soil aggregation and water retention capabilities (Mc-Elligoti et al., 2011). Thus, the addition of biochar has been demonstrated to improve field capacity (Dumroese et al., 2011), which in turn promotes enhanced plant growth and improves water efficiency (Alburquerque et al., 2014). However, the effects of biochar on water availability vary according to soil texture. In a clayey soil, Bayabil et al. (2015) and Blanco-Conque (2017) concurred that the introduction of biochar does not significantly influence the available water, while Kameyama et al. (2016) highlighted the positive effect of biochar on enhancing the availability of water. Conversely, de Jesus Duarte et al. (2019) observed that the application of biochar resulted in a reduction of available water.

In coarse textures, a higher and more uniform response was noticed for the application of biochar, resulting in significant improvements in WHC, while diminishing the requirements for frequent irrigation. This response can be ascribed to their significant impacts on increasing microporosity and extensive specific surface area (Blanco-Conque, 2017). The following findings substantiate the beneficial impact of biochar application on soil-water retention: Laird et al. (2010) reported that biochar-amended soil exhibited an increase in moisture content by 15% relative to the control. Uazomo et al. (2011) also noted a dramatic 97% enhancement in available water following biochar application. Burrell et al. (2016) indicated that straw derived biochar improved available water, while wood chip biochar showed negligible effects when being applied at equivalent amounts. Speratti et al. (2017) compared the effects of different agricultural biochars on soil water content and found that application of cotton biochar demonstrated the highest water retention capabilities, followed by swain manure, eucalyptus, and filter cake biochars- all of performed better than the control treatment.

5. Cation exchange capacity (CEC) as affected by the soil application of organic amendments

The cation exchange capacity (CEC) is a crucial indicator for assessing soil productivity and quality (Downi et al., 2009). This metric serves as an important pointer of soil fertility, as it plays a vital role in reducing the leaching of cations from plant root zones (Gamal, 2009), thereby improving the effectiveness of fertilizer application (Chan et al., 2008).

Organic amendments have been shown to significantly increase CEC due to their abundance of their functional groups (Agegnehu et al., 2014). According to Amlinger et al. (2007), the CEC values of organic materials typically range from 300 to 1400 cmolc kg^{-1}, values that are considerably higher than those of most mineral soils. Consequently, organic matter can account for 20–70% of the total CEC in various soil types, thus playing a vital role in improving overall soil productivity (Downie et al., 2009).

5.1 Effect of compost on cation exchange capacity (CEC)

Addition of compost into the soil system significantly raised soil CEC through augmentation of the organic carbon reservoir. This is primarily attributed to the negatively charged functional groups on organic residues, which facilitate retention and exchange of nutrients, thereby improving their accessibility to plants (Laird et al., 2010).

In a comprehensive study spanning five years, soil CEC increased by approximately 3-7% following compost application (Erhart and Hart, 2010). Likewise, Amadji et al. (2009) confirmed that applying 20 ton per hectare of compost to a sandy soil significantly boosted both CEC and concentrations of exchangeable cations, highlighting the potential of compost as an effective tool for increasing soil fertility, particularly in low-retentive, coarse-textured soils.

5.2 Effect of biochar on cation exchange capacity (CEC)

Biochar is characterized by a high cation exchange capacity (CEC), particularly when subjected to ageing. When biochar is incorporated into soil, biochar contributes additional negatively charged sorption sites, increasing the overall capacity of soils to retain cations (Major et al., 2009; Lee et al., 2010). In a 3 year field experiment, Hong-Xia et al. (2011) observed that the addition of biochar at a rate of 4500 kg h^{-1} led to an increase in CEC of the surface soil layer (0-15 cm) compared to the unamended control. Another investigation conducted by Shun et al. (2014) confirmed the significant rise in soil CEC, from 18.35 cmolc kg^{-1} in the control treatment to 25.33 cmolc kg^{-1} following biochar application. Additionally, Abrishmkesh et al. (2015) further validated these findings by identifying notable improvements in soil CEC resulting from biochar incorporation. In sandy soils, Gamage et al. (2016) found considerable increases in soil CEC when being added from 1 to 50 g kg. These changes were not only related to the elevated increases in biochar addition dose, but also to a range of factors, including soil pH, soil age, and the weathering characteristics of the biochar, as evidenced by the findings of Major et al. (2009) and Lee et al. (2010). Furthermore, Cheng et al. (2008) reported that aged biochar exhibited a greater capacity to increase CEC compared to fresh biochar. In this context, Lin et al. (2012) validated the assertion that the aging process of biochar is a critical determinant in its interaction with soil and the subsequent increase in sorption sites.

6. Soil pH as affected by the soil application of organic amendments

Compost is generally characterized by a neutral or slightly alkaline pH and its incorporation into soil can influence soil pH levels either by increasing or decreasing soil pH (Jonson et al., 2006). These variations are governed mainly by the balance between proton-releasing and proton-consuming processes. For instance, in alkaline soil environments, the incorporation of compost has been observed to lower soil pH, primarily due to the release of hydrogen ions (H^+) during nitrification, as well as the production of organic acids during decomposition (Rashad et al., 2011). Conversely, the application of compost to acidic soils has the potential to elevate pH levels (Agegnehu et al., 2014) , a result of ammonification and the consequent production of ammonia (NH_3), in addition to the release of alkaline cations, such as magnesium (Mg) and potassium (K), during organic matter mineralization (Hubbard et al., 2008; Agegnehu et al., 2014). Accordingly, compost serves to buffer (Jonson et al., 2006) or stabilize soil pH levels (Gamal, 2009; Sohi et al., 2009).

7. Effect of organic amendments on soil organic carbon

7.1 Effect of compost on soil organic carbon

Application of compost markedly improves levels of soil organic carbon (SOC (Bouajila and Snaa, 2011), which is attributed to the enhancement of stable organic carbon (Bouajila and Sana, 2011). These improvements can effectively reduce soil erosion or crusting, thereby facilitating water infiltration, and increasing water retention capability (Van Hute, 2014). According to Amlinger et al. (2007) propose that the typical soil organic matter requirements can be adequately met via the application of 7-10 Mg/h of compost.

In long term experiments, Lynch et al. (2006) observed that 19-34% of the total soil carbon (C) remained in the soil two years following the last application of compost. Additionally, Bouajila and Snaa (2011) reported an increase in SOC to 1.09% with compost application at 120 tons ha^{-1}, compared to 0.64% in the untreated control. Moreover, Sukatarono et al. (2011) noted that the incorporation of coconut compost into sandy soils increased soil organic matter content that persisted post-harvest. Agegnehu (2017) observed that addition of 25 metric tons of compost per hectare raised soil organic matter by 23%.

7.2 Effect of biochar on soil organic matter and soil organic carbon (SOC)

Incorporation of biochar into soils raises organic matter content and this, in turn, improve soil structure (Jurrgar et al., 2018). These enhancements may be attributed to the recalcitrant nature of biochar, which promote microbial decomposition, in addition to the physicochemical protection of the native soil organic carbon (SOC) This protective role reduces organic carbon loss and contributes to long-term carbon sequestration (Chan et al., 2008).

It is important to note that the stability of SOC is influenced by both the type of biochar used and the properties of the soil (Ndor et al., 2015). For example, Agegnehu (2017) found that applying 10- and 20-tons ha^{-1} of biochar increased SOC by 12.5% and 23.25%, respectively, compared to control soils. These findings emphasize the positive synergy impacts of biochar application and soil systems for improving soil fertility, carbon sustainability, and soil health (Jurgar et al., 2018). Based on the abovementioned effects of both compost and biochar on increasing soil fertility, Table 1 can summarize these impacts as follows:

Table 1. Comparative effects of compost and biochar on soil physical and chemical properties

Soil Property	Effect of Compost	Effect of Biochar
Bulk Density	Reduces bulk density, especially with high application rates	Reduces bulk density, more pronounced in coarse-textured soils
Porosity	Increases both micro- and macro-pore spaces	Increases porosity due to its high intrinsic pore volume
Water Holding Capacity (WHC)	Enhances WHC through organic matter and improved microbial activity	Enhances WHC, especially in sandy soils; effect varies in clayey soils
Cation Exchange Capacity (CEC)	Increases CEC via negatively charged functional groups in organic matter	Increases CEC through surface aging and formation of sorption sites
Soil pH	Buffers pH—can raise pH in acidic soils and slightly lower it in alkaline soils	Raises or stabilizes pH due to its generally alkaline nature
Soil Organic Carbon (SOC)	Increases SOC significantly; however, rapid microbial degradation limits its longevity	Increases SOC due to biochar's recalcitrant carbon structure and long-term stability

8. Nutrient availability and status in plants as affected by the soil application of organic amendments

Organic amendments-such as compost and biochar- have remarkable abilities to immobilize potentially toxic metals and remediate contaminated soils and water (Gameel et al., 2024; Gameel et al., 2025; Jahin et al., 2025). This beneficial action is largely due to their high adsorption capacity, as demonstrated in studies conducted by Abdelhafez et al. (2014 and 2016), Mohamed et al. (2018), and Wang et al. (2019). However, it is important to note that this mechanism may unintentionally interfere with nutrient availability, especially in arid soils, where nutrient scarcity is common therein due to limited soil moisture and low organic content.

8.1 Effect of compost on nutrients availability

Compost acts as a natural reservoir of essential plant nutrients, such as nitrogen (N), phosphorus (P), potassium (K), magnesium (Mg), and a variety of micronutrients, which are liberated into the soil in available forms to be utilized by plants upon microbial decomposition of organic substances (Agegnehu et al., 2014; Abbas et al., 2020; Hussein et al., 2022). Several studies confirm the positive impacts of compost on nutrient availability in various soil types. For instance, Awad et al. (2003) found that application of 24 Mg ha-1 of compost or biogas manure significantly raised the availability of N, P, and K as well as Fe, Mn, Cu, and Zn, in sandy soils of Wadi El Molak, Ismailia, Egypt. Also, El-Sedfy (2008) and El-Kamar (2008) reported enhancements in both soil macro- and micronutrients following compost application at rates of 14 to 19 tons ha^{-1}. Gamal (2009) observed that N, P, and K content in plants were correlated positively and significantly with the applied dose of compost, i.e. 0 to 12 tons per hectare.

According to Brown and Cotton (2011) and Sohi et al. (2009), soils amended with compost exhibited nutrient concentrations comparable to those found in soils treated with mineral fertilizers. Sunborn (2017) added that the addition of compost not only enhanced the levels of several nutrients, including P, K, Cu, Mg, Mn, and Zn, but also contributed positively to organic matter content and exchangeable capacity, further enhancing nutrient retention and availability.

8.2 Effect of biochar on the availability of soil nutrients

The application of biochar increased notably cation exchange capacity of soil, thereby facilitating the retention of nutrients in their bioavailable forms (Lehmann et al., 2003; Zhang et al., 2023), particularly in sandy soils, where nutrients were suspectable to be leached during irrigation (Steiner et al., 2008). It also functions as a slow-release fertilizer, ensuring prolonged nutrient supply over many growing seasons (Elshony et al., 2019; Abdelhafez et al., 2021; Tolba et al., 2021). These improved the efficiency of nutrient use biochar (Lehmann et al., 2009; Downie et al., 2009).

Han et al. (2016) conducted a study over a three-year experimental period and found that biochar application significantly elevated soil organic carbon, nitrate, ammonia and total nitrogen, while reducing phosphorus leaching. Similarly, Agegnehu (2017) found that the application of 10 tons of biochar per hectare significantly elevated the levels of soil organic carbon, total nitrogen, and available phosphorus and nitrogen (both nitrate and ammonium). Pandit et al. (2018) confirmed these improvements across two growing seasons.

Nevertheless, while many studies have emphasized the capacity of biochar to retain essential soil nutrients and enhance their availability in soils, including nitrogen, phosphorus, and potassium in forms readily accessible for plant absorption (Vaughn et al., 2015; Rens et al., 2018), others reported potential drawbacks for using biochar on nutrient availability. For example, Kim et al. (2015) found that biochar induced nitrogen deficiency in certain plant species, including lettuce. Furthermore, the alkalizing effect of biochar is considered another important factor in stabilizing potentially toxic elements (Wang et al., 2019), may paradoxically result in a diminished availability of phosphorus (Cerozi and Fitzsimmons, 2016) and micronutrients deficiencies (Rutkowska et al., 2014).

8.3 Effect of compost on plant nutrient concentrations

Application of compost enhances the availability of soil nutrients, thereby increases their uptake and accumulations within plant tissues (Lazcano et al., 2009). This phenomenon likely occurs due to nutrient release during decomposition of compost (direct effect), in conjunction with enhancements in soil microbial activities and improvements in soil structure and moisture retention (Nardi et al., 2001).

Hala and Osama (2006) discovered that the application of 14 tons of compost per hectare notably elevated concentrations of nitrogen (N), phosphorus (P), and potassium (K) in peanut plants. El-Kamar (2008) found similar improvements in N, P, K, Fe, Zn, and Mn in both wheat grains and peanut seeds after application of 24 tons ha^{-1}. Islam and Nahar (2012) observed enhanced uptake of N, P, K, Zn, Mn, Ca, and Mg in potato due to application of 30 tons ha^{-1} of compost. Lin et al. (2012) and Agegnehu (2017) likewise detected significant increases in N, P, and K concentrations in wheat, barley, and peanut crops following compost application.

8.4 Effect of biochar on plant nutrient contents and uptake

Numerous studies confirmed the advantageous effects of biochar in enhancing nutrient availability and concentrations within tissues of various crops such as maize grown in sandy soil (Liang et al., 2009). In a related study, Chan et al. (2008) noted that the uptake of nitrogen (N) by radish plants cultivated in soil amended with biochar was positively correlated with increasing the added rate of biochar, attributing this effect not only to the increases that occurred in nitrogen uptake but also to the effect of diminished nitrogen loss, thereby optimizing the efficacy of nitrogen fertilizer utilization. Major et al. (2009) noted significant improvements in the nutritional status of maize plants when biochar was applied under field conditions. Ismael et al. (2012) found that repeated biochar application raised leaf nitrogen content and overall crop productivity in Semsem fields. Likewise, Nigussie et al. (2012) found a substantial increase in the uptake of nitrogen, phosphorus, and potassium (NPK) by plants due to the addition of 15 tons per hectare of biochar.

Agegnehu et al. (2015) observed a marked increase in N, P and K contents in crops during the mid-growth stage owing to the introduction of biochar to sandy soil, though nitrogen alone was enhanced at the late growth stage. The combined application of compost and biochar yielded the most favorable nutrient uptake outcomes, indicating a synergistic effect between these two additives. In this aspect, Badr et al. (2015) found that biochar significantly increased N, P, K, and crude protein uptake in wheat, while Cheng-yuan et al. (2015) noted enhanced biological nitrogen fixation in peanut, leading to a 22–133% increase in nitrogen uptake. However, while biochar generally improves nutrient availability, its alkaline nature can diminish the productivity of arid soils, potentially leading to micronutrient deficiencies or reduced nutrient solubility (Khalil et al., 2023). To address this limitation, acid-modified biochar has emerged as a promising alternative, to achieve the United States' developmental objectives for sustainability (Abdel-Salam et al., 2025; Abuzaid et al., 2025)

9. Plant growth and productivity as affected by the soil application of organic amendments

9.1 Effect of compost on yield

Several studies have confirmed that compost applications can significantly boost crop yields, especially in poor fertile sandy soils. Hala and Osama (2006) reported that 15 Mg ha^{-1} of compost were enough to produce the optimal peanut seed yield when incorporated into sandy soil. They attributed these enhancements to the notable and significant improvements in soil chemical and physical properties, as well as the concurrent increases in plant-available nutrients. El-Kamar (2008) reported that applying 19 t ha^{-1} of compost led to yield increases by 144% for peanuts and 215% for wheat. Also, El-Sedfy (2008) indicated that the addition of 19 ton ha^{-1} of compost led to significant increases in both wheat and soybean yields. These results consistently highlight compost's role in enhancing soil fertility and crop performance. Likewise, Lazcano et al. (2009) and Oworu et al. (2010) noted the beneficial effects of compost on boosting crop yields, which were mostly attributed to enhanced nutrient uptake and improved soil water retention. Additionally, Erhart and Hart (2010) confirmed the role of its functional groups to retain nutrients within the topsoil; hence minimizing their losses via leaching from soil.

Laila (2011) found that the application of 12 and 16.6 ton ha^{-1} of compost raised maize yield by 102% and 107%, respectively. Van-Haute (2014) similarly observed that addition of compost substantially increased maize and bean yields. Naluyange et al. (2014) assessed the influence of water hyacinth compost on the growth and yield of common beans, revealing that its yield per unit area resulting from compost application surpassed that of the control treatment. Ali (2011) stated that the addition of 10 ton ha^{-1} of compost led to enhanced wheat and grain yields compared to the control treatment. Agegnehu (2017) concluded that the combined application of compost and biochar led to maize and peanut yield increases of 10–20% and 17–24%, respectively, underscoring the benefits of integrated organic inputs.

9.2 Effect of biochar application on crop yield

The effect of biochar application on agricultural productivity is multifaceted and mostly depends on a variety of factors, including the rate of application, biotechnological characteristics of biochar, soil properties, crop response, and agricultural management practices (Jeffery et al., 2011; Mukherjee and Lal, 2013). Explanations for the observed improvements in crop yields owing to application of biochars can be primarily attributed to (i) enhanced nutrient availability and increased nutrient use efficiency, as well as the (ii) favorable modifications in soil physical properties that support better root development and/or improve the retention of water and nutrients (Hossain et al., 2010; Jeffery et al., 2011; Farid et al., 2018). Antonio et al. (2013) highlighted that the incorporation of biochar into soil generally raised wheat grain production, even in the absence of mineral fertilizers, with yield increases ranging from 3% to 42%. The highest wheat grain yields were attained through the combined application of biochar and mineral fertilizers. Similarly, Haiying et al. (2013) demonstrated that both bamboo and wood biochars enhanced the growth and yield of wheat grown in sandy soils.

Biochar application could be significantly superior to other organic and inorganic fertilizers on plant growth (Alborquerque, 2014). Dil et al. (2014) documented that the introduction of biochar into a coarse-textured soil markedly enhanced maize biomass production. Ali (2011) found that the application of 25 and 50 tons per hectare of biochar significantly enhanced both the yield and quality of wheat grains, with a notable 38% increase in nitrogen content compared to control treatments.

Cheng-yuan et al. (2015) observed that biochar application improved peanut biomass and pod yield grown on both red ferrosol and redasi-hydroal soils. Moreover, Xiao et al. (2016) reported that the application of 30 tons per hectare of straw biochar led to significant increases in maize biomass, higher grain yields, and greater uptake of nitrogen, phosphorus, and potassium by plants than the control. They attributed the advantageous effects of biochar to its influence on soil chemical and physical properties, including increased porosity, higher soil organic carbon content, total soil nitrogen, and the availability of phosphorus and potassium.

10. The combination between compost and biochar and the experimental hypotheses

Combining biochar with composted organic materials is considered a highly sustainable approach for improving soil fertility and crop productivity. This synergistic combination enhances the benefits of both amendments, notably by increasing soil organic matter content, enriching nutrient availability, and improving water retention capacity, particularly in sandy soils (Liu et al., 2012; Wu et al., 2017; Farid et al., 2022). This advantageous combination substantially augments the efficacy of each amendment if applied solely (Wu et al., 2017), i.e. marked enhancement in soil organic matter content, elevating nutrient concentrations, and improving the water retention capability of sandy soil (Liu et al., 2012). Such improvements are thought to be essential for promoting healthier soil and fostering better plant growth and agricultural productivity.

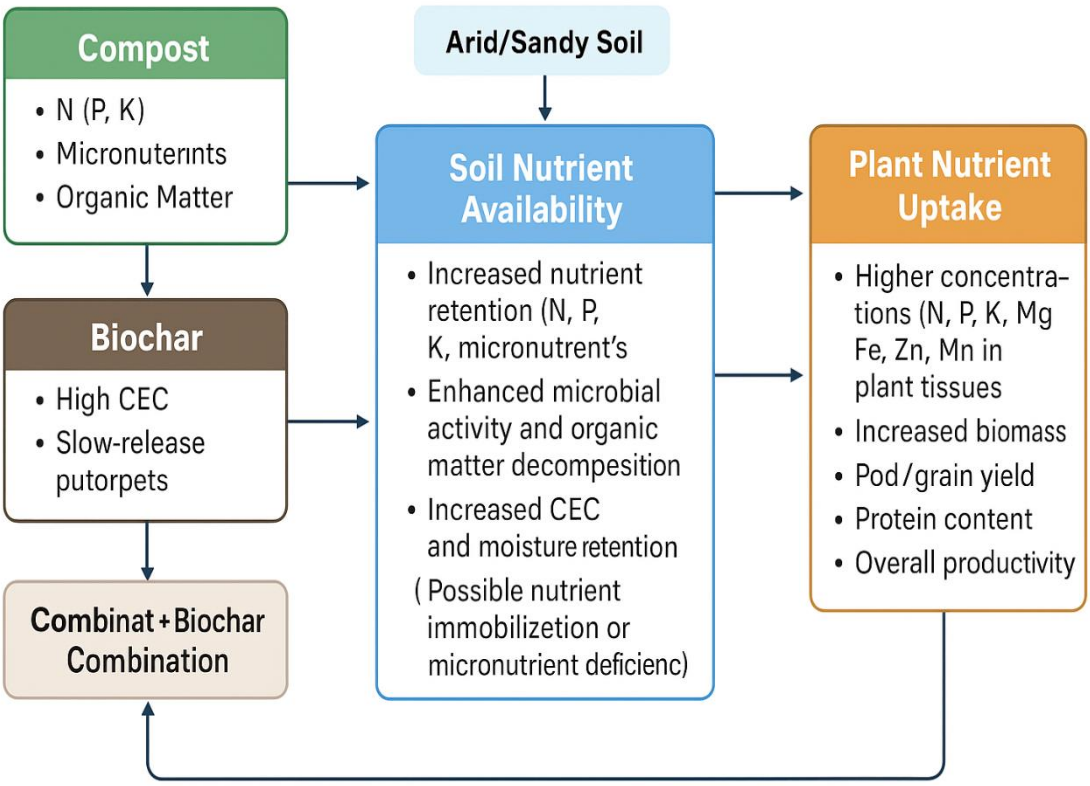

Figure 1. A flowchart diagram for the effects of both compost and biochar on soil fertility and productivity

Conclusion

Compost and biochar serve as critical amendments for improving physical and chemical characteristics of soil, thereby contributing substantially to the advancement of sustainable agricultural practices. Compost stimulates microbial activity and promotes nutrient cycling within the soil ecosystem, fostering improved soil fertility and biological function. However, compost is subject to rapid microbial degradation in soil, which necessitates frequent reapplications to maintain its beneficial effects and sustain soil productivity over time. Conversely, biochar offers a range of advantages, such as long-term carbon sequestration and significant improvements to soil structure, which can result in better water retention and increased nutrient availability. It is crucial that forthcoming research initiatives prioritize the optimization of application rates, specifically adjusted for various soil types and differing environmental conditions. Such an approach will be indispensable for fully realizing the myriad benefits that these amendments can provide in the sustainable enhancement of soil health and productivity.

Author Contributions

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Conceptualization, and supervision H.H.A., and M.H.H.A.; writing original draft, F.A., and M.E., reviewing and editing, I.M.F., and I.M. The final paper has been reviewed and approved by all authors.

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Conflicts of Interest

The authors declare no conflict of interest.

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