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Additional of Organic Amendments in the Soil to Increase the Various Crop Yield: A Review

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ABSTRACT

Agricultural production is threatened by the scarcity of current natural resources, an increasing total population, climatic change, and degraded soils. To feed the world's growing population, development strategies must be implemented that sustainably increase agricultural production while at the same time reducing the negative impacts of the activities. A number of amendments are currently being researched to improve the structure and fertility of soils. The properties of organic materials (biochar (BC), husk, and compost) were examined. The properties of BC have a large specific surface area, are highly porous, and have a high cation exchange capacity (CEC). These amendments could be used to slow down the continuous soil degradation and maintain soil productivity while facing global challenges. While the environmental effects have been extensively studied, the extent to which they can contribute to long-term intensification has yet to be determined. This review aims to contribute to the topic by providing a concise summary that combines both environmental evidence and agronomic considerations.

1. Introduction

Agriculture is the backbone of many industries and is a key to a nation's socio-economic growth as it is an essential element and factor in national development. The standards of living, sufficient food, housing, clean water, and a stable and safe atmosphere are the major issues to be secured [1]. Food security is also fundamental to human life and survival [2]. Agriculture is vital in countries' social and economic practices, including reducing poverty [3]. In the last 100 years, technological advances have given agriculture a new form. Previous research indicates that agricultural growth is closely related to poverty. Rural areas, populated mainly by low-income families, heavily depend on agriculture for living expenses [4].

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Unlike other economic practices, agriculture is fundamental to human life. For instance, food is crucial for living beings, and agriculture is the cornerstone of ecosystems in rural areas. Anything that happens to agriculture is not just an economic issue; there will be environmental, social, biological, ethical, and cultural consequences. There will be many losses in natural and cultural resources if agricultural production is continuously unsustainable. Therefore, essential policies that must be required for agriculture should be sustainable. In short, sustainable agriculture is a concept used to describe a cost-effective, ecologically sound, and responsible agricultural production practice [5].

Global food and feed demand were estimated to double in the 21st century, putting even more strain on land, water, and nutrients to be used [6]. The overall trend in global food security has seen a shift from shortages to surpluses in the second half of the last century, resulting in more food resources and reduced prices in the industrialized world [7]. By 2030, global food demand is expected to increase by half and cultivated land area by 10% (land required for biofuel production is omitted), assuming there will be a 40% yield increase for significant commodity crops [8]. Regarding low global stocks, crop failure because of inclement weather will induce immediate price reactions [9].

The global demand and consumption of crops, specifically fuel, feed, and food (3F), are experiencing significant growth. There has been an increase in the market for plant-based materials over the past few years [10]. A productivity increment on current agricultural land would also have ecological effects. Still, the negative impacts are typically cheaper and may be beneficial in certain situations depending on how the land was previously used [11]. Increased use of nitrogen fertilizers can affect water quality, increase the size of hypoxic zones, and increase nitrous oxide emissions, which are problems for both methods of raising output [12]. Further productivity increases could be accomplished on established agricultural land through conservation tillage or transgene pest management. Farmers can use conservation tillage to reduce erosion, stabilise moisture content, and increase soil nutrients [13]. The control of transgenic insects can reduce the use of broad-spectrum insecticides [14,15]. Technological innovations, including soil material amendments, have improved seed and fertilizer varieties, farming practices and global crop production [16].

Organic soil amendments can improve crop productivity, fertility, quality, and yield [17]. Soil fertility refers to the soil's ability to deliver the nutrients required for the plant's continued growth and development. There are many organic modification sources and forms that are used to enhance the consistency, fertility, and productivity of the soil. The addition of soil amendments may influence various observable soil properties. Soil modified with manure or compost exhibited higher EC values [18]. Using organic modifications or organic crop residues also increases organic matter in the soil [19]. Typically, in soils that have not undergone tillage practices, the capacity for retaining or storing soil water is generally greater [20]. Plant yield can also be increased by adding organic soil amendments. Soil modification is presumed to be able to rehabilitate soil degradation by increasing soil carbon content, surface area, and cation exchangeability [21-23]. Changes in soil physical characteristics can affect human adaptation to the environment because soil physical characteristics can have a direct effect on crop production and yield. The soil's physical properties also impact water penetration, soil erosion, and soil depletion [24]. It can be concluded that the organic additive in the soil will simultaneously enhance and conserve the soil condition and yield of plants.

2. The Need for Sustainable Agriculture Production: A Challenge in the Agriculture Sector

Sustainable agriculture has become a global concern that needs to be highlighted. With over 9 billion people to feed and provide energy by 2050, we urgently need to make the ways in which we use natural resources more sustainable [25]. The conservation or enhancement of natural resources in the sense of agriculture is another aspect of sustainable intensification [26] and increasing the availability of environmental resources while reducing the harmful effects [27]. A higher resource input than extensive systems is characterized by intensive agricultural methods. However, this form of intensification relies on heavily using fertilizers and pesticides for a few crops or monocultures [25]. Compared to natural biodiversity, limited biodiversity in heavy agricultural land-use settings may have resulted in the extinction of species or functional classes that are essential to ecosystem function [28]. Water shortages, decreased soil fertility, and climate change are all issues that agriculture faces, which also lead to environmental concerns such as the inefficient use of fertilizers [25]. By 2050, it is expected that the use of nitrogen fertilizers will double, significantly increasing environmental emissions [29]. Base cations are also degraded by intensive cultivation and the enormous use of nitrogen fertilizers and thus acidify soil [30], which negatively impacts soil fertility. Microorganisms' activities are affected by the changes in the soil's acidity due to alterations in organic matter decomposition, mineralization of nutrients, and immobilization [31].

The use of irrigation in agriculture has emerged as a critical area of discussion to effectively manage soil moisture levels because agriculture is the largest water consumer of all industries, and this consumption could be 1072 billion cubic meters by 2050 if trends in current crop production practise continue. In addition, more importance is given to developing crops requiring high water than crops requiring low water. There is also an urgent need to increase the quality of water usage or, more specifically, the productivity of water [32]. A sustainable water use strategy is essential in Indian agriculture to provide food security while conserving limited water resources; as a result, technologies that improve water use efficiency are widely used in the country [32]. The world is expected to need 70–100 percent more food to feed an estimated 9 billion people by 2050 [33]. Applying organic amendments to soil demonstrated its ability to retain soil moisture effectively. In addition, agriculture must address three interrelated challenges: maintaining food protection through rising revenue and production, adjusting to climate change, and contributing to climate change mitigation [34]. Agriculture must face three interrelated obstacles simultaneously: ensuring food protection through increased income and production, responding to climate change, and contributing to climate change mitigation [35-37]. This challenge will exacerbate global pressure on ordinary resources, especially water, and will require significant changes in our food classifications. To overcome these challenges, feeding systems must simultaneously be more reliable and versatile, from the farm level to the world level, at each level [35]. In reserve activity, they must evolve rapidly to be more capable of responding to various situations and circumstances. Over a third of Sudan's land area is eligible for agricultural improvement and development. To improve water and nutrient retention, educating farmers about the benefits of biochar farming is critical to enhance soil conditions and increase productivity [38].

3. Improving the Soil Condition and Yield by Organic Additive

Numerous soil additions are being utilized to improve the fertility of the soil and its structure, including husk, compost, and biochar (BC). These have been found to improve soil properties and plant production. Natural fertilizers perform critical functions that synthetic inorganic fertilizers cannot: they improve soil physical structure, raise organic matter content, stimulate fungal and bacterial activity, and minimize eutrophication (excess Nitrogen and Phosphorus in rivers and streams).

3.1 Organic

The term "organic" refers to fertilizers that contain nutrients derived from the remains or by-products of a once-living animal. Figure 1 shows the overall benefit of using organic soil amendments in agriculture. The farmers are constantly on the lookout for the substitution of traditional inorganic fertilizers to manage the rising expenses associated with rising energy and fertilizer costs, as well as the degradation of soil and surface water caused by the rigorous use and release of inorganic fertilizers such as nitrogen (N) and phosphorus (P). One of the advantages of organic fertilizers is that they supply nutrients to growing plants in a slow-release manner, particularly the essential nutrients nitrogen, phosphorus, and potassium (NPK). The soil must be sufficiently moist and warm for soil microbes to degrade and break down the organic fertilizers. The incorporation of biofertilizers into croplands, in general, utilizes renewable sources efficiently and reduces the necessity for inorganic synthetic fertilizers. Organic amendments often enhance soil structure, nutrient content, and microbial activity. This is because sugars and amino acids are present in organic compounds as simple molecules that contribute to microbiological activity and fertility and because soil microbes secrete many enzymes. The carbon, nitrogen, and phosphorus cycles are controlled by three enzymes that are measured in the rhizosphere region of the plant, described as the zone of high microbiological and enzymatic activities where the soil and the root meet, to ascertain the soil microbiological activity following soil alteration. The application of waste to soil (e.g., sewage treatment waste, poultry manure, horse manure, and cow dung) is advocated to resolve the disposal problem. Due to the importance of this waste as organic fertilizer, this practice is widespread in agricultural fields. Treatment I (3⁄4 NPK + 1⁄2 organic fertilizer) resulted in the highest intake of N, P, and K, i.e., 52.11mg plant^{-1}, 80.85mg plant$^{-1,}$ and 54.17mg plant^{-1}, respectively, and the highest intake of 400.15 g sweet corn, respectively [39]. Organic soil adjustments have frequently been employed to immobilize soil heavy metals (HMs) by altering speciation to considerably less bioavailable fractions related to carbonates (i.e., free metals), metal oxides, or organic matter (OM) [40,41].

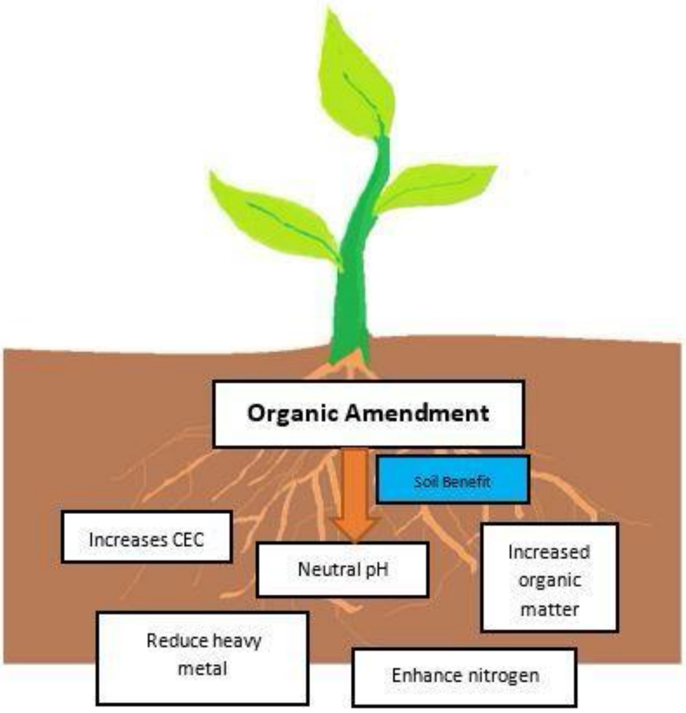

Fig. 1. Benefit of organic soil amendment

3.1.1 Biochar (BC)

Biochar is widely recognized as a highly desirable organic additive in agriculture. BC has a large specific surface area and a high porosity due to its high cation exchange capacity (CEC) [25]. The large surface area and porosity of biochar enable the absorption or retention of nutrients, contaminants, and water while also providing a home for beneficial microbes. Biochar is a substance that is formed through the process of pyrolysis, which involves the thermal breakdown of organic materials without the presence of air [41]. It is important to note that biochar differs from charcoal because it is primarily used as a soil amendment. The biochar properties are notably affected by the chemical composition of the feedstock and the pyrolysis temperature. This is because each feedstock possesses a distinct elemental makeup, leading to varying thermal degradation at different temperatures. The ash portion of biochar was typically composed of nutrients necessary for plant development, such as calcium (Ca), potassium (K), phosphorus (P), nitrogen (N), sulphur (S), magnesium (Mg), manganese (Mn), zinc (Zn), and iron (Fe) [41]. The solid, carbon-rich material obtained by pyrolysis using various biomasses is biochar. In biochar-treated soils, pH and CEC values were substantially more significant. With the application of biochar, the content of P and K increased. With the addition of straw biochar, the P content was raised in the treatments of straw biochar + regular chemical fertilizer (SCRF) and straw biochar + 70% regular chemical fertilizer (SC+70%RF) [42]. In the usage of BC, it was observed that the ratio of oxygen (O) to carbon (C) doubled as a result of soil extraction [42]. The capture of biochar nitrate can be a significant contribution to the overall retention of nitrate in biochar agroecosystems, which could avoid nitrate loss from agroecosystems and can be transformed into slow-release fertilizers to reduce the demand for global N fertilizer [43].

Characterizing the properties of biochar made from different types of biomasses in various production settings will help scientists learn more about how different types of biochar affect the properties of soil and the levels of nutrients in crops [41]. The utilization of BC was seen as an effective carbon neutralization technique resulting from carbon storage alone and the reduction of greenhouse gas emissions (GHG), including N_2O, CH_4, and CO_2. However, there were major variations in the implications of BC on each of the gases [44]. Several incubations and long-term field experiments showed a decrease in soil bulk density with biochar addition [45], and more recent studies [46] recorded a reduction in sandy loam soil bulk density with biochar addition. In addition, the author found that after two rising seasons, aggregate stability increased by 7-9 percent and 17–20 percent, respectively. The use of rice hull-derived biochar enhanced the percentage of water-stable aggregates by 36–69% [47]. The soil modification with biochar showed a notable increase in water-stable aggregate [48]. It was concluded from a literature study that alteration of soil with a biochar rate of around 2% weight per weight (w/w) seems to be effective in reducing soil bulk density [49]. There was an increment of specific surface area to 150 m^2g^{-1} when the biochar application rate was 0 to 20 $g.kg^{-1}$ [45]. Based on differing forms of contact with soil, aged biochar usually appears to have a higher surface area than newly added biochar [50].

Biochar incorporation recently enhanced water storing capacity by 11 percent and 14 percent at 22 t ha^{-1}; water holding capacity by 28 percent and 32 percent under the Thar Desert and Kubuqi soils compared to the control soil [51]. The BC's impact on soil chemical characteristics can be caused by:

i. increased CEC [52]
ii. heavy metal sorption [53]
iii. soil immobilization of organic and inorganic toxic compounds [54,55].

Biochar's most pronounced favourable effect was that it acted as a liming agent by increasing pH and decreasing exchangeable alumina (Al) in acidic soil [56]. In the meta-analysis, the greatest positive impact of biochar exists in acidic and neutral pH soils, and the minimal effect of biochar in soil is a driving mechanism and an improvement in crop yield [57]. More recently, several studies have confirmed the improvement of soil organic carbon and total nitrogen using biochar as a soil modification [58,59]. Several studies have shown that total N [60,61] can be enhanced by biochar modification. Biochar is a porous body in which pores are a soil microorganism habitat [62,63]. Biochar macropores (>200 nm) are the right size for bacteria and are likely to reflect most of the protected microbial habitats [62]. The extraction of lead (Pb) and atrazine from the aqueous solution of biochar derived from milk manure at a temperature of 500 °C has been accomplished [64]. With the removal of Pb and atrazine by up to 100 percent and 77 percent, respectively, the biochar showed strong adsorption potential for Pb and atrazine.

The feasibility of utilizing biochar for immobilising metal ions in degraded soil has been investigated [65]. The investigation on terbuthylazine sorption in soils supplemented with biochar revealed that the adsorption coefficient increased by 63 times and 2.7 times in the biochar-amended soils with high-temperature pyrolysis at 700 °C (BC700) and 500 °C (BC350), respectively. Radish production increased (up to 96%) following the administration of biochar generated from poultry manure in a greenhouse experiment, indicating that this higher yield was primarily due to the biochar's ability to boost N availability [67]. During the two rice/wheat rotations, seasonal applications of 4.5 t ha^{-1} and 9.0 t ha^{-1} biochar increased total rice/wheat crop biomass by 24.3% and 34.3%, respectively [68]. In some experiments, applying biochar did not boost maize yield or plant N uptake [69].

Employing the biochar reduced cadmium (Cd) and zinc (Zn) leachate contents by 300 and 45 times, respectively [70]. The pore structure of biochar and its large surface area plays a crucial role in its ability to retain water. This quality is important because it shows that biochar doesn't have a lot of water-soluble arsenic (As), cadmium (Cd), or zinc (Zn). This means biochar is safe for soil treatment and won't harm the environment. As a result, they concluded that sorption is an important factor for metal retention in BC. The utilization of chicken manure-produced biochar at a concentration of 5% (w/w) resulted in a significant reduction of 89% and 94% in the concentrations of extractable cadmium (Cd) and lead (Pb), respectively. On the other hand, biochar created from plant waste was reduced by 30% in the concentration of extractable Cd and 37% in the concentration of extractable Pb [71]. A study showed that adding hardwood-derived biochar to soil contaminated with various elements (Cd, Cu, Zn, and As) resulted in the mobilization of As and Cu. In contrast, Cd and Zn were immobilized [70]. In this work, a correlation was seen between the leaching of copper (Cu) and the presence of a high concentration of dissolved organic carbon (DOC) at a raised pH generated by biochar. Conversely, it was found that leaching was solely attributed to the increase in soil pH [71]. Biochar can also increase soil quality and efficiency because biochar's carbonates, oxides, and hydroxides would serve as liming agents when added to soil [72].

The chemical nature of BC is intensely aromatic, with the accompanying functional groups providing a net negative charge to the biochar particle's surface, which led to higher CEC, enhanced adsorption potential for both organic and inorganic chemicals, and improved nutrient retention [73]. Furthermore, BC is a low-density substance, which could lower the density of soil bulk [74], increasing soil aeration, water infiltration, the strength of aggregates, and root penetration [75]. Adding higher quantities of biochar to the soil improved the microbe environment, facilitating growth through increased porosity [76]. Biochar from some feedstocks (sewage sludge, municipal waste, and food waste) contains excessive Na content, which increases the salinity of the soil [77].

In the horticultural industry, the hot topic on the rise globally is to decrease or eliminate the employment of peat and seek environmentally and economically sustainable means of development. Biochar is an excellent alternative to peat and vermiculite in terms of primary nutrient supply and total biomass productivity [78,79]. BC has recently experimented on a soilless fertigation substrate, where substantial improvements have been observed in the yield of pepper and tomato [80] at rates of 1% and 5% of wood-based biochar, respectively. The strawberry plants' biochar (1% or 3% biochar-amended potting mixture) prevented fungal diseases [81].

In China, cultivating rice paddies (Oryza sativa L., cv Wuyunjing 7) resulted in varying yields of 10 and 40 tonnes per hectare. It was shown that these yields had a maximum increase of 14% under the highest application rate, specifically in the absence of nitrogen [82]. Rice straw-derived biochar pyrolyzed for 2 to 8 hours at 250°C - 400°C with 1% NPK improved maize yield by 146% in the presence of NPK and 64% in the absence [83]. Soil pH was increased from 4-4.5 to 6.0-6.5 due to the addition of biochar [84]. The use of biochar derived from maize fields resulted in a significant increase in maize yields [85]. The pyrolysis of radish was conducted at two different temperatures, namely 450°C and 550°C, and the application rates varied from 0 to 50 t/ha, with an additional 100 kg N/ha. The results showed that the yield of radish without adding nitrogen was 42% at an application rate of 10 t/ha, while it increased to 96% at an application rate of 50 t/ha [86]. While radish (*Raphanus sativus*) as a biochar product is a green waste, when applied at 10 - 100 t/ha, the rate of nitrogen application is increased by 280 percent (100 $kgha^{-1}$) compared to 95 percent without biochar [87]. Biochar's effects on bioavailability and heavy metal transport have received much attention [88,89].

Research points to improving biological nitrogen fixation and helpful mycorrhizal relationships in widespread beans (Phaseolus vulgaris) by biochar application [90,91]. The reasons for the rise in biological nitrogen fixation with adding biochar are not fully understood. However, potential explanations include the lower availability of nitrogen in the soil due to the high carbon-to-nitrogen ratio of the biochar, which leads to nitrogen immobilization. Additionally, the availability of nutrients other than nitrogen, such as phosphorus, potassium, calcium, magnesium, or micronutrients, may also play a role. In Brazil, the incidence of local plant species increased by 63% in areas where biochar was used [92]. Several studies have shown that after its combination with soil, the properties of biochar most essential for plant cultivation will improve over time [93,94]. Laboratory studies using modern methods show that biochar has a mean soil residence time of several thousand years [93]. The effects of biochar on soil alteration and fertilization were evaluated by evaluating the increase in pH and soil organic carbon. Results showed a limited yet statistically significant contribution to improving soil properties from biochar application [95].

Biochar from various feedstocks has had a beneficial influence on soil fertilization [96]. Among the biochar feedstocks considered, cow manure biochar applied at a rate of between 10 and 20 t/ha [97] and poultry litter biochar [98] had the strongest (significant) positive impact. Biochar from rice residues was found to be beneficial in rice-based systems based on a long-term analysis, but the actual effect on soil fertility and organic carbon was dependent on site-specific conditions [99]. The efficiency of biochar application practices is generally location-dependent and not applicable to all geographic zones, and climatic conditions [100] change with the biochar modification pH, especially in the long term [101,102]. Biochar modifications have increased the organic carbon of the soil (SOC) and total nitrogen [103].

With 90 g/kg biochar applied to soil, the proportion of N derived from biological N fixation increased significantly from 50 percent without biochar additions to 72 percent [101]. In addition to the decrease in overall N and P discharge, biochar-containing soils showed increased water retention and improved runoff water characteristics due to excellent biochar water uptake and CEC capabilities [104]. Biochar is made by pyrolysis from biomass and applied to the soil for improved soil health and the productivity of crops. Modified soil properties have been shown through biochar application, e.g., increased soil pH and soil electrical conductivity (EC) [105]. Adsorbing Na^+ properties and reduced soil electrical conductivity (EC) have also been shown by biochar modifications [106,107].

Several studies have shown increased organic matter, total organic carbon, and soil water-holding ability with biochar modification [108,109]. The stability of organic carbon generated during the process of biochar production renders it a promising soil amendment for enhancing soil quality and sequestering carbon. In addition to biochar, soil increased some plant growth and yield characteristics such as plant height [110], leaf number [110], crop yield [111], final mass [110], crop productivity and growth, and also increased chlorophyll content [112,113]. However, these effects of biochar are inconsistent, depending mainly on the types of biochar, crop, type of soil, and trial conditions [114]. Table 1 summarises the advantages of biochar in agriculture.

Table 1
Summary of the advantages of biochar in agriculture

Organic amendment	Highlights	References
Biochar	Phosphorus (P) and Potassium (K) content was increased.	[42]
	As slow-release fertilizers to reduce the demand for global N fertilizer.	[43]
	Effective carbon neutralization technique.	[44]
	Decreases in sandy loam soil bulk density with biochar addition.	[46]
	Enhanced the percent of water-stable aggregates.	[47]
	A notable increase in water stable aggregate.	[48]
	To reduce soil bulk density.	[49]
	Enhanced water storing	[51]
	Increased Cation exchange capacity (CEC)	[52]
	Heavy metal sorption.	[53]
	Soil immobilization of organic and inorganic toxic compounds.	[54,55]
	Neutral pH soils	[57]
	Enhance total nitrogen	[60,61]
	Ability to extract Pb and atrazine from the aqueous solution	[64]
	The suspension of metal ions in damaged soil.	[65]
	Increase the yield and ability to boost N availability.	[67]
	Reduced Cd and Zn leachate.	[70]
	Liming agents.	[72]
	Improved nutrient retention.	[73]
	Strength of aggregates and root penetration.	[75]
	Increase microbe environment, facilitating growth through increased porosity.	[77]
	Increase the total biomass productivity.	[78,79]
	Improvements in the yield of pepper and tomato	[80]
	Effects on bioavailability and heavy metal	[88,89]
	Fixation of nitrogen and helpful mycorrhizal relationships in widespread beans (Phaseolus vulgaris)	[90,91]
	Increase in biological N fixation.	[101]
	Increased soil pH and EC.	[105]
	Increased organic matter, total organic carbon, and soil water	[108,109]
	Increased some plant growth and yield characteristics such as plant height, leaf number, crop yield, final mass, crop productivity	[110,111]
	Increased chlorophyll content [112,113].	[112,113]

3.1.2 Husk

In applying husk amendment to soil, the highest plant height was achieved with a mixture of decayed Jatropha husk and NPK fertilizer applied at a 50:50 ratio [115]. In the first crop cycle, there was a 32.81 percent rise in biomass with a 25 t/ha application rate relative to the control. However, plant biomass was significantly reduced for all therapies and any parameter calculated in the second cropping cycle [116]. The findings indicated that the use of rice husk biochar could be used in Guyana to improve the soil quality of marginal soils [116]. Compared to control plants treated with uncomposted organic fertilizer, there was a substantial improvement in the growth and biochemical parameters of the plants [117]. The results differ from the microbial treatments used in T-composted rice husk composting: *T. Hamatum* (JUF1), *bradyrhizobium sp-II* (JUR2) alone, and JUF1 in combination with *Rhizobium sp-I* (JUR1) are successful in elongating the shoot and root length, increasing sunflower plant mineral (nitrogen and phosphorus) quality, carbohydrate, total chlorophyll and crude protein [117]. Soil water retention and urea release rates have enhanced plant growth due to the addition of superabsorbent composite (SAC). Applying 11.9% of crop water requirements (CWR) with one wt% SAC produced better crop production than non-SAC [118].

Biochar application also reduced the exchangeable aluminium (Al) and soluble iron (Fe), soil strength, and soil bulk density while increasing the exchangeable K and Ca, available soil water content, soil pH, porosity, CEC, C-organic, and available P. Of these changes, rice biomass was substantially affected only by exchangeable Al, soluble Fe, phosphorus, soil carbon, and soil strength [119]. The highest maize yield was found when biochar and rice husk charcoal were applied at a dose of 6–9 t/ha. The results of this study indicated that biochar and husk charcoal could be used to increase acid soil fertility and productivity as an alternative liming material [120].

3.1.3 Compost

In compost application, the single recommended nitrogen phosphate (NP) and the combined use of 50 percent vermicompost have substantially increased barley's grain yield and biomass yield [121]. Mean grain yields of 2567 kg/ha and 2549 kg/ha for barley were obtained by applying 50:50 conventional compost and vermicompost on the basis of N equivalence with the recommended NP fertilizer rate, which significantly reduces the cost of chemical NP fertilizer required for barley output [121]. Soil modifications affected soil properties and crop growth, with compost modifications increasing soil pH, organic matter, and multiple nutrient concentrations, as well as the emergence and yield of crops compared to fertilizer-only treatments. Compost treatment also decreased the infestation and harm caused by bean mites in 2018 [122]. It provides organic matter and nutrients to the soil, enhances soil texture and water retention ability, and suppresses plant diseases with the help of beneficial microorganisms. Many researchers seek to improve compost quality at a reduced cost by reducing the process and length of composting. The composting process also provides the co-benefit of a reduced environmental impact, ideally [123]. To enhance soil quality, all compost amendments were found. The plant development was supplied by nutrient-rich, manure-based composts, but high concentrations of N and P were also leached. Without excess nutrient loss, some therapies have produced adequate nutrients for plant growth. The composts derived from manure, which are abundant in nutrients, exhibited the most substantial enhancement in plant development [124].

When compared to the amount of biowaste compost (BWC) applied, there was a significant increase in soil organic matter (SOM) and soil organic carbon (SOC). This rise lasted 120 days before SOM and SOC levels started to fall. The findings revealed that the treated soils had higher microbiological activity than the control soils [125]. Walker *et al.,* reportedly discovered that applying manure reduced the amounts of metals lead (Pb), Copper (Cu), and Zinc (Zn) in *Chenopodium album L.* plant tissue [126]. Compared to plants growing in either compost-treated or control soil, the higher soil pH was mostly due to manure application. The use of plant-based waste compost reduced nutrient absorption of Zn, Pb, and Cu in Greek Cress by 16, 54, and 21 in calcareous polluted soils, respectively [127]. Compost treatment substantially reduced more than half of wheat Cadmium (Cd) toxicity by reducing wheat tissue Cd uptake and thereby enhancing wheat growth [128]. For example, some reports suggest that the addition of compost to damaged soils can potentially increase the mobility of certain metals (loids), particularly Arsenic (As) [129].

The solubility of metals, the absorption and flow of plant nutrients, the development of plants, active microbes, and a slew of other features and reactions are all influenced by soil pH [130]. The addition of organic-based compost and manure to soil increases soluble organic carbon, microbial biomass carbon [131], a variety of microorganisms such as bacteria [132], soil respiration [133], and the operation of various soil enzymes [134]. Compost is commonly used to enhance soil quality as an organic amendment. Extensive compost studies have shown a complex influence on the production of soils and plants. Compost-modified soil showed increased soil pH and EC [135,136]. Organic materials are also capable of decreasing the pH of the soil, as organic material mineralization produces organic acids [137]. The addition of compost usually contributes to enhanced soil organic matter and soil function due to an increment in water storage capacity [138]. Several studies have shown that compost benefits crop yield and plant efficiency [139].

4. Conclusions

Advancement can be beneficial agronomically but harmful to the environment, or vice versa. A diverse strategy is required to create solutions combining economic success with ecological soundness to work sustainably. The same may be applied to soil amendments, whose consequences must be addressed both environmentally and agronomically. This paper covers the organic additions (biochar, husk, and compost). The porous amendments biochar has a high CEC. Biochar lowers heavy metal contamination in soils and GHG emissions from soils by enhancing nutrient delivery to plants and water-holding capacity. The biochar also boosts crop yields in tropical, acidic soils. Its principal benefit in temperate soils is to reduce greenhouse gas emissions and fertilizer costs. If biochar is produced locally or as a by-product of other processes, it has a lot of potential for economically effective purchase. All amendments have an effect based on the circumstances in which they are implemented. Rainfall, application rates, and application times must all be considered.

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References

[1] Qurat-ul-ain Mastoi, Istikoma, and Abdul Rahman Ahmad Dahlan. "Agro-tech in Malaysia and Literature Review Knowledge Sharing from Agro-Technology Using Nations."

[2] Akinboyo, O. L. "Five decades of agricultural policies: What role has statistics played." *CBN Bullion* 32, no. 1 (2008): 134-165.

[3] Lawal, Wahab A. "An analysis of government spending on agricultural sector and its contribution to GDP in Nigeria." *International Journal of Business and Social Science* 2, no. 20 (2011).

[4] Ghatak, Shambhu. "What has the World Development Report 2008 to say about Indian agriculture?." *Development in Practice* 20, no. 1 (2010): 131-137. https://doi.org/10.1080/09614520903456388

[5] Murad, Wahid, Nik Hashim Nik Mustapha, and Chamhuri Siwar. "Review of Malaysian agricultural policies with regards to sustainability." (2008). https://doi.org/10.3844/ajessp.2008.608.614

[6] Spiertz, J. H. J., and F. Ewert. "Crop production and resource use to meet the growing demand for food, feed and fuel: opportunities and constraints." *NJAS: Wageningen Journal of Life Sciences* 56, no. 4 (2009): 281-300. https://doi.org/10.1016/S1573-5214(09)80001-8

[7] Thornton, Philip K. "Livestock production: recent trends, future prospects." *Philosophical Transactions of the Royal Society B: Biological Sciences* 365, no. 1554 (2010): 2853-2867. https://doi.org/10.1098/rstb.2010.0134

[8] Popp, Jozsef, Zoltán Lakner, Mónika Harangi-Rákos, and Miklos Fari. "The effect of bioenergy expansion: Food, energy, and environment." *Renewable and sustainable energy reviews* 32 (2014): 559-578. https://doi.org/10.1016/j.rser.2014.01.056

[9] Chatzopoulos, Thomas, Ignacio Pérez Domínguez, Matteo Zampieri, and Andrea Toreti. "Climate extremes and agricultural commodity markets: A global economic analysis of regionally simulated events." *Weather and Climate Extremes* 27 (2020): 100193. https://doi.org/10.1016/j.wace.2019.100193

[10] Edgerton, Michael D. "Increasing crop productivity to meet global needs for feed, food, and fuel." *Plant physiology* 149, no. 1 (2009): 7-13. https://doi.org/10.1104/pp.108.130195

[11] Tilman, David, Kenneth G. Cassman, Pamela A. Matson, Rosamond Naylor, and Stephen Polasky. "Agricultural sustainability and intensive production practices." *Nature* 418, no. 6898 (2002): 671-677. https://doi.org/10.1038/nature01014

[12] Donner, Simon D., and Christopher J. Kucharik. "Corn-based ethanol production compromises goal of reducing nitrogen export by the Mississippi River." *Proceedings of the National Academy of Sciences* 105, no. 11 (2008): 4513-4518. https://doi.org/10.1073/pnas.0708300105

[13] Lal, Rattan. "Soil carbon sequestration impacts on global climate change and food security." *science* 304, no. 5677 (2004): 1623-1627. https://doi.org/10.1126/science.1097396

[14] Qaim, Matin, and David Zilberman. "Yield effects of genetically modified crops in developing countries." *Science* 299, no. 5608 (2003): 900-902. https://doi.org/10.1126/science.1080609

[15] Cattaneo, Manda G., Christine Yafuso, Chris Schmidt, Cho-ying Huang, Magfurar Rahman, Carl Olson, Christa Ellers-Kirk *et al.,* "Farm-scale evaluation of the impacts of transgenic cotton on biodiversity, pesticide use, and yield." *Proceedings of the National Academy of Sciences* 103, no. 20 (2006): 7571-7576. https://doi.org/10.1073/pnas.0508312103

[16] Najafi, Ehsan, Naresh Devineni, Reza M. Khanbilvardi, and Felix Kogan. "Understanding the changes in global crop yields through changes in climate and technology." *Earth's Future* 6, no. 3 (2018): 410-427. https://doi.org/10.1002/2017EF000690

[17] Al-Busaidi, Waleed, Mumtaz Khan, Rhonda Janke, Mohammed Al-Sheriqi, and Rashid Al-Yahyai. "Efficacy of soil amendments in organic farming systems." *Agrociencia* 54, no. 1 (2020): 1-31.

[18] Loper, Shawna, Amy L. Shober, Christine Wiese, Geoffrey C. Denny, Craig D. Stanley, and Edward F. Gilman. "Organic soil amendment and tillage affect soil quality and plant performance in simulated residential landscapes." *HortScience* 45, no. 10 (2010): 1522-1528. https://doi.org/10.21273/HORTSCI.45.10.1522

[19] Hannachi, N., Stefania Cocco, F. Fornasier, A. Agnelli, Giorgia Brecciaroli, L. Massaccesi, D. Weindorf, and Giuseppe Corti. "Effects of cultivation on chemical and biochemical properties of dryland soils from southern Tunisia." *Agriculture, Ecosystems & Environment* 199 (2015): 249-260. https://doi.org/10.1016/j.agee.2014.09.009

[20] Bello, O. S., M. G. Solomon, and O. A. Iyapo. "The effects of over cultivation on some soil properties, nutrients response and yields of major crops grown on acid sand soils of Calabar South-Southern part of Nigeria." In *2010 19th World Congress of Soil Science, Soil Solutions for a Changing World*, pp. 1-6. 2010.

[21] Darusman, Darusman, Devianti Devianti, and Edi Husen. "Improvement of soil physical properties of cambisol using soil amendment." *Aceh International Journal of Science and Technology* 7, no. 2 (2018): 93-102. https://doi.org/10.13170/aijst.7.2.10119

[22] Sohi, Saran P., Evelyn Krull, Elisa Lopez-Capel, and Roland Bol. "A review of biochar and its use and function in soil." *Advances in agronomy* 105 (2010): 47-82. https://doi.org/10.1016/S0065-2113(10)05002-9

[23] Barrow, C. J. "Biochar: potential for countering land degradation and for improving agriculture." *Applied Geography* 34 (2012): 21-28. https://doi.org/10.1016/j.apgeog.2011.09.008

[24] Blanco-Canqui, Humberto, and Sabrina J. Ruis. "No-tillage and soil physical environment." *Geoderma* 326 (2018): 164-200. https://doi.org/10.1016/j.geoderma.2018.03.011

[25] Keiblinger, Katharina Maria, and Rosana Maria Kral. "Sustainable intensification of agricultural production: A review of four soil amendments." *Die Bodenkultur: Journal of Land Management, Food and Environment* 69, no. 3 (2018): 141-153. https://doi.org/10.2478/boku-2018-0013

[26] Pretty, Jules N. "The sustainable intensification of agriculture." In *Natural resources forum*, vol. 21, no. 4, pp. 247-256. Oxford, UK: Blackwell Publishing Ltd, 1997. https://doi.org/10.1111/j.1477-8947.1997.tb00699.x

[27] Schiefer, Jasmin, Georg J. Lair, and Winfried EH Blum. "Potential and limits of land and soil for sustainable intensification of European agriculture." *Agriculture, Ecosystems & Environment* 230 (2016): 283-293. https://doi.org/10.1016/j.agee.2016.06.021

[28] Bender, S. Franz, Cameron Wagg, and Marcel GA van der Heijden. "An underground revolution: biodiversity and soil ecological engineering for agricultural sustainability." *Trends in ecology & evolution* 31, no. 6 (2016): 440-452. https://doi.org/10.1016/j.tree.2016.02.016

[29] Galloway, James N., Alan R. Townsend, Jan Willem Erisman, Mateete Bekunda, Zucong Cai, John R. Freney, Luiz A. Martinelli, Sybil P. Seitzinger, and Mark A. Sutton. "Transformation of the nitrogen cycle: recent trends, questions, and potential solutions." *Science* 320, no. 5878 (2008): 889-892. https://doi.org/10.1126/science.1136674

[30] Tian, Dashuan, and Shuli Niu. "A global analysis of soil acidification caused by nitrogen addition." *Environmental Research Letters* 10, no. 2 (2015): 024019. https://doi.org/10.1088/1748-9326/10/2/024019

[31] Fageria, N. K., and V. C. Baligar. "Ameliorating soil acidity of tropical Oxisols by liming for sustainable crop production." *Advances in agronomy* 99 (2008): 345-399. https://doi.org/10.1016/S0065-2113(08)00407-0

[32] Girijaveni, V., K. Sammi Reddy, K. L. Sharma, and G. Moulika. "Zeolites are emerging soil amendments for improving soil physical and chemical properties in agriculture: A Review." *International Journal of Agriculture, Environment and Biotechnology* 11, no. 6 (2018): 841-849. https://doi.org/10.30954/0974-1712.12.2018.5

[33] Chen, Yongshan, Marta Camps-Arbestain, Qinhua Shen, Balwant Singh, and Maria Luz Cayuela. "The long-term role of organic amendments in building soil nutrient fertility: a meta-analysis and review." *Nutrient Cycling in Agroecosystems* 111 (2018): 103-125. https://doi.org/10.1007/s10705-017-9903-5

[34] Singh, Balwant, Lynne M. Macdonald, Rai S. Kookana, Lukas van Zwieten, Greg Butler, Stephen Joseph, Anthony Weatherley *et al.,* "Opportunities and constraints for biochar technology in Australian agriculture: looking beyond carbon sequestration." *Soil research* 52, no. 8 (2014): 739-750. https://doi.org/10.1071/SR14112

[35] Shareef, Tawheed Mohammed Elhessin, and Baowei Zhao. "The fundamentals of biochar as a soil amendment tool and management in agriculture scope: an overview for farmers and gardeners." *Journal of Agricultural Chemistry and Environment* 6, no. 1 (2016): 38-61. https://doi.org/10.4236/jacen.2017.61003

[36] Beddington, John R., Mohammed Asaduzzaman, Megan E. Clark, Adrian Fernández Bremauntz, Marion D. Guillou, Molly M. Jahn, Erda Lin *et al.,* "The role for scientists in tackling food insecurity and climate change." *Agriculture & Food Security* 1, no. 1 (2012): 1-9. https://doi.org/10.1186/2048-7010-1-10

[37] Delzeit, Ruth, Kacana Sipangule, and Rainer Thiele. "Achieving food security in the face of climate change." (2015).

[38] Schmidt-Rohr, Klaus, and Hans Wolfgang Spiess. *Multidimensional solid-state NMR and polymers*. Academic Press, 1994.

[39] Sofyan, E. T., D. S. Sara, and Y. Machfud. "The effect of organic and inorganic fertilizer applications on N, P-uptake, K-uptake and yield of sweet corn (Zea mays saccharata Sturt)." In *IOP Conference Series: Earth and Environmental Science*, vol. 393, no. 1, p. 012021. IOP Publishing, 2019. https://doi.org/10.1088/1755-1315/393/1/012021

[40] Lwin, Chaw Su, Byoung-Hwan Seo, Hyun-Uk Kim, Gary Owens, and Kwon-Rae Kim. "Application of soil amendments to contaminated soils for heavy metal immobilization and improved soil quality—A critical review." *Soil science and plant nutrition* 64, no. 2 (2018): 156-167. https://doi.org/10.1080/00380768.2018.1440938

[41] Muhammad Irfan, Rafiullah, Farah Naz Kaleri, Muhammad Rizwan, and Imran Mehmood. "Potential value of biochar as a soil amendment: A review." *Pure and applied biology (PAB)* 6, no. 4 (2017): 1494-1502. https://doi.org/10.19045/bspab.2017.600161

[42] He, Li-li, Zhe-ke ZHONG, and Hui-min YANG. "Effects on soil quality of biochar and straw amendment in conjunction with chemical fertilizers." *Journal of Integrative Agriculture* 16, no. 3 (2017): 704-712. https://doi.org/10.1016/S2095-3119(16)61420-X

[43] Hagemann, Nikolas, Claudia I. Kammann, Hans-Peter Schmidt, Andreas Kappler, and Sebastian Behrens. "Nitrate capture and slow release in biochar amended compost and soil." *PloS one* 12, no. 2 (2017): e0171214. https://doi.org/10.1371/journal.pone.0171214

[44] Xie, Tao, Bala Yamini Sadasivam, Krishna R. Reddy, Chengwen Wang, and Kurt Spokas. "Review of the effects of biochar amendment on soil properties and carbon sequestration." *Journal of Hazardous, Toxic, and Radioactive Waste* 20, no. 1 (2016): 04015013. https://doi.org/10.1061/(ASCE)HZ.2153-5515.0000293

[45] Laird, David, Pierce Fleming, Baiqun Wang, Robert Horton, and Douglas Karlen. "Biochar impact on nutrient leaching from a Midwestern agricultural soil." *Geoderma* 158, no. 3-4 (2010): 436-442. https://doi.org/10.1016/j.geoderma.2010.05.012

[46] Obia, Alfred, Jan Mulder, Vegard Martinsen, Gerard Cornelissen, and Trond Børresen. "In situ effects of biochar on aggregation, water retention and porosity in light-textured tropical soils." *Soil and Tillage Research* 155 (2016): 35-44. https://doi.org/10.1016/j.still.2015.08.002

[47] Kim, Hyuck-Soo, Kwon-Rae Kim, Jae E. Yang, Yong Sik Ok, Gary Owens, Thomas Nehls, Gerd Wessolek, and Kye-Hoon Kim. "Effect of biochar on reclaimed tidal land soil properties and maize (Zea mays L.) response." *Chemosphere* 142 (2016): 153-159. https://doi.org/10.1016/j.chemosphere.2015.06.041

[48] Liu, Zuxiang, Xiaomin Chen, Yan Jing, Qiuxia Li, Jiabao Zhang, and Qianru Huang. "Effects of biochar amendment on rapeseed and sweet potato yields and water stable aggregate in upland red soil." *Catena* 123 (2014): 45-51. https://doi.org/10.1016/j.catena.2014.07.005

[49] Mukherjee, Atanu, and Rattan Lal. "Biochar impacts on soil physical properties and greenhouse gas emissions." *Agronomy* 3, no. 2 (2013): 313-339. https://doi.org/10.3390/agronomy3020313

[50] Mukherjee, A., A. R. Zimmerman, and W. Harris. "Surface chemistry variations among a series of laboratory-produced biochars." *Geoderma* 163, no. 3-4 (2011): 247-255. https://doi.org/10.1016/j.geoderma.2011.04.021

[51] Laghari, Mahmood, Muhammad Saffar Mirjat, Zhiquan Hu, Saima Fazal, Bo Xiao, Mian Hu, Zhihua Chen, and Dabin Guo. "Effects of biochar application rate on sandy desert soil properties and sorghum growth." *Catena* 135 (2015): 313-320. https://doi.org/10.1016/j.catena.2015.08.013

[52] Liang, Biqing, Johannes Lehmann, Dawit Solomon, James Kinyangi, Jonathan Grossman, B. J. O. J. F. J. J. E. G. O'Neill, Jan O. Skjemstad *et al.,* "Black carbon increases cation exchange capacity in soils." *Soil science society of America journal* 70, no. 5 (2006): 1719-1730. https://doi.org/10.2136/sssaj2005.0383

[53] Freddo, Alessia, Chao Cai, and Brian J. Reid. "Environmental contextualisation of potential toxic elements and polycyclic aromatic hydrocarbons in biochar." *Environmental pollution* 171 (2012): 18-24. https://doi.org/10.1016/j.envpol.2012.07.009

[54] Beesley, Luke, Eduardo Moreno-Jiménez, Jose L. Gomez-Eyles, Eva Harris, Brett Robinson, and Tom Sizmur. "A review of biochars' potential role in the remediation, revegetation and restoration of contaminated soils." *Environmental pollution* 159, no. 12 (2011): 3269-3282. https://doi.org/10.1016/j.envpol.2011.07.023

[55] Ogbonnaya, Uchenna, and Kirk T. Semple. "Impact of biochar on organic contaminants in soil: a tool for mitigating risk?." *Agronomy* 3, no. 2 (2013): 349-375. https://doi.org/10.3390/agronomy3020349

[56] Yuan, Jin-Hua, Ren-Kou Xu, Wei Qian, and Ru-Hai Wang. "Comparison of the ameliorating effects on an acidic ultisol between four crop straws and their biochars." *Journal of soils and sediments* 11 (2011): 741-750. https://doi.org/10.1007/s11368-011-0365-0

[57] Jeffery, Simon, Frank GA Verheijen, Marijn van der Velde, and Ana Catarina Bastos. "A quantitative review of the effects of biochar application to soils on crop productivity using meta-analysis." *Agriculture, ecosystems & environment* 144, no. 1 (2011): 175-187. https://doi.org/10.1016/j.agee.2011.08.015

[58] Han, Fengpeng, Lulu Ren, and Xing-Chang Zhang. "Effect of biochar on the soil nutrients about different grasslands in the Loess Plateau." *Catena* 137 (2016): 554-562. https://doi.org/10.1016/j.catena.2015.11.002

[59] Wang, Ruoshui, Yaohu Kang, and Shuqin Wan. "Effects of different drip irrigation regimes on saline–sodic soil nutrients and cotton yield in an arid region of Northwest China." *Agricultural Water Management* 153 (2015): 1-8. https://doi.org/10.1016/j.agwat.2015.01.025

[60] DeLuca, T. H., M. D. MacKenzie, M. J. Gundale, and W. E. Holben. "Wildfire-produced charcoal directly influences nitrogen cycling in ponderosa pine forests." *Soil Science Society of America Journal* 70, no. 2 (2006): 448-453. https://doi.org/10.2136/sssaj2005.0096

[61] Smider, Benjamin, and Balwant Singh. "Agronomic performance of a high ash biochar in two contrasting soils." *Agriculture, Ecosystems & Environment* 191 (2014): 99-107. https://doi.org/10.1016/j.agee.2014.01.024

[62] Jaafar, Noraini M., Peta L. Clode, and Lynette K. Abbott. "Microscopy observations of habitable space in biochar for colonization by fungal hyphae from soil." *Journal of Integrative Agriculture* 13, no. 3 (2014): 483-490. https://doi.org/10.1016/S2095-3119(13)60703-0

[63] Quilliam, Richard S., Helen C. Glanville, Stephen C. Wade, and Davey L. Jones. "Life in the 'charosphere'–Does biochar in agricultural soil provide a significant habitat for microorganisms?." *Soil Biology and Biochemistry* 65 (2013): 287-293. https://doi.org/10.1016/j.soilbio.2013.06.004

[64] Cao, Xinde, and Willie Harris. "Properties of dairy-manure-derived biochar pertinent to its potential use in remediation." *Bioresource technology* 101, no. 14 (2010): 5222-5228. https://doi.org/10.1016/j.biortech.2010.02.052

[65] Shen, Zhengtao, Amelia Md Som, Fei Wang, Fei Jin, Oliver McMillan, and Abir Al-Tabbaa. "Long-term impact of biochar on the immobilisation of nickel (II) and zinc (II) and the revegetation of a contaminated site." *Science of the total environment* 542 (2016): 771-776. https://doi.org/10.1016/j.scitotenv.2015.10.057

[66] Wang, Hailong, Kunde Lin, Zhenan Hou, Brian Richardson, and Jay Gan. "Sorption of the herbicide terbuthylazine in two New Zealand forest soils amended with biosolids and biochars." *Journal of Soils and Sediments* 10 (2010): 283-289. https://doi.org/10.1007/s11368-009-0111-z

[67] Chan, K. Y冊, L冊 Van Zwieten, I冊 Meszaros, A. Downie, and S. Joseph. "Agronomic values of greenwaste biochar as a soil amendment." *Soil Research* 45, no. 8 (2007): 629-634. https://doi.org/10.1071/SR07109

[68] Zhao, Xu, Jiangwei Wang, Shenqiang Wang, and Guangxi Xing. "Successive straw biochar application as a strategy to sequester carbon and improve fertility: A pot experiment with two rice/wheat rotations in paddy soil." *Plant and soil* 378 (2014): 279-294. https://doi.org/10.1007/s11104-014-2025-9

[69] Güereña, David, Johannes Lehmann, Kelly Hanley, Akio Enders, Charles Hyland, and Susan Riha. "Nitrogen dynamics following field application of biochar in a temperate North American maize-based production system." *Plant and soil* 365 (2013): 239-254. https://doi.org/10.1007/s11104-012-1383-4

[70] Beesley, Luke, and Marta Marmiroli. "The immobilisation and retention of soluble arsenic, cadmium and zinc by biochar." *Environmental pollution* 159, no. 2 (2011): 474-480. https://doi.org/10.1016/j.envpol.2010.10.016

[71] Park, Jin Hee, Girish Kumar Choppala, Nanthi Sirangie Bolan, Jae Woo Chung, and Thammared Chuasavathi. "Biochar reduces the bioavailability and phytotoxicity of heavy metals." *Plant and soil* 348 (2011): 439-451. https://doi.org/10.1007/s11104-011-0948-y

[72] Krishnakumar, S., A. G. Rajalakshmi, B. Balaganesh, P. Manikandan, C. Vinoth, and V. Rajendran. "Impact of biochar on soil health." *International Journal of Advanced Research* 2, no. 4 (2014): 933-950.

[73] Kammann, Claudia I., Hans-Peter Schmidt, Nicole Messerschmidt, Sebastian Linsel, Diedrich Steffens, Christoph Müller, Hans-Werner Koyro, Pellegrino Conte, and Stephen Joseph. "Plant growth improvement mediated by nitrate capture in co-composted biochar." *Scientific reports* 5, no. 1 (2015): 11080. https://doi.org/10.1038/srep11080

[74] Rogovska, Natalia, David Laird, Richard Cruse, Pierce Fleming, Tim Parkin, and David Meek. "Impact of biochar on manure carbon stabilization and greenhouse gas emissions." *Soil Science Society of America Journal* 75, no. 3 (2011): 871-879. https://doi.org/10.2136/sssaj2010.0270

[75] Glaser, Bruno, Johannes Lehmann, and Wolfgang Zech. "Ameliorating physical and chemical properties of highly weathered soils in the tropics with charcoal–a review." *Biology and fertility of soils* 35 (2002): 219-230. https://doi.org/10.1007/s00374-002-0466-4

[76] Hairani, Anna, Mitsuru Osaki, and Toshihiro Watanabe. "Effect of biochar application on mineral and microbial properties of soils growing different plant species." *Soil science and plant nutrition* 62, no. 5-6 (2016): 519-525. https://doi.org/10.1080/00380768.2016.1212648

[77] Liu, Xiaoyu, Afeng Zhang, Chunying Ji, Stephen Joseph, Rongjun Bian, Lianqing Li, Genxing Pan, and Jorge Paz-Ferreiro. "Biochar's effect on crop productivity and the dependence on experimental conditions—a meta-analysis of literature data." *Plant and soil* 373 (2013): 583-594. https://doi.org/10.1007/s11104-013-1806-x

[78] Tian, Yun, Xiangyang Sun, Suyan Li, Haiyan Wang, Lanzhen Wang, Jixin Cao, and Lu Zhang. "Biochar made from green waste as peat substitute in growth media for Calathea rotundifola cv. Fasciata." *Scientia horticulturae* 143 (2012): 15-18. https://doi.org/10.1016/j.scienta.2012.05.018

[79] Headlee, William L., Catherine E. Brewer, and Richard B. Hall. "Biochar as a substitute for vermiculite in potting mix for hybrid poplar." *Bioenergy Research* 7 (2014): 120-131. https://doi.org/10.1007/s12155-013-9355-y

[80] Graber, Ellen R., Yael Meller Harel, Max Kolton, Eddie Cytryn, Avner Silber, Dalia Rav David, Ludmilla Tsechansky, Menahem Borenshtein, and Yigal Elad. "Biochar impact on development and productivity of pepper and tomato grown in fertigated soilless media." *Plant and soil* 337 (2010): 481-496. https://doi.org/10.1007/s11104-010-0544-6

[81] Meller Harel, Yael, Yigal Elad, Dalia Rav-David, Menachem Borenstein, Ran Shulchani, Beni Lew, and Ellen R. Graber. "Biochar mediates systemic response of strawberry to foliar fungal pathogens." *Plant and Soil* 357 (2012): 245-257. https://doi.org/10.1007/s11104-012-1129-3

[82] Zhang, Afeng, Liqiang Cui, Gengxing Pan, Lianqing Li, Qaiser Hussain, Xuhui Zhang, Jinwei Zheng, and David Crowley. "Effect of biochar amendment on yield and methane and nitrous oxide emissions from a rice paddy from Tai Lake plain, China." *Agriculture, ecosystems & environment* 139, no. 4 (2010): 469-475. https://doi.org/10.1016/j.agee.2010.09.003

[83] Peng, X. Y. L. L., L. L. Ye, C. H. Wang, H. Zhou, and B. Sun. "Temperature-and duration-dependent rice straw-derived biochar: Characteristics and its effects on soil properties of an Ultisol in southern China." *Soil and tillage research* 112, no. 2 (2011): 159-166. https://doi.org/10.1016/j.still.2011.01.002

[84] Rodríguez, Lylian, Patricia Salazar, and T. R. Preston. "Effect of biochar and biodigester effluent on growth of maize in acid soils." *Integrated Farming Systems for Food and Energy in a Warming, Resource-depleting World* (2009): 84.

[85] Kimetu, Joseph M., Johannes Lehmann, Solomon O. Ngoze, Daniel N. Mugendi, James M. Kinyangi, Susan Riha, Lou Verchot, John W. Recha, and Alice N. Pell. "Reversibility of soil productivity decline with organic matter of differing quality along a degradation gradient." *Ecosystems* 11 (2008): 726-739. https://doi.org/10.1007/s10021-008-9154-z

[86] Chan, K. Y., Lukas Van Zwieten, I. Meszaros, A. Downie, and S. Joseph. "Using poultry litter biochars as soil amendments." *Soil Research* 46, no. 5 (2008): 437-444. https://doi.org/10.1071/SR08036

[87] Chan, K. Y卌, L卌 Van Zwieten, I卌 Meszaros, A. Downie, and S. Joseph. "Agronomic values of greenwaste biochar as a soil amendment." *Soil Research* 45, no. 8 (2007): 629-634. https://doi.org/10.1071/SR07109

[88] Borchard, N., K. Prost, T. Kautz, A. Moeller, and J. Siemens. "Sorption of copper (II) and sulphate to different biochars before and after composting with farmyard manure." *European Journal of soil science* 63, no. 3 (2012): 399-409. https://doi.org/10.1111/j.1365-2389.2012.01446.x

[89] Houben, David, Laurent Evrard, and Philippe Sonnet. "Mobility, bioavailability and pH-dependent leaching of cadmium, zinc and lead in a contaminated soil amended with biochar." *Chemosphere* 92, no. 11 (2013): 1450-1457. https://doi.org/10.1016/j.chemosphere.2013.03.055

[90] Rondon, Marco A., Johannes Lehmann, Juan Ramírez, and Maria Hurtado. "Biological nitrogen fixation by common beans (Phaseolus vulgaris L.) increases with bio-char additions." *Biology and fertility of soils* 43 (2007): 699-708. https://doi.org/10.1007/s00374-006-0152-z

[91] Warnock, Daniel D., Johannes Lehmann, Thomas W. Kuyper, and Matthias C. Rillig. "Mycorrhizal responses to biochar in soil–concepts and mechanisms." *Plant and soil* 300 (2007): 9-20. https://doi.org/10.1007/s11104-007-9391-5

[92] Major, Julie, Christoph Steiner, Antonio Ditommaso, Newton PS Falcão, and Johannes Lehmann. "Weed composition and cover after three years of soil fertility management in the central Brazilian Amazon: compost, fertilizer, manure and charcoal applications." *Weed Biology and Management* 5, no. 2 (2005): 69-76. https://doi.org/10.1111/j.1445-6664.2005.00159.x

[93] Cheng, Chih-Hsin, Johannes Lehmann, and Mark H. Engelhard. "Natural oxidation of black carbon in soils: changes in molecular form and surface charge along a climosequence." *Geochimica et Cosmochimica Acta* 72, no. 6 (2008): 1598-1610. https://doi.org/10.1016/j.gca.2008.01.010

[94] Major, Julie, Marco Rondon, Diego Molina, Susan J. Riha, and Johannes Lehmann. "Maize yield and nutrition during 4 years after biochar application to a Colombian savanna oxisol." *Plant and soil* 333 (2010): 117-128. https://doi.org/10.1007/s11104-010-0327-0

[95] Biederman, Lori A., and W. Stanley Harpole. "Biochar and its effects on plant productivity and nutrient cycling: a meta-analysis." *GCB bioenergy* 5, no. 2 (2013): 202-214. https://doi.org/10.1111/gcbb.12037

[96] Steiner, Christoph, Wenceslau G. Teixeira, Johannes Lehmann, Thomas Nehls, Jeferson Luis Vasconcelos de Macêdo, Winfried EH Blum, and Wolfgang Zech. "Long term effects of manure, charcoal and mineral fertilization on crop production and fertility on a highly weathered Central Amazonian upland soil." *Plant and soil* 291 (2007): 275-290. https://doi.org/10.1007/s11104-007-9193-9

[97] Uzoma, Kingsley Chinyere, Mitsuhiro Inoue, H. Andry, Haruyuki Fujimaki, A. Zahoor, and Eiji Nishihara. "Effect of cow manure biochar on maize productivity under sandy soil condition." *Soil use and management* 27, no. 2 (2011): 205-212. https://doi.org/10.1111/j.1475-2743.2011.00340.x

[98] Dias, Bruno O., Carlos A. Silva, Fábio S. Higashikawa, Asunción Roig, and Miguel A. Sánchez-Monedero. "Use of biochar as bulking agent for the composting of poultry manure: effect on organic matter degradation and humification." *Bioresource technology* 101, no. 4 (2010): 1239-1246. https://doi.org/10.1016/j.biortech.2009.09.024

[99] Haefele, S. M., Y. Konboon, W. Wongboon, S. Amarante, A. A. Maarifat, E. M. Pfeiffer, and C. J. F. C. R. Knoblauch. "Effects and fate of biochar from rice residues in rice-based systems." *Field Crops Research* 121, no. 3 (2011): 430-440. https://doi.org/10.1016/j.fcr.2011.01.014

[100] Stavi, Ilan, and Rattan Lal. "Agroforestry and biochar to offset climate change: a review." *Agronomy for Sustainable Development* 33 (2013): 81-96. https://doi.org/10.1007/s13593-012-0081-1

[101] Rondon, Marco A., Johannes Lehmann, Juan Ramírez, and Maria Hurtado. "Biological nitrogen fixation by common beans (Phaseolus vulgaris L.) increases with bio-char additions." *Biology and fertility of soils* 43 (2007): 699-708. https://doi.org/10.1007/s00374-006-0152-z

[102] Zhang, Afeng, Liqiang Cui, Gengxing Pan, Lianqing Li, Qaiser Hussain, Xuhui Zhang, Jinwei Zheng, and David Crowley. "Effect of biochar amendment on yield and methane and nitrous oxide emissions from a rice paddy from Tai Lake plain, China." *Agriculture, ecosystems & environment* 139, no. 4 (2010): 469-475. https://doi.org/10.1016/j.agee.2010.09.003

[103] Zhang, Honghua, Kunde Lin, Hailong Wang, and Jay Gan. "Effect of Pinus radiata derived biochars on soil sorption and desorption of phenanthrene." *Environmental Pollution* 158, no. 9 (2010): 2821-2825. https://doi.org/10.1016/j.envpol.2010.06.025

[104] Beck, Deborah A., Gwynn R. Johnson, and Graig A. Spolek. "Amending greenroof soil with biochar to affect runoff water quantity and quality." *Environmental pollution* 159, no. 8-9 (2011): 2111-2118. https://doi.org/10.1016/j.envpol.2011.01.022

[105] Trupiano, Dalila, Claudia Cocozza, Silvia Baronti, Carla Amendola, Francesco Primo Vaccari, Giuseppe Lustrato, Sara Di Lonardo, Francesca Fantasma, Roberto Tognetti, and Gabriella Stefania Scippa. "The effects of biochar and its

combination with compost on lettuce (Lactuca sativa L.) growth, soil properties, and soil microbial activity and abundance." *International Journal of Agronomy* 2017 (2017). https://doi.org/10.1155/2017/3158207

[106] Lashari, Muhammad Siddique, Yingxin Ye, Haishi Ji, Lianqing Li, Grace Wanjiru Kibue, Haifei Lu, Jufeng Zheng, and Genxing Pan. "Biochar–manure compost in conjunction with pyroligneous solution alleviated salt stress and improved leaf bioactivity of maize in a saline soil from central China: a 2-year field experiment." *Journal of the Science of Food and Agriculture* 95, no. 6 (2015): 1321-1327. https://doi.org/10.1002/jsfa.6825

[107] Ali, Shafaqat, Muhammad Rizwan, Muhammad Farooq Qayyum, Yong Sik Ok, Muhammad Ibrahim, Muhammad Riaz, Muhammad Saleem Arif, Farhan Hafeez, Mohammad I. Al-Wabel, and Ahmad Naeem Shahzad. "Biochar soil amendment on alleviation of drought and salt stress in plants: a critical review." *Environmental Science and Pollution Research* 24 (2017): 12700-12712. https://doi.org/10.1007/s11356-017-8904-x

[108] Ndor, E., S. M. Amana, and C. L. A. Asadu. "Effect of biochar on soil properties and organic carbon sink in degraded soil of Southern Guinea Savanna Zone, Nigeria." *Int. J. Plant Soil Sci* 4, no. 3 (2015): 252-258. https://doi.org/10.9734/IJPSS/2015/12376

[109] Zhang, Yunhe, Omololu John Idowu, and Catherine E. Brewer. "Using agricultural residue biochar to improve soil quality of desert soils." *Agriculture* 6, no. 1 (2016): 10. https://doi.org/10.3390/agriculture6010010

[110] Carter, Sarah, Simon Shackley, Saran Sohi, Tan Boun Suy, and Stephan Haefele. "The impact of biochar application on soil properties and plant growth of pot grown lettuce (Lactuca sativa) and cabbage (Brassica chinensis)." *Agronomy* 3, no. 2 (2013): 404-418. https://doi.org/10.3390/agronomy3020404

[111] Agegnehu, Getachew, Michael I. Bird, Paul N. Nelson, and Adrian M. Bass. "The ameliorating effects of biochar and compost on soil quality and plant growth on a Ferralsol." *Soil Research* 53, no. 1 (2015): 1-12. https://doi.org/10.1071/SR14118

[112] Olmo, Manuel, José Antonio Alburquerque, Vidal Barrón, María Carmen Del Campillo, Antonio Gallardo, Mariano Fuentes, and Rafael Villar. "Wheat growth and yield responses to biochar addition under Mediterranean climate conditions." *Biology and Fertility of Soils* 50 (2014): 1177-1187. https://doi.org/10.1007/s00374-014-0959-y

[113] Hua, Li, Yingxu Chen, and Weixiang Wu. "Impacts upon soil quality and plant growth of bamboo charcoal addition to composted sludge." *Environmental technology* 33, no. 1 (2012): 61-68. https://doi.org/10.1080/09593330.2010.549845

[114] Atkinson, Christopher J., Jean D. Fitzgerald, and Neil A. Hipps. "Potential mechanisms for achieving agricultural benefits from biochar application to temperate soils: a review." *Plant and soil* 337 (2010): 1-18. https://doi.org/10.1007/s11104-010-0464-5

[115] Osundare, Opeyemi Tunde, Ayodele Anthony Fajinmi, and Christopher John Okonji. "Effects of organic and inorganic soil amendments on growth performance of plantain (Musa paradisiaca L.)." *African Journal of Agricultural Research* 10, no. 3 (2015): 154-160. https://doi.org/10.5897/AJAR2014.8645

[116] Persaud, Tracy, Oudho Homenauth, David Fredericks, and Seon Hamer. "Effect of rice husk biochar as an amendment on a marginal soil in Guyana." *World Environment* 8, no. 1 (2018): 20-25.

[117] Badar, Rabia, and Shamim A. Qureshi. "Composted rice husk improves the growth and biochemical parameters of sunflower plants." *Journal of Botany* 2014 (2014). https://doi.org/10.1155/2014/427648

[118] Rashad, Mohamed, El-Refaie Kenawy, Ali Hosny, Mohamed Hafez, and Maha Elbana. "An environmental friendly superabsorbent composite based on rice husk as soil amendment to improve plant growth and water productivity under deficit irrigation conditions." *Journal of Plant Nutrition* 44, no. 7 (2021): 1010-1022. https://doi.org/10.1080/01904167.2020.1849293

[119] Masulili, Agusalim, Wani Hadi Utomo, and M. S. Syechfani. "Rice husk biochar for rice based cropping system in acid soil 1. The characteristics of rice husk biochar and its influence on the properties of acid sulfate soils and rice growth in West Kalimantan, Indonesia." *Journal of Agricultural Science* 2, no. 1 (2010): 39. https://doi.org/10.5539/jas.v2n1p39

[120] Nurhidayati, N., and M. Mariati. "Utilization of maize cob biochar and rice husk charcoal as soil amendment for improving acid soil fertility and productivity." *Journal of Degraded and Mining Lands Management* 2, no. 1 (2014): 223.

[121] Abera, Tolera, Tolcha Tufa, Tesfaye Midega, Haji Kumbi, and Buzuayehu Tola. "Effect of integrated inorganic and organic fertilizers on yield and yield components of Barley in Liben Jawi District." *International Journal of Agronomy* 2018 (2018): 1-7. https://doi.org/10.1155/2018/2973286

[122] Larkin, Robert P. "Effects of selected soil amendments and mulch type on soil properties and productivity in organic vegetable production." *Agronomy* 10, no. 6 (2020): 795. https://doi.org/10.3390/agronomy10060795

[123] Yee, L. L., L. C. Tin, L. J. Shiun, J. J. Klemešd, H. C. Siong, and N. N. A. Mansorf. "Feedstock amendment for the production of quality compost for soil amendment and heavy metal immobilization." *Chem Eng Trans* 56 (2017): 409-504.

[124] Heyman, Hannah, Nina Bassuk, Jean Bonhotal, and Todd Walter. "Compost quality recommendations for remediating urban soils." *International Journal of Environmental Research and Public Health* 16, no. 17 (2019): 3191. https://doi.org/10.3390/ijerph16173191

[125] Mekki, Ali, Fathi Aloui, and Sami Sayadi. "Influence of biowaste compost amendment on soil organic carbon storage under arid climate." *Journal of the Air & Waste Management Association* 69, no. 7 (2019): 867-877. https://doi.org/10.1080/10962247.2017.1374311

[126] Walker, David J., Rafael Clemente, and M. Pilar Bernal. "Contrasting effects of manure and compost on soil pH, heavy metal availability and growth of Chenopodium album L. in a soil contaminated by pyritic mine waste." *Chemosphere* 57, no. 3 (2004): 215-224. https://doi.org/10.1016/j.chemosphere.2004.05.020

[127] van Herwijnen, René, Tony R. Hutchings, Abir Al-Tabbaa, Andy J. Moffat, Mike L. Johns, and Sabeha K. Ouki. "Remediation of metal contaminated soil with mineral-amended composts." *Environmental Pollution* 150, no. 3 (2007): 347-354. https://doi.org/10.1016/j.envpol.2007.01.023

[128] Liu, Lina, Hansong Chen, Peng Cai, Wei Liang, and Qiaoyun Huang. "Immobilization and phytotoxicity of Cd in contaminated soil amended with chicken manure compost." *Journal of Hazardous Materials* 163, no. 2-3 (2009): 563-567. https://doi.org/10.1016/j.jhazmat.2008.07.004

[129] Hartley, William, Nicholas M. Dickinson, Philip Riby, Elizabeth Leese, Jackie Morton, and Nicholas W. Lepp. "Arsenic mobility and speciation in a contaminated urban soil are affected by different methods of green waste compost application." *Environmental Pollution* 158, no. 12 (2010): 3560-3570. https://doi.org/10.1016/j.envpol.2010.08.015

[130] Garcıa-Gil, J. C., S. B. Ceppi, M. I. Velasco, A. Polo, and N. Senesi. "Long-term effects of amendment with municipal solid waste compost on the elemental and acidic functional group composition and pH-buffer capacity of soil humic acids." *Geoderma* 121, no. 1-2 (2004): 135-142. https://doi.org/10.1016/j.geoderma.2003.11.004

[131] Baker, Luke R., Paul M. White, and Gary M. Pierzynski. "Changes in microbial properties after manure, lime, and bentonite application to a heavy metal-contaminated mine waste." *Applied soil ecology* 48, no. 1 (2011): 1-10. https://doi.org/10.1016/j.apsoil.2011.02.007

[132] Cheng, Zhiqiang, and Parwinder S. Grewal. "Dynamics of the soil nematode food web and nutrient pools under tall fescue lawns established on soil matrices resulting from common urban development activities." *Applied Soil Ecology* 42, no. 2 (2009): 107-117. https://doi.org/10.1016/j.apsoil.2009.02.005

[133] Iovieno, Paola, L. Morra, A. Leone, L. Pagano, and Anna Alfani. "Effect of organic and mineral fertilizers on soil respiration and enzyme activities of two Mediterranean horticultural soils." *Biology and fertility of soils* 45 (2009): 555-561. https://doi.org/10.1007/s00374-009-0365-z

[134] Antonious, George F. "Enzyme activities and heavy metals concentration in soil amended with sewage sludge." *Journal of Environmental Science and Health Part A* 44, no. 10 (2009): 1019-1024. https://doi.org/10.1080/10934520902996971

[135] Loper, Shawna, Amy L. Shober, Christine Wiese, Geoffrey C. Denny, Craig D. Stanley, and Edward F. Gilman. "Organic soil amendment and tillage affect soil quality and plant performance in simulated residential landscapes." *HortScience* 45, no. 10 (2010): 1522-1528. https://doi.org/10.21273/HORTSCI.45.10.1522

[136] Arthur, Emmanuel, Wim M. Cornelis, Jan Vermang, and E. De Rocker. "Amending a loamy sand with three compost types: impact on soil quality." *Soil Use and Management* 27, no. 1 (2011): 116-123. https://doi.org/10.1111/j.1475-2743.2010.00319.x

[137] Pattanayak, S. K., K. N. Mishra, M. K. Jena, and R. K. Nayak. "Evaluation of green manure crops fertilized with various phosphorus sources and their effect on subsequent rice crop." *Journal of the Indian Society of Soil Science* 49, no. 2 (2001): 285-291.

[138] Emami, Hojat, and Ali Reza Astaraei. "Effect of organic and inorganic amendments on parameters of water retention curve, bulk density and aggregate diameter of a saline-sodic soil." *Journal of Agricultural Science and Technology* 14, no. 7 (2012): 1625-1636.

[139] Maucieri, Carmelo, Alberto Barco, and Maurizio Borin. "Compost as a substitute for mineral N fertilization? Effects on crops, soil and N leaching." *Agronomy* 9, no. 4 (2019): 193. https://doi.org/10.3390/agronomy9040193