Chapter

Biochar Application for Improved Resource Use and Environmental Quality

Stephen Yeboah, Patricia Oteng-Darko, Joseph Adomako and Abdul Rauf Alhassan Malimanga

Abstract

Agroecosystems have become very important not only for their role in achieving food security but also in mitigation of greenhouse gas emissions. This agro-ecological function has become very important since society expects agriculture to be more sustainable, by decreasing fertilizer inputs while reducing greenhouse gas emission. Mitigation measures to reduce net GHG emissions include increasing soil C sequestration by reduced tillage, biochar and straw application, and increased crop-use efficiency of fertilizer-N. An adequate management of soils and crops could result in a reduction of GHG emissions through complex interactive factors. However, which factors are mainly responsible for the differences in emissions across soil and environment type remain unclear and the mechanism underlying GHG emissions are complex. It is therefore imperative to determine how biochar could mitigate greenhouse gas emissions without adverse effect on crop yield. This chapter will predominantly review biochar application for improved resource use and reduce greenhouse gas emission in sub-Saharan Africa, except in some cases where specific mechanisms have been elucidated in other regions. We consider future perspectives on whether biochar application offers economic opportunities for smallholder farmers in developing countries, with a particular focus on Ghana. These issues provided the motivation for this chapter.

Keywords: biochar, greenhouse gas, resource use, crop productivity, soil quality

1. Introduction

Global demand for food will increase during the coming decades, yet agricultural systems are already strained across the globe. The agricultural systems are either too extensive or intensive, which is a threat to sustainable food production. Agriculture is also both a major contributor to greenhouse gas emission (GHG) and very susceptible to climate change. This increases the urgency for making agriculture climate smart, both through adaptation and mitigation by reducing GHG emissions. At the same time, arable land and other production resources are limited, and area expansion for food production is not desirable. Increasing the overall production of agricultural productivity without further increase of the area used for food production or its environmental footprint in a climate smart way is therefore essential. This means that food production and the type of food produced has to change to conform to good practices.

Sustainably producing sufficient, safe, and nutritious food implies that we should focus on increasing the efficiency along the production chain and across multiple resources (including land, water, nutrients, energy, labor) and recapturing waste into useful resource such as fertilizer and pesticides. This requires a radical change from the traditional linear "take-make-use-waste-recycle production model toward a sustainable production system with optimal use of resources and full reuse of wastes as shown in **Figure 1**.

Biochar is a carbon-rich residue that is important for an optimal use of resources with a focus on the lowest footprint per unit of quality food. Biochar is a recalcitrant source of C, which when applied to the soil slows down the turnover of native SOC, enhances the use efficiency of applied fertilizer-N, and therefore, reduces fertilizer-induced GHG emissions [1]. The soil incorporation of crop residues, particularly with high C/N ratio, improves soil organic C levels, enhances biological activity, and increases nutrient availability [2]. Recalcitrant C-rich biochar is a suitable means to mitigate climate change and improve soil fertility [3] and crop productivity [4]. These functions of biochar are collaborated by Yeboah et al., who reported improved soil organic carbon and moisture when biochar was applied in semi-arid Loess plateau of China. However, the effects have been shown to vary depending upon the type of biochar used and the environmental and soil conditions under which the material is applied.

These responses have limited widespread use of such management practices on cropping lands. Varied results have been obtained depending on soil and environmental conditions under which the technology is applied. The research results achieved are very diverse, and it is credible that the application of sustainable soil management technologies such as biochar, residue, and farmyard manure could imply higher yields of crops and lower greenhouse gas emissions compared to conventional agricultural practices. In addition, application of these technologies as a GHG mitigation strategy requires the understanding of the mechanism underlying the production of the greenhouse gas emission and developing the necessary

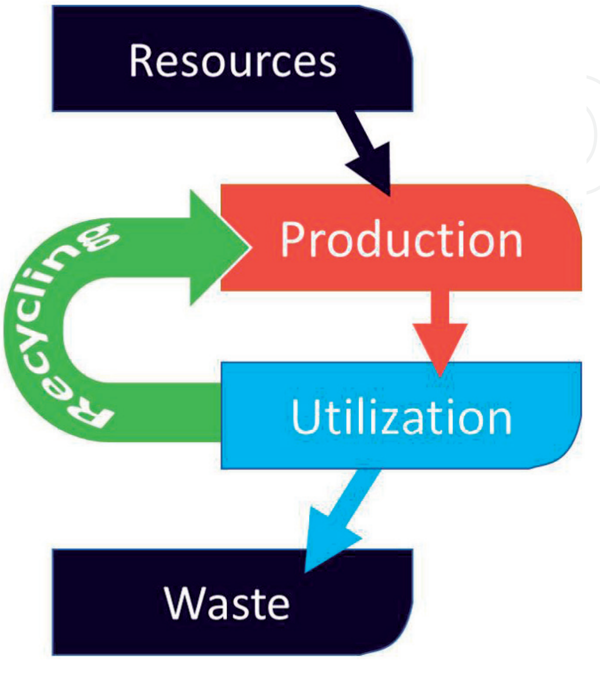

Figure 1.
Production system with recycling. Authors' personal communication.

component technologies to reduce the emissions without confounding effect on the agricultural yields. We consider future perspectives on whether biochar application offers economic opportunities for smallholder farmers in developing countries by considering the case study of Ghana. These issues provided motivation for this chapter.

2. Biochar for C-use efficiency

It is well known that the global atmospheric concentrations of the major greenhouse gases (GHGs) have been increasing [5], the largest coming from agriculture and land-use changes like urbanization and industrialization. This is an important issue in agriculture, both because of the impacts on agricultural production and agriculture being a major contributor to buildup of greenhouse gases in the atmosphere [4]. But net GHG emissions from farming-related activities can be reduced by increasing carbon (C) sequestration in soil and crop biomass. Current increases in atmospheric GHG levels require that novel approaches are undertaken to mitigate impacts of climate change, such as management practices conducive to improved soil C sequestration [6]. Recently, different means have been proposed to increase soil C in soil and thus decrease CO_2 emission. One such mitigation strategy is to sequester atmospheric CO_2 captured through photosynthesis in biomass and convert into a more stable form of carbon called biochar.

The sequestration of C and N in soils could be achieved through the adoption of crop residue retention. In drylands, the application of crop residues, among other measures, is recommended for the management of soil organic matter [7]. The application of biochar plays a dual role of sequestrating organic C and enhancing soil productivity [8], mainly because biochar contains high C content and could protect organic C from utilization. A similar result was found by Yeboah et al. [4] as shown below (**Figure 2**).

The significance of retaining crop residues was emphasized in the study by the difference of organic C between the organic amended soils. The authors attributed the increased C content in soil to its high C content and the fact that biochar could slow down organic C utilization by microbes. The higher organic C produced by the biochar-treated soils could be related to its ability to stabilize the native carbon

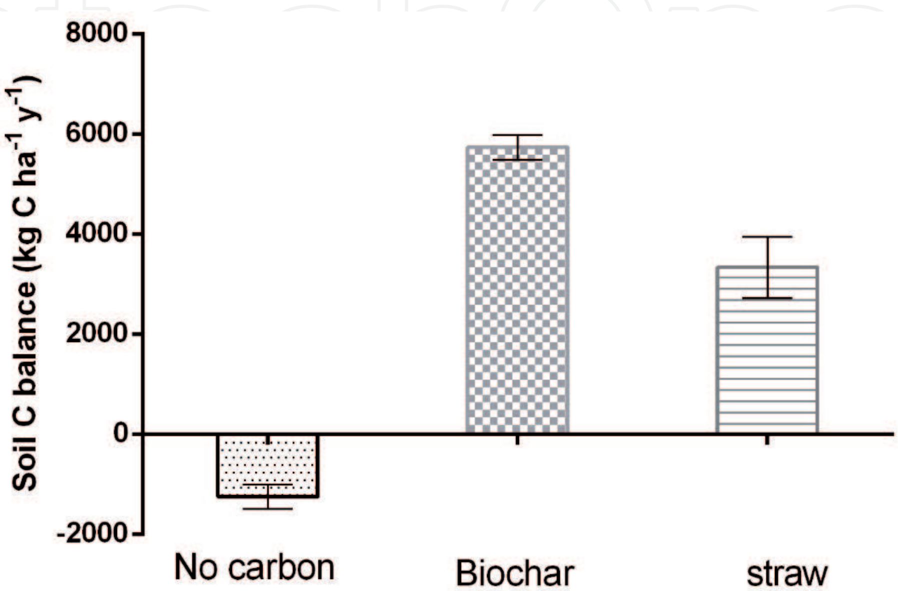

Figure 2.
Soil C balance under different treatments. Data replotted from [4] thesis, unpublished.

and recalcitrant to microbial decomposition. The resistance of biochar to microbial decomposition is dependent on its chemical composition resulting from the heat treatment and properties of the initial biomass [8]. There is consensus that biochars produced at higher temperatures contain more aromatic structures, which confer intrinsic recalcitrance. Due to its high surface area and porosity, biochar may also stabilize native SOC by reducing microbial activity as reported by several other researchers [7, 8].

Biochar amendment could exert high carbon recalcitrance against microbial decay, which in turn may reduce emission of GHGs. However, the effect of biochar on carbon emissions in soils are very complex and changes in emissions can be a response of diverse mechanisms. It is believed that biochar amendment affects CO_2 emissions by changing the characteristics of the soil and of the microbial diversity [8]. The increase in soil microbial biomass could be due to the increased C-use efficiency following the accumulation of soil organic C and microbes on the biochar surface. This is possible since crop residues serve as a precursor of the soil organic C pool, and returning more crop residues to the soil in the form of biochar is associated with increases in organic C concentration [2]. This function is particularly important in the stressful environment like water- and nutrient-limited conditions where the factors that limit yields of global agriculture production are many.

3. Biochar increases crop productivity

The challenge of meeting the demand for food has received great attention worldwide. The current increases in food production in the last four decades may be due to increased N fertilization and area of cultivation. However, the increased utilization of agricultural lands including the indiscriminate use of N fertilizer has resulted in negative effects on agriculture, socio-economic and environmental quality such as global warming [9]. Agricultural and environmental sustainability issues have stimulated attempts to increased crop yields while decreasing N fertilization. The potential to increase C inputs to soils is associated with high yield agriculture. It is within this framework that the ability to develop and implement innovative soil management practices becomes a key to improving the productive capacity of soils. This will enhance the resilience of the agroecosystem which is a key priority to crop production.

Aside the carbon sequestration potential of biochar amendment to agricultural soils, the production of biochar and its application to soil will deliver immediate benefits through increased crop production [10]. Biochar additions to agricultural fields are expected to increase yields [11] and reduce loss of nutrients [10]. A reduced number of studies have examined application of different carbon sources and patterns on crop productivity of loess soils.

In a study by Yeboah et al. [4], the greatest grain yield of spring wheat was recorded on biochar-treated soils and the lowest on soils without carbon amendment (**Figure 3**).

Yield increases with biochar application have been documented in controlled environments as well as in the field [7, 11], and several underlying mechanism have been attributed to this phenomenon. Bruun et al. [12] noted that improvements to the habitat for beneficial soil microbes are the most likely causes of productivity improvements associated with the application of biochar. However, other authors [9, 13] have reported that when biochar and inorganic fertilizers are applied together, an increased nutrient supply to plants may be the most important factor in increasing crop yields. The mechanism may be complex but the effect of biochar on soil quality could be prominent in influencing yield. It is therefore opined that

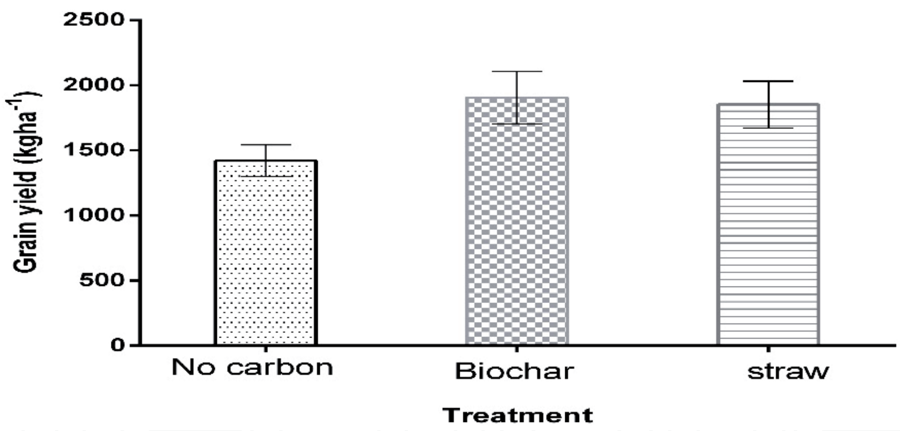

Figure 3.
Effect of different carbon sources on grain yield of spring wheat. Data replotted from [4].

improved crop yields in biochar amended study could be attributed to increased nutrient availability through enhanced soil quality. Our study evidenced a positive effect of biochar amendment on soil quality and spring wheat yield consistent over 3 years.

Such sustainable increasing effect could also be supported by other field experiments on dry croplands. Steiner et al. [14] reported cumulative yield increases of rice and sorghum in Brazil after four cropping seasons when 11 t ha^{-1} biochar made from rice straw was applied. Steiner et al. [14] found increased maize yield after three repeated maize stubble biochar applications of 7 t ha^{-1} of over 2 years. However, Asai et al. [15] reported a decreased grain yield following the application of biochar amendment without N fertilization in a soil that had poor N availability.

4. Biochar for mitigating greenhouse gas emissions

In an effort to reduce the concentrations of greenhouse gases (GHGs) in the atmosphere in order to reduce the potential effects, considerable attention has been paid to soil management practices. According to Snyder et al. [16], improving cropland management practices such as reduced tillage and residue retention has the potential to reduce agricultural greenhouse gas emission irrespective of type of cultivation. Recent increases in atmospheric GHG levels require that novel approaches are undertaken to mitigate impacts of climate change, such as management practices conducive to improved soil C sequestration [17]. Nitrogen fertilization and crop residue retention play a major role in GHG emission. Soil carbon sequestration through the application of recalcitrant C-rich biochar is mentioned as a suitable means to mitigate climate change.

A number of mechanisms have been proposed in the literature to explain the effect of biochar amendment on soil N_2O emissions, with limited amounts of evidence to support them. Since biochar has significant impact on soil environment and affects many soil parameters, such as pH or the availability of soil minerals, it is very likely that biochar will have significant effects on the production of N_2O. Diverse studies confirm this—most of them reporting reduced N_2O emissions from soil following biochar application [18], similar effect in the field [19], and no suppression of soil N_2O emissions [20]. Biochar amendment has been observed to modify soil physical properties such as reduced soil bulk density or increased water holding capacity, therefore increasing soil aeration. This may lead to lower soil N_2O emissions as soil aeration influenced both nitrifier and denitrifier activity. By changing the physical properties of the soil, biochar may suppress N_2O production from denitrification by increasing the air content of the soil or by absorbing water from the soil, thus improving aeration of the soil [18]. Biochar amendment may increase soil pH (**Figure 4**) when applied to soil [11]. Changes in soil pH may result in changes in nitrifier or denitrifier enzymatic activity and therefore soil N_2O emissions.

There is limited evidence, mostly from studies in rice paddies to suggest that biochar amendment affects soil CH_4 emissions [20]. The greater uptake of methane may be attributed to the protected environment created for the CH_4 oxidizers and improved soil porosity. The aerobic, well-drained soils can be a sink for CH_4 due to the possible high rate of CH_4 diffusion and ensuing oxidation by methanotrophs. Improved soil physical properties such as low bulk density and the associated increase in total porosity, mostly due to the relative increase in macroporosity [21], may significantly decrease CH_4 emissions. Increased availability of labile C substrates following biochar addition stimulates the activities of methanogenic bacteria that may account for increased CH_4 emissions [22]. However, this could be a short-term effect since labile carbon fraction in biochar could be mineralized rapidly. Karhu et al. [23] observed increased soil CH_4 consumption in arable soil due to increased soil aeration following biochar application. Biochar addition to soil has been assumed to increase soil temperature and soil pH. However, the effect of biochar on soil temperature and soil pH has not been suggested as mechanisms to explain differences in overall soil CH_4 [10].

Carbon dioxide is produced mainly from the decomposition of plant residues and organic matter by soil microbes and respiration from microbes and roots. Carbon dioxide can be divided into autotrophic and heterotrophic respiration based on different biological sources [10]. The effect of biochar on carbon emissions in soil are very complex and changes in CO_2 emissions can be a response of diverse mechanisms. Biochar amendment affects CO_2 emissions by changing the physical and chemical characteristics of the soil and of the microbial diversity [10]. CO_2 emission could be reduced through the effect of biochar application on C-mineralizing enzymes [25]. Some studies have shown that biochar addition could stimulate the mineralization of soil organic carbon (SOC) [11, 12] and correspondingly increase emissions of CO_2. However, conversely, the suppression of SOC mineralization has also been reported [25], thereby causing a decrease in CO_2 emissions. Biochar application could also stimulate CO_2 emission by enhancing soil properties [10]. As indicated in Refs. [16, 22], transforming carbon in plant residues into stable

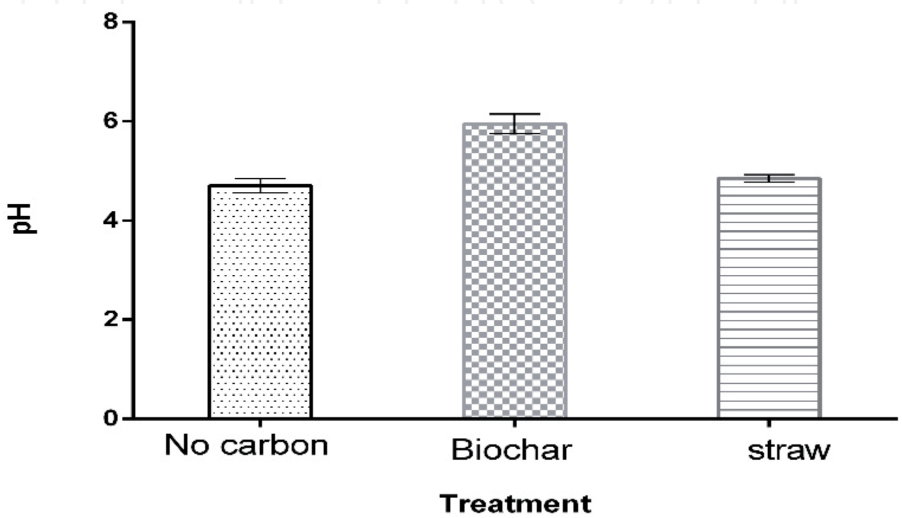

Figure 4.
Soil pH of different treatments. Data replotted from [24].

C form is the main role for decreasing CO_2 emission compared to the natural plant residues. Therefore, the mechanism underlying biochar effect on CO_2 emission is unclear, because it could have occurred because of several interactive factors.

5. Biochar for soil fertility

The decline of soil fertility is a major problem confronting crop production and environmental sustainability. The functions of soil depend on three main properties, physical, chemical, and biological, which influence global cycles of organic C and N [26]. The adoption of sound soil management strategies such as appropriate tillage methods, crop residues practices, biochar application, and efficient N fertilization has been suggested to improve soil properties [27]. These strategies can be achieved by increased input of crop residues while minimizing C loses by erosion, decomposition, and carbon emission. While conservation agriculture systems have been noted to improve soil organic C [27], conventional plow-based farming systems could accelerate carbon mineralization and thus reduce soil C content, which are attributed to soil aggregates disruption and increased oxidization through soil disturbances [28]. The incorporation of biochar into soil varies soil structure, porosity, and bulk density. According to Oguntunde et al. [29], this may in turn have consequences for important soil functions such as soil aeration and plant growth. In Ref. [30], it is postulated that biochar application results in an increase in soil C.

The expectation of increased soil fertility attributed to biochar application emanated from the studies of the terra preta that contains high proportions of black carbon [29]. The high soil organic matter content of the terra preta provides the evidence of the enhancement due to biochar application. In contrast to mainstream chemical fertilizer, biochar also contains bioavailable elements such as selenium that has potential to assist in enhancing crop growth. It is not clear concerning the potential effects of biochar on microbial activity in soil. Assuming that plant inputs and hence microbial substrate remain unchanged, enhanced microbial activity alone would diminish soil organic matter. However, this is contrary to the observation in terra preta, where soil organic matter is generally higher than in similar surrounding soil [26]. However, a change in the balance of microbial activity between different functional groups could benefit crop nutrition, specifically enhancement of mycorrhizal fungi [11], and this could feedback into higher net primary productivity and carbon input.

There are several reasons why biochar might be expected to decrease the potential for nutrient leaching in soils, and thus enhance nutrient cycling and also protect against leaching loss. In field studies where positive yield response to biochar application has been observed [7, 13], enhanced nutrient dynamics could be the reason for the observed results.

6. Biochar improves nitrogen use efficiency

Biochar is a recalcitrant source of C, which when applied to the soil slows down the turnover of native SOC, enhances the use efficiency of applied fertilizer-N, and, therefore, reduces fertilizer-induced GHG emissions [1]. Biochar improves N use efficiency through indirect processes including the improvement of soil conditions to maximize nitrogen uptake. This means through the application of biochar, nitrogen in the soil is conserved or the nitrogen that is applied through fertilization (added nitrogen) is conserved. Calys-Tagoe et al. [24] found higher N conserved

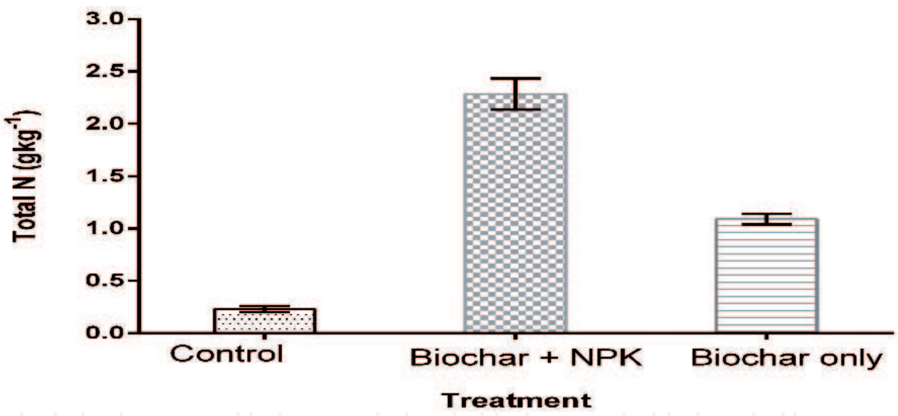

Figure 5.
Total N content of different treatments. Data replotted from [24].

in the soil when biochar was applied in combination with nitrogen fertilizer (**Figure 5**). Biochar amendment is said to conserve N in the soil and improve soil biological and physicochemical properties, which increases the ability of the soil to utilize nitrogen and other essential nutrients in the soil.

There are several reasons to expect that biochar might improve nitrogen use efficiency. It is believed that biochar improves nitrogen uptake by plants through the following ways: (1) retaining N in soil through adsorption of ammonia (NH_3) and ammonium (NH_4^+), (2) reducing nitrous oxide (N_2O) emissions, (3) reducing nitrate (NO_3^-) leaching, and (4) enhancing biological fixation of N in the soil [19]. These functions of biochar in soils have shown to increase nitrogen uptake by plants [37] and improve nitrogen use efficiency [19], either through the action of biochar as fertilizer and/or the improvement of soil condition for enhanced nitrogen uptake. Biochar application resulted in increased N uptake by plants, which was attributed to the ability of biochar to supply more N.

The improved N use efficiency function of biochar is very significant as it can impact the overall carbon balance of agricultural activities. A low ratio of fertilizer nitrogen application to crop nitrogen uptake can, therefore, influence the overall C balance. Higher fertilizer use efficiency may lead to a lower fertilizer requirement per unit yield and usually lower nitrous oxide emission resulting in improved environmental quality.

7. Biochar for pests and disease suppression

Crop pests and diseases constitute important threat to food security and reduce income levels along the value chain of both producers and consumers worldwide. With the increasing global population, the need to maximize food production to feed the world is of utmost importance. To achieve this, there is the need to minimize losses caused by pests and diseases to mitigate the possibility of global food insecurity. Controlling biotic stresses to maximize crop production must, however, be sustainable and environmentally friendly. In view of this, sustainable crop production through integrated pest and disease management (IP&DM) strategies has gained worldwide recognition and the use of organic soil amendments (OSA) such as biochar is an integral tool for the success of this strategy. Apart from managing pest and disease pathogens, OSA have the potential of improving soil tilth, nutrient availability, water-holding capacity, soil microbial diversity, and population dynamics, and reduces nutrient-leaching loss [31].

The desire to effectively control plant diseases without compromising environmental quality and safety has increased the demand for research into finding sustainable ways of managing pests and diseases. In the context of sustainability, research into the use of organic substances such as animal manure, green manure, organic agro wastes, and compost management have gained tremendous interest among researchers and various stakeholders. OSA do not only have the advantage of improving soil structure and quality but also found to increase the suppressive potential of treated soils thereby inhibiting diseases caused by plant pathogens [32]. OSA have successfully been used to reduce the activities of several plant pathogens such as plant parasitic nematodes, *Fusarium* spp., *Phytophthora* spp., *Pythium* spp., *Rhizoctonia solani*, *Sclerotinia* spp., *Sclerotium* spp., and *Verticillium dahlia* [32]. The use of untreated OSAs have, however, been found to exacerbate activities of disease pathogens and can increase their incidence and severity. Also, the release of certain phytotoxic compounds such as xanthatin and 4-epiisoxanthanol during the decomposition process can damage the roots of plants [32] and make them vulnerable to pathogen attack [33]. The benefits of OSA however, outweigh the constraints and the search for numerous agents for use as OSA is continuous with reports emanating from several research works globally. One such OSA agent that has received global attention and interest is the biochar. This is obtained from the slow pyrolysis of biomass in the absence of air. It is a by-product from the biofuel industry and a high-carbon material [34]. As an OSA, there has been an increased interest in its importance as soil health and disease management agent. Current studies have proven its role in carbon sequestration leading to the removal of desirable carbon from the atmosphere. In addition to this, current studies have pointed to the fact that apart from increasing the cation exchange capacity in organic matter deficient soils, improving the pH status of acidic soils, and increasing nutrition and water holding capacities of soils, it also enriching microorganisms in the soil that improve soil suppression potential against pathogens. Suppressive soils are able to inhibit disease development by stimulating biota activity, increasing and favoring populations of biocontrol agents, and reduce the inoculum potential of both foliar and soilborne pathogens [35]. With regard to soilborne pathogens, biochar has successfully been used to suppress the activities and infection capabilities of pathogens. Data available shows that the application of biochar reduced the infection potential of *Meloidogyne graminicola* in rice [36] and other plant-parasitic nematodes, while it increased the population of free-living nematodes that may be beneficial to the improvement of soil health. Bonanomi et al. [37] reported that the application of biochar was found to be effective in suppressing foliar pathogens such as *Rhizoctonia solani*, *Fusarium*, and *Phytophthora* species. Similarly, the application of biochar was reported to reduce the severity of gray mold disease on both *Lycopersicon esculentum* and *Capsicum annuum* [38]. Also, *Fusarium* root rot disease incidence in asparagus reduced following the application of biochar inoculated with mycorrhizal fungi [39]. Nerome et al. [40] reported that the application of biochar obtained from municipal organic waste inhibited the infection capacity of *Ralstonia solanacearum* to cause disease, increasing the advocacy to use biochar and its amended composts to control fungi and bacterial disease in crop production. The disease suppression potential of biochar is influenced by several mechanisms. According to Rawat et al. [41], the effectiveness of biochar to inhibit disease is linked to the presence of calcium compounds as well as improving the physical, chemical, and biological characteristics of the soil. Similarly, Noble and Coventry [42] hypothesized the induction of systemic resistance in the host plants, enhanced abundance and activities of beneficial microbes, modification of soil quality in terms of nutrient availability, and abiotic conditions; direct fungitoxic effect and sorption of allelopathic and phytotoxic compounds as mechanisms by which biochar suppresses plant diseases.

Different pesticides are used in crop production to reduce the impact of targeted agent. In addition to its disease suppressive potential, biochar also reduces the impact of pesticides on the environment through the absorption and adsorption of different pesticides [43] to reduce the bioavailability of pesticides due to its large surface area and high porosity. The sorption capacity of biochar amendment is however dependent on age as Martin et al. [44] reported that the herbicide, atrazine adsorption in biochar amended soil decreased with the age of biochar an indication that aging has influence on its usefulness in pesticide sorption. Biochar can again protect roots of plants from phytotoxic compounds in the soil released by roots of other plants, through the decomposition of plant residues and soil amendment as well as agro-waste products and immature compost [45]. The high sorption rate of biochar, on the other hand, can negatively affect the efficacy of agrochemicals and increase the application rates of pesticides.

8. Biochar application: a case study in Ghana

In recent years, agricultural growth in Ghana has seen accelerated growth, but most of this growth is driven by the expansion of the cultivated area rather than by increased yield per unit area. It has been suggested that yield should be increased by at least 20% annually across the staple crops to meet the food needs of the people [46]. This is envisaged to be difficult with the current impact of climate change (evident by the rising temperatures and increased mid-season drought), resource scarcity, and environmental degradation. In sub-Saharan African (SSA), soil fertility decline, mainly through continuous cropping and rapid organic matter mineralization, is the main cause of food insecurity and poverty. Smallholder agricultural production systems in most SSA countries including Ghana are characterized by low productivity due to low and erratic rainfall patterns, outdated agricultural practices, and low application of nutrient inputs. To intensify agriculture, chemical fertilizer is highly utilized.

To pursue the fastest and most practical route to sustainable food production, substantial improvement in crop and soil management practices, which are currently suboptimal, is required. The deployment of soil management technologies such as biochar application is a surest means to reversing the rapid decline in soil fertility in sub-Saharan Africa, particularly Ghana. The large availability of biomass resources in Ghana gives a great potential for biochar production and utilization in the country. This is very important in the tropics since turnover rates of organic matter are much faster. Waste management as a social problem has spared neither the developed nor developing nations as statistics have proven that some developed nations are seriously grappling with this bane. Ghana produces 1.7 billion tons of waste annually (source: ghananewsagency.org).

Biochar research is a recent development in Ghana and so there is a paucity of information regarding its effects on soil properties, crop growth, and yield in Ghanaian soils. The effect of biochar and/or compost applications on the soil pH of the Aiyinase and Cape Coast soils in Ghana after the 14-day incubation period is shown in **Figure 6**. The results revealed a significant increase in the soil pH, following sole and combined applications of compost and biochar in both soils. Also, the application of biochar and compost, alone or in combination, increased soil total organic carbon (TOC) contents in both the Aiyinase and Cape Coast soils (**Figure 6**). The application of biochar significantly improved soil chemical properties with reference to the control.

A case study in Ghana illustrates the significance of biochar application in augmenting water retention in a dryland crop (**Figure 7**). A farmer reports 100%

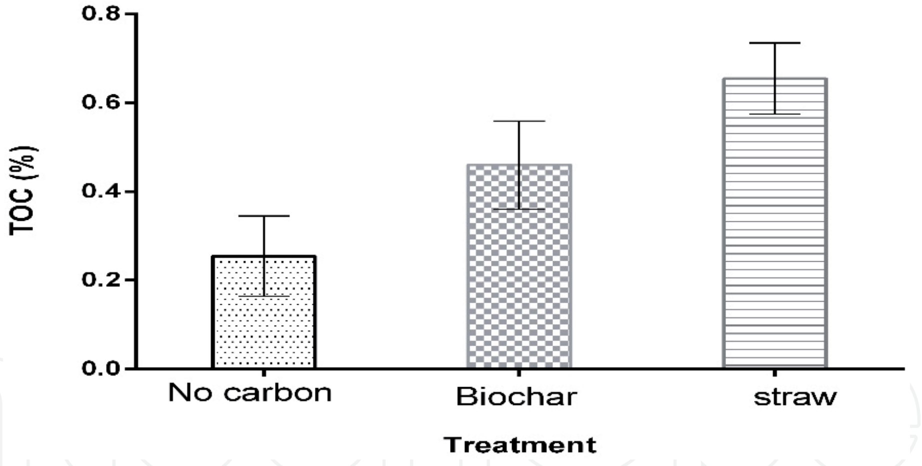

Figure 6.
Total organic carbon as affected by different treatments. Data replotted from [24].

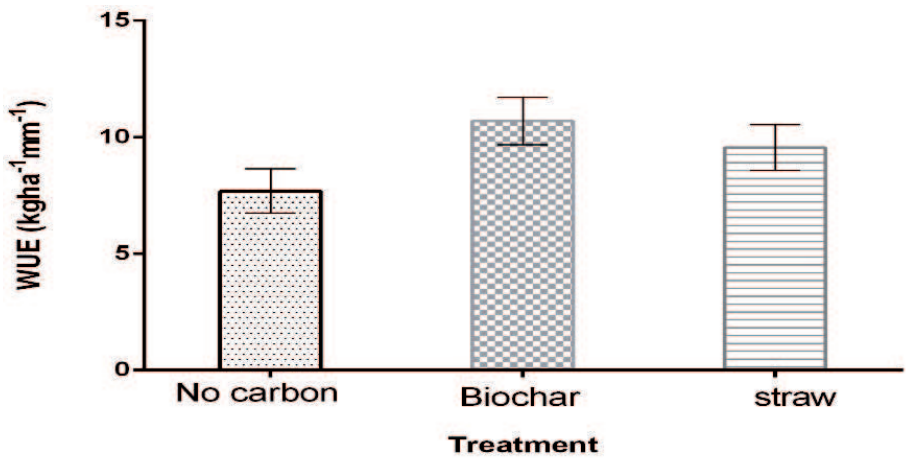

Figure 7.
Total organic carbon as affected by different treatments. Data replotted from [4].

increase in yields. "Her perception is that the underlying mechanism for the effects she sees is entirely physical, citing two factors: enhanced rainwater infiltration and enhanced soil moisture retention" [10]. Given the fact that drought-susceptible sandy soils are prevalent in Ghana, crop performance is much influenced by rainfall (timing and intensity).

The results of studies in Ghana indicate the potential exist for farmers to produce their own biochar on-farm, although various factors must be considered in deciding whether this methodology is appropriate in a particular context. Factors such as capacity of farmers determine the pyrolysis conditions and activation methods.

9. Conclusion

Rainfed agricultural ecosystem in Ghana is extremely fragile, improving soil fertility and crop productivity, and reducing greenhouse gas emission (GHG) is a key factor for developing sustainable agriculture. The review provides insights into the potential of biochar in improving the agroecological system with reference to Ghana. Given the fact that yield gaps are greater in many developing countries, there is considerable need for better soil management technologies to ensure higher yields for improved food security. Biochar application offers a great potential in improving tropical soils and crop productivity.

Conflict of interest

Authors declare no competing interest.

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References

[1] Lehmann J. A handful of carbon. Nature. 2007;**447**:143-144. DOI: 10.1038/447143a

[2] Russell AE, Cambardella CA, Laird DA, Jaynes DB, Meet DW. Nitrogen fertilizer effects on soil carbon balances in Midwestern U.S. agricultural systems. Ecological Applications. 2009;**19**(5):1102-1113. DOI: 10.1890/07-1919.1

[3] Laird D, Fleming P, Wang B, Horton R, Karlen D. Biochar impact on nutrient leaching from a Midwestern agricultural soil. Geoderma. 2010;**158**:436-444. DOI: 10.1016%2Fj.geoderma.2010.05.012

[4] Yeboah S, Zhang R, Cai L, Li L, Xie J, Luo Z, et al. Soil water content and photosynthetic capacity of spring wheat as affected by soil application of nitrogen-enriched biochar in a semiarid environment. Photosynthetica. 2017;**55**(3):532-542. DOI: 10.1007/s11099-016-0672-1

[5] IPCC. Climate Change: Mitigation of Climate Change. Intergovernmental Panel on Climate Change [Internet]. 2014. Available from: http://www.ipcc.ch/report/ar5/wg3/

[6] Woolf D, Amonette JE, Street-Perrott FA, Lehmann J, Joseph S. Sustainable biochar to mitigate global climate change. National Communication. 2010;**1**:1-9. DOI: 10.1038/ncomms1053

[7] Yeboah S, Zhang RZ, Cai LQ, Jun W. Different carbon sources enhance system productivity and reduce greenhouse gas intensity. Plant, Soil and Environment. 2018;**64**(10):463-469. DOI: 10.17221/83/2018-pse

[8] Zimmerman AR, Gao B, Ahn MY. Positive and negative carbon mineralization priming effects among a variety of biochar amended soils. Soil Biology and Biochemistry. 2011;**43**(1):1169-1179. DOI: 10.1016/j.soilbio.2011.02.005

[9] Rasouli S, Whalen JK, Madramootoo CA. Review: Reducing residual soil nitrogen losses from agroecosystems for surface water protection in Quebec and Ontario, Canada: Best management practices, policies and perspectives. Canadian Journal of Soil Science. 2014;**94**:109-127. DOI: 10.4141/cjss2013-015

[10] Lehmann CJ, Joseph S. Biochar systems. In: Lehmann CJ, Joseph S, editors. Biochar for Environmental Management: Science and Technology. London: Earthscan; 2009. p. 448

[11] Blackwell P, Evelyn K, Greg B, Allan H, Zakaria S. Effect of banded biochar on dryland wheat production and fertiliser use in south–western Australia: An agronomic and economic perspective. Australian Journal of Soil Research. 2010;**48**(7):531-545

[12] Bruun EW, Muller-Stover D, Ambus P, Hauggaard-Nielsen H. Application of biochar to soil and N_2O emissions: Potential effects of blending fast–pyrolysis biochar with anaerobically digested slurry. European Journal of Soil Science. 2011;**62**:581-589. DOI: 10.1111/j.1365-2389.2011.01377x

[13] Borchard N, Wolf A, Laabs V, Aeckersberg R, Scherer HW, Moeller A, et al. Physical activation of biochar and its meaning for soil fertility and nutrient leaching—A greenhouse experiment. Soil Use and Management. 2012;**28**:177-184. DOI: 10.1111/j.1475-2743.2012.00407.x

[14] Steiner C, Teixeira WG, Lehmann J, Nehls T, de Macêdo JLV, Blum WEH, et al. 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. 2007;**291**(1-2):275-290. DOI: 10.1007/s11104-007-9193-9

[15] Asai H, Samson BK, Stephan HM, Songyikhangsuthor K, Homma K, Kiyono Y, et al. Biochar amendment techniques for upland rice production in northern Laos. Field Crops Research. 2009;**111**:81-84. DOI: 10.1016/j.fcr.2008.10.008

[16] Snyder CS, Bruulsema TW, Jensen TL, Fixen PE. Review of greenhouse gas emissions from crop production systems and fertilizer management effects. Agriculture, Ecosystems and Environment. 2009;**133**:247-266. DOI: 10.1016/j.agee.2009.04.021

[17] Powlson DS, Gregory PJ, Whalley WR, Quinton JN, Hopkins DW, Whitmore AP, et al. Soil management in relation to sustainable agriculture and ecosystem services. Food Policy. 2011;**36**:S72-S87. DOI: 10.1016/j.foodpol.2010.11.025

[18] Yanai Y, Toyota K, Okazaki M. Effect of charcoal addition on N_2O emissions from soil resulting from rewetting air–dried soil in short–term laboratory experiments. Soil Science and Plant Nutrition. 2007;**53**:181-188. DOI: 10.1111/j.1747-0765.2007.00123.x

[19] Zhang A, Cui L, Pan G, Li L, Hussain Q, Zhang X, et al. Effect of biochar amendment on yield and methane and nitrous oxide emissions from a rice paddy from Tai Lake plain, China. Agriculture, Ecosystems and Environment. 2010;**139**:469-475. DOI: 10.1016/j.agee.2010.09.003

[20] Clough TJ, Bertram JE, Ray JL, Condron LM, O'Callaghan M, Sherlock RR, et al. Unweathered wood biochar impact on nitrous–oxide emissions from a bovine-urine-amended pasture soil. Soil Science Society of America Journal. 2010;**74**:852-860. DOI: 10.1111/j.1747-0765.2007.00123.x

[21] Yeboah S, Zhang R, Cai L, Song M, Li L, Xie J, et al. Greenhouse gas emissions in a spring wheat–field pea sequence under different tillage practices in semi-arid Northwest China. Nutrient Cycling in Agroecosystems. 2016;**106**:77-91. DOI: 10.1007/s10705-016-9790-1

[22] Wang L, Tian H, Song C. Xu X, Chen G, Ren W, Lu C. Net exchanges of CO_2, CH_4 and N_2O between marshland and the atmosphere in Northeast China as influenced by multiple global environmental changes. Atmospheric Environment, 2012, 63:77-85. doi:10.1016/j.atmosenv.2012.08.069

[23] Karhu K, Mattila T, Bergstrom I, Regina K. Biochar addition to agricultural soil increased CH_4 uptake and water holding capacity—Results from a short–term pilot field study. Agriculture, Ecosystems and Environment. 2011;**140**:309-313. DOI: 10.1016/j.agee.2010.12.005

[24] Calys-Tagoe E, Sadick A, Yeboah E, Amoah B. Biochar effect on maize yield in selected farmers fields in the northern and upper east regions of Ghana. Journal of Experimental Agriculture International. 2019;**30**(6): 1-9. DOI: 10.9734/jeai/2019/44168

[25] Jin H. Characterization of Microbial Life Colonizing Biochar and Biochar–Amended Soils. 2010. Available from: http://search.proquest.com.ezprozy.webfeat.lib.ed.ac.uk/docview/741717654

[26] Lal R. Soil carbon sequestration to mitigate climate change. Geoderma. 2004;**121**:1-22. DOI: 10.1016/j.geoderma.2004.01.032

[27] Andruschkewitsch R, Geisseler D, Koch HJ, Ludwig B. Effects of tillage on

contents of organic carbon, nitrogen, water–stable aggregates and light fraction for four different long–term trials. Geoderma. 2013;**192**:368-377. DOI: 10.1016/j.geoderma.2012.07.005

[28] Ussiri D, Lal R, Jarecki MK. Nitrous oxide and methane emissions from long–term tillage under a continuous corn cropping system in Ohio. Soil and Tillage Research. 2009;**104**:247-253

[29] Oguntunde PG, Abiodun BJ, Ajayi AE, van de Giesen N. Effects of charcoal production on soil physical properties in Ghana. Journal of Plant Nutrition and Soil Science. 2008;**171**(4):591-596. DOI: 10.1002/jpln.200625185

[30] Keith A, Singh B, Singh BP. Interactive priming of biochar and labile organic matter mineralization in a smectite-rich soil. Environmental Science & Technology. 2011;**45**:9611-9618. DOI: 10.1021/es202186j

[31] Eyles A, Bound SA, Oliver G, Corkrey R, Hardie M, Green S, et al. Impact of biochar amendment on the growth, physiology and fruit of a young commercial apple orchard. Trees. 2015;**29**(6):1817-1826. DOI: 10.1007/s00468-015-1263-7

[32] Bonanomi G, Sicurezza MG, Caporaso S, Assunta E, Mazzoleni S. Phytotoxicity dynamics of decaying plant materials. New Phytologist. 2006;**169**:571-578. DOI: 10.1111/j.1469-8137.2005.01611.x

[33] Bonanomi G, Antignani V, Barile E, Lanzotti V, Scala F. Decomposition of *Medicago sativa* residues affects phytotoxicity, fungal growth and soil-borne pathogen diseases. Journal of Plant Pathology. 2011;**93**:57-69. DOI: 10.4454/jpp.v93i1.274

[34] Chan KY, Van Zwieten L, Meszaros I, Downie A, Joseph S. Agronomic values of greenwaste biochar as a soil amendment. Soil Research. 2007;**45**:629-634. DOI: 10.1071/SR07109

[35] Graber ER, Frenkel O, Jaiswal AK, Elad Y. How may biochar influence severity of diseases caused by soilborne pathogens? Carbon Management. 2014;**5**:169-183. DOI: 10.1080/17583004.2014.913360

[36] Huang WK, Ji HL, Gheysen G, Debode J, Kyndt T. Biochar-amended potting medium reduces the susceptibility of rice to root-knot nematode infections. BMC Plant Biology. 2015;**15**(1):267. DOI: 10.1186/s12870-015-0654-7

[37] Bonanomi G, Antignani V, Pane C, Scala F. Suppression of soilborne fungal diseases with organic amendments. Journal of Plant Pathology. 2007;**89**:311-324

[38] Mehari ZH, Elad Y, Rav-David D, Graber ER, Harel YM. Induced systemic resistance in tomato (*Solanum lycopersicum*) against *Botrytis cinerea* by biochar amendment involves jasmonic acid signaling. Plant and Soil. 2015;**395**(1-2):31-44. DOI: 10.1007/s11104-015-2445-1

[39] Thies JE, Rillig M. Characteristics of biochar: Biological properties. In: Lehmann M, Joseph S, editors. Biochar for Environmental Management Science and Technology. London: Earthscan; 2009. pp. 85-105. DOI: 10.4324/9781849770552-13

[40] Nerome M, Toyota K, Islam TM, Nishimima T, Matsuoka T, Sato K, et al. Suppression of bacterial wilt of tomato by incorporation of municipal biowaste charcoal into soil. Soil Microorganisms. 2005;**59**(1):9-14

[41] Rawat J, Saxena J, Sanwal P. Biochar: A sustainable approach for improving plant growth and soil properties. In:

Abrol V, Sharma P, editors. Biochar—An Imperative Amendment for Soil and the Environment. London: IntechOpen; 2019. DOI: 10.5772/intechopen.82151

[42] Noble R, Coventry E. Suppression of soil-borne plant diseases with composts: A review. Biocontrol Science and Technology. 2005;**15**:3-20. DOI: 10.1080/09583150400015904

[43] Kookana RS, Sarmah AK, Van Zwieten L, Krull E, Singh B. Biochar application to soil: Agronomic and environmental benefits and unintended consequences. In: Donald LS, editor. Advances in Agronomy 112. New York: Academic Press; 2011. pp. 103-143. DOI: 10.1016/B978-0-12-385538-1.00003-2

[44] Martin SM, Kookana RS, Van Zwieten L, Krull E. Marked changes in herbicide sorption-desorption upon ageing of biochars in soil. Journal of Hazardous Materials. 2012;**231-232**:70-78. DOI: 10.1016/j.jhazmat.2012.06.040

[45] Tiquia SM. Reduction of compost phytotoxicity during the process of decomposition. Chemosphere. 2010;**79**:506-512. DOI: 10.1016/j.chemosphere.2010.02.040

[46] International Food Policy Research Institute (IFPRI). New GSSP policy note. In: Arhin BG, editor. Ghana Strategy Support Program, GSSP. Ghana Agricultural News Digest; 2014