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Effects of Biochar in Soil Chemical and Biological Property and Mitigating Climate Change: Review

Wakjira Tesfahun
Raya University, College of Agriculture and Natural Science

Abstract
Biochar is a solid material obtained from the carbonization of any biomass including weeds, crop residues and other wastes of plant origin. Currently, the use of biochar has got scientific attention in agriculture sector. Using renewable energy from noncompetitive waste residue is now a day becoming a commercial reality. I review here the role of biochar in improving soil chemical and biota property of soil and mitigation of climate change. Biochar addition to the soil is a promising option for improving soil chemical property by improving cation exchange capacity (CEC) and soil pH and reducing exchangeable acidity of the soil. Also biochar was found to increase soil biota, through increasing nutrient availability, enhancing habitat suitability, increasing water retention and aeration and reducing toxic chemicals in the soil. Biochar has a significant role in climate change mitigation through sequestration of carbon in the soil and reduction of nitrous oxide (N2O) and methane (CH4) gas emissions to atmosphere by improving uptake of the soil. However, some fundamental mechanism and manipulation of biochar remain understandable and need further investigation.
Keywords: Biochar , climate change mitigation , soil biota , soil physiochemical properties

1. Introduction

Biochar has the potential to produce additional environmental welfares. It was observed that application of biochar improves soil physical and chemical characteristics by increased soil pH, cation exchange capacity and reducing nitrogen leaching, thereby reducing fertilizer and lime requirements (Van Zwieten *et al*., 2010) and also increase soil water holding capacity and permeability, reduce soil strength, modify soil bulk density and aggregate stability (Busscher *et al*., 2010). Biochar may also adsorb pesticides, nutrients and minerals in soil, preventing the movement of these chemicals to surface water or groundwater, and the subsequent degradation of these waters from agricultural activity.

Biochar has also been validated to reduce methane and nitrous oxide emissions from agricultural soils (Zhang *et al*., 2010), which give a bonus in mitigating climate change effects. These environmental welfareshave great economic value in the form of boosting agricultural production and productivity, safeguarding water quality protection and abridgedthe emission of greenhouse gasses. Due to its multiple benefits, biochar has acquired attention from climate and policy analysts. Recently, Woolf *et al*. (2010) indicated that increased and well-managed biochar generation with consequent application to soil could play a substantial role in mitigating greenhouse gasses emissions and climate change effects.

Furthermore, biochar has also been tested to increase soil biological community composition(Grossman *et al*., 2010) and microbial biomass by 125 % (Liang *et al*. 2010). Therefore, this paper reviews the role of biochar in soil chemical and biological property and climate change mitigation.

2. Effects of biochar on chemical properties

2.1. Soil pH

There are a number of studies showed that soil pH was increased due to biochar amendments especially in acidic soil (Yuan and Xu, 2011; Yamato *et al*., 2006; Major *et al*., 2010). The increased in soil pH attributed from the integration of highly alkaline nature of biochars , high base cation concentration which in turn released protons into the soil solution and the acidity reduced through proton consumption reaction and higher availability of CaCo3. Other justification was given by Nelissen *et al*. (2012) who reported that that incorporation of biochar to soil improves NH_4^+ immobilization and subsequently decrease nitrification which in turns conquer the discharge of H^+ concentration to the soil and relieve soil acidification.However, ameliorating ability of biochar are depends on Pyrolytic parameter (higher pyrolytic temperature i.e > 400 ^oC help to produce alkaline pH), feed stock (Fig.1) (Lei *et al*., 2009) and soil properties (Wang *et al*., 2014).

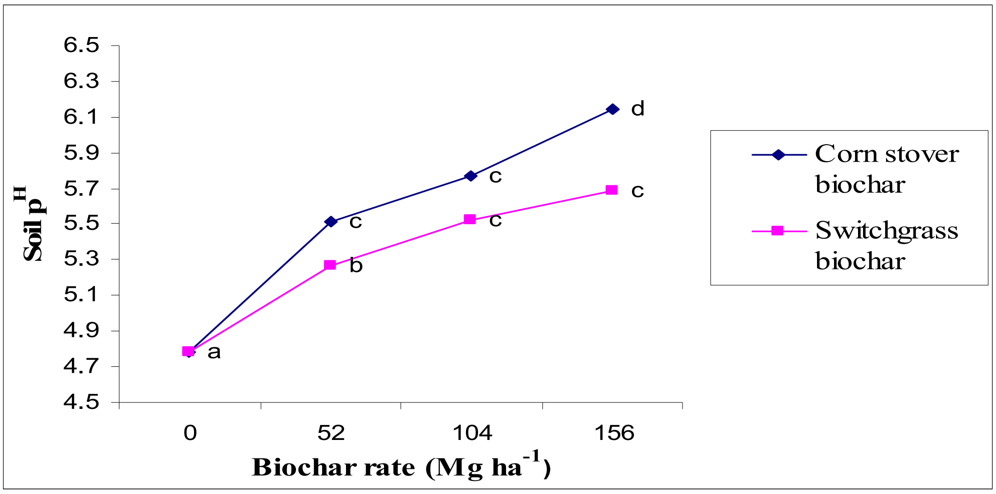

Figure 1. Soil pH as affected by different type of feed stock and rates
Source: Rajesh *et al*. (2013)

In Similar way to feed stock and pyrolytic temperature, the alkalinity nature of biochar was a key factor that affecting liming potential of the acidic soil (Yuan *et al.*, 2011). Fig.2. revealed that a very good linear correlation relationship between soil pH and biochar alkalinity.Thus tell us ameliorating effect of biochar on acid soils mainly influenced by on its alkalinity.

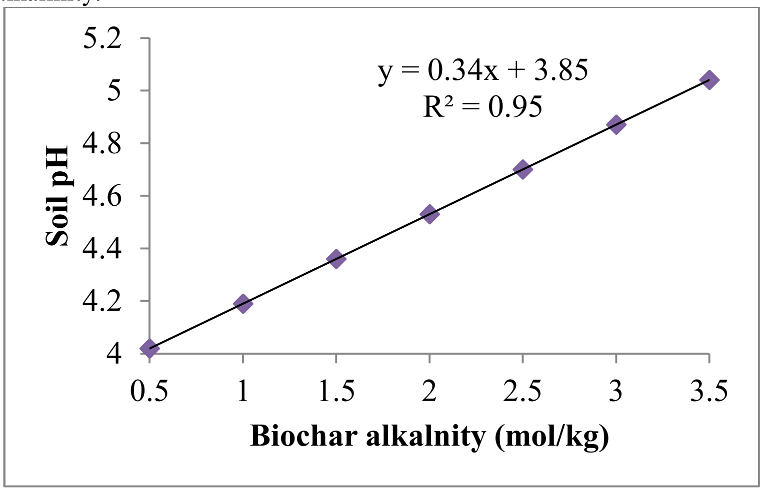

Fig.2. Soil pH as affected by level of biochar alkalinity
Source: Ren –Kou (2011)

2.2 Cation exchangeablecapacity (CEC)

Significant increment of cation exchange capacity was reported from a number of studies. (Bayu*et al.*, 2015; Rajesh *et al*., 2013). The possible reason for increased in CEC due to the amendments of biocharmightbe high surface area, high porous, possesses organic materials of variable charge that have the potential to increase soil CEC and base saturation when added to soil (Glaser *et al.*, 2002). Laird *et al*. (2010) indicated that the biochar treatments significantly increased cation exchange capacity by 4 to 30 % compared to the controls. Similarly, cation exchange capacity of the highly weathered soil was increased from 7.41 to 10.8 cmol kg^{-1} after biochar treatment (Jien and Wang, 2013). Available evidences also suggest that, the intrinsic CEC of biochar is consistently higher than that of whole soil, clays or soil organic matter (Sohi *et al*., 2009). Therefore, it is quite logical that soil treated with biochar had a highest CEC than the corresponding un-treated soil. Studies by Agusalim *et al*. (2010) and Chan *et al*. (2008) have also revealed the increase in soil CEC after the application of biochar.

2.3. Effects on Exchangeable acidity

Exchangeable acidity is the measure the concentration H^+ and Al^{3+} ions reserved on soil colloid after the active acidity is measured (Mccarty ,2003). When the exchangeable acidity of the soil is high with a subsequent low pH, it affects the soil condition and many processes in the soil. In an acidic condition, aluminum fixes phosphorus causing its deficiency in plants, the bioavailability of iron, aluminum, or manganese can be very high and may reach toxic levels at lower pH (Lui *et al*.,2014).

A number of studies indicated that biochar application decreased the exchangeable acidity (Table 1) of the soil (Tariku *et al*., 2017; Chan *et al*.,2008). According to Ritchie (1994) who indicated that biochar application increases soil pH which in turns decreased acidity by precipitates exchangeable Al^{3+} into insoluble hydroxyl Al-species. Apart from increase in soil pH, Yuan *etal*. (2011) reported that amendments of biochar can release their base cations into acidic soil which can contribute in exchange reactions and replace the exchangeable Al^{3+} and H^+ on the soil surface and lessening the soil exchangeable acidity.

Table 1. Effect of biochar application on Exchangeable acidity.

Rate of biochar t ha^{-1}	Exchangeable acidity (Cmol/Kg)
Control	5.43a
6	5.04a
12	3.89a
18	2.24b
LSD (P< 0.05)	2.02
CV (%)	15.12

Means followed by the same letter(s) across columns and row are not significantly different (*P* = 0.05)
Source; Tariku *et al*. (2017).

These results suggested that the influences of biochar on soil physical and chemical properties are varied with different application conditions. Long-term field trials need to be conducted to test whether soil properties can be influenced permanently through biochar application.

4. Role of biochar in climate change mitigation

Climate change is one of the chief intimidations to agriculture in the vicinity of futures. Its most apparent effects would be on temperature, precipitation, insect pest and pathogen, weeds soil and water quality. It observed that agricultural activities contribute 25% greenhouses gas emission and major source of methane (48%) and nitrous oxide (52%) from rice fields (Lakshmi *et al*., 2015). Therefore, strong action should be carried out to reduce emissions and increase removal of greenhouse gasses from the atmosphere.

Biochar has been described as a possible means to sequester carbon (C) to mitigate climate change (Sohi*et al*., 2010). Currently, there are extensive literature reviews about the use of biochar to mitigate climate change by increasing carbon storage in soils (Lehmann *et al*., 2011).Biochar counteract climate change problems by the following two key ways. Firstly, by its molecular structure, in which chemically and biologically more stable than the original carbon form, which making it more difficult to be converted back to CO_2, meaning it can store carbon for a long time. Most recently, Woolf *et al*. (2010) predicted that sustainable biochar systems could amount to net avoided emissions of up to 1.8 Gt CO_2-Ce a year, for total net avoided emissions of 130 Gt CO_2-Ce over 100 years.

Secondly, biochar in soil change emissions of other greenhouse gases from soil such as nitrous oxide (N_2O) or methane (CH_4) (Zhang *et al*., 2010; Taghizadeh-Toosi*et al*., 2011). A three years trail by Rondon*et al*. (2005) on soybean crop was found 50 % reduction of N_2O emission from the soil, when biochar applied at the rate of 20 t ha^{-1} compared to control. The reduction of N_2O emission is highly dependent for two factors (*viz*. biochar rates and moisture content of soil). Spoaks*et al*. (2009) found that N_2O emission significantly reduced at the higher rate (20 - 60 t ha^{-1}) of biochar and no reduction at lower rates (2-10 t ha^{-1}). Yami*et al*. (2007) observed that N_20 emission was dependent on soil moisture content. The water pore space filled up to78% reduced the emissions of by 89% when biochar was added, compared to the control. Conversely, when the soil pore space filled by water up to 83%, reduced N2O emission nearly by 50% when biochar incorporated.

In a field experiment addition of 9 t $ha^{-1}$of biochar was found to increase soil uptake of methane (CH_4) and reduced methane emission by 96% compared unamended soil (Karhu *et al*., 2011). However, in some cases it observed that application of biochar at 20 t ha^{-1} increased annual CH_4 sinks by 200 mg CH_4 m^{-2}, when compared to control (Rondon *et al*., 2006). Similarly, Zhang *et al*. (2010) observed that applying wheat straw biochar at rate of 0, 10 or 40 t ha^{-1}caused greater CH_4 emissions. These studies indicates that ,biochar has a solution in mitigating climate change by reducing the negative effects of greenhouse gasses from the soil and more research is necessary to understand the mechanisms and measure the effects of biochar application on greenhouses gases emissions when different biochar raw materials are incorporated to different type of soils and production systems.

5. Role of biochar in Soil microorganism

Biochar has a role in changing soil microorganism abundance (Liang *et al*., 2010; Grossman *et al*., 2010). A study of Domene *et al*. (2014) indicated that microbial abundance increased from 366.1 (control) to 730.5 μg C g^{-1} after application of biochar at the rate of 30 t ha^{-1}. Thus changes have a direct effects on nutrient cycles (Steiner *et al*., 2008b) and indirect effect plant growth (Warnock *et al*., 2007). The effects of biochar on soil biota may be driven as much by its physical properties as by its chemical properties. Some possible reasons that responsible for the increase of microbial abundancewere listed below.

5.1. Reduction in tensile strength

Incorporation of biochar reduced tensile strength by 50% and 72% at amendment rate of 50 and 100 ton ha^{-1} respectivelycompared to initial value of 64.4kpa (Chan *et al*., 2007).Thus reduction in soil tensile strength (i) make the plant root and mycorrhizal nutrient excavating more effective (ii) make it physically easier for invertebrates to move through the soil (iii) altering predator/prey dynamics (Lehmann *et al*.,2011).

5.2. Sorption of toxins

Sorption of compounds to biochar that would otherwise inhibit microbial growth may increase microbial abundance. Compounds such as catechol that are toxic to microorganisms (Chen *et al*., 2009) were found to be strongly sorbed to comparatively high temperature biochars produced from ash-rich corn stover (Kasozi *et al*., 2010). This is due to surface of biochars which contain a number of chemically reactive groups, such as COOH, OH, ketone, that give biochar a great potential to adsorb toxic substances, such as Al, manganese (Mn) in acid soils and arsenic (As), cadmium (Cd) in heavy metal contaminated soils. Thus, biochar could be used to rehabilitate environments that may be hostile to plant growth.

5.3. Avoidance of desiccation

Periodic drying of soil leads to stress and, ultimately, to dormancy or mortality of microorganisms(Schimel *et al*., 2007). The large surface area of biochars (Liang *et al*., 2006; Downie*et al*., 2009) helps to increase water holding capacity of soil and promote the growth of microorganism.

5.4. Altered pH

The pH of soils may change, after biochar additions, because of the acidity or basicity of biochar. Different living conditions will be formed for microorganisms with different pH of biochar. For example, AciegoPietry and Brookes (2008) indicated that microbial biomass C increased from about 20 to 180 μg biomass C g^{-1} soil and microbial biomass ninhydrin-N increased from about 0.5 to 4.5 μgninhydrin- N g^{-1} soil with rising pH values from 3.7 to 8.3 under otherwise identical environmental conditions, which demonstrated that the rising soil pH could increase microbial biomass. Moreover, there are different influences on different microbial abundance if pH values are changed. With the increase of pH up to values around 7, bacterial populations were possible to increase, whereas, no change in fungi abundance was observed (Rousk *et al*., 2010).

5.5. Suitable shelter

Moreover, biochar, containing a well-developed pore structure, may provide living environment for microorganisms. Both bacteria and fungi are hypothesized to be better protected against predators or competitors by exploring pore habitats in biochar (Thiesand Rillig, 2009). In general, it is hypothesized that the large porosity of biochar provides surfaces for soil microbes to colonize and grow, where their predators cannot access them (i.e. the "refuge" hypothesis). Furthermore, the fact that these surfaces sorb inorganic nutrients well as organic substances and gases might provide ideal environments for microbes.

6. Future line of work

Biochar has the potential for broad application in increases soil cation exchange capacity, pH and microbial biomass ,carbon sequestration, reduction of greenhouse gas emissions, remediation of heavy metal toxicity which in turn provides favorable chemical and biological condition for optimum crop growth. However, few basic mechanism and exploitation of biochar remain understandable. The following knowledge gaps are listed below.

- There is very limited understanding of the mechanism through which biochar effects on fluctuations of methane (CH4) and nitrous oxide (N2O).
- The shelf life of biochar (i.e. decomposition rate) is still remaining unclear.
- Most laboratory and filed works were mainly focused on short term effect of soil as a result of this long term experiments in soil and physical properties is very limited.
- Application mechanism of biochar to the soil remains unclear. Since biochar is highly dependent on a factors like feed stock and soil type and application rates.