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BIOCHAR: A MECHANISM OF SOIL AMMENDMENT FOR AGRICULTURAL PRODUCTIVITY

EFFA, EMMANUEL BASSEY AND OTIE, VICTORIA OKO

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ABSTRACT

A review on the role of biochar in agricultural productivity revealed the importance of biochar as a soil amendment system for sustainable agriculture. There is a growing interest in its use, as a fertilizing material or as incorporation into farming systems for amending soils. It is a fact that biochar is fast assuming the status of a quick fix solution to all soil degradation problems associated with the sustainable management of plant nutrients for strategic increases in crop yields. These call for a careful examination of the benefits and definite drawbacks of biochar. To avoid the abuse of biochar, there is need to quantitatively and qualitatively study its application and deployment for soil amelioration and nutrient boost for crop production. This involves field studies and extensive review of available literatures, to clear any doubt that may exist in the use of biochar. A well-established knowledge based on its beneficial potentials will inform both scientists and farm practitioners how best to engage biochar. This review essentially seeks to highlight the usefulness of biochar and its possible applications and drawbacks as a tool in sustainable agriculture.

KEYWORDS: Biochar, sustainability, Nutrients

INTRODUCTION

Crop growth and yield have never been more challenged than now, with the escalation of climate change. The challenges of food production and climate change have been made worse by the interplay of other biotic and abiotic factors which have compromised soil quality and resulted in declines in food yield per hectare (Thalman and Santelia, 2017). Food security in Nigeria and Sub-Saharan Africa as a whole has reached the levels of insecurity, with large numbers to feed but little yields from the farm. Biochar is believed to be a simple, yet powerful tool to ameliorate soil conditions. In the course of charring organic materials, much of the carbon becomes “fixed” into a more stable form, and when the resulting biochar is applied to soils, the carbon is effectively sequestered (Liang *et al*. 2008).

According to Rawat (2019), the strength of soil is dependent on nutrient availability. In other words, soils that have lost their nutrient supply capacity could be termed weak soils. The emphasis of today’s sustainable agriculture is the development of sustainability in plant nutrient supply. Green plants need a number of soil mineral macronutrients such as nitrogen (N), phosphorus (P), and potassium (K) for their growth as well as several micronutrients for balance in yield. Soil nutrient levels may decrease over time after crop harvesting, as nutrients are not returned to the soil (Pathak, 2010).

In Nigeria, the soil in many agro-ecological zones is deficient both in macronutrients like N.P.K. as well as secondary nutrients such as sulfur, calcium, and magnesium; and micronutrient elements as boron, zinc, copper, and iron. Hence, serious amelioration has to be undertaken in form of fertilization and nutrient fortification to increase crop nutrient profiles and boost yields. According to Kannan *et al*. (2016), biochar is a carbonaceous material generated from organic waste, by a process called pyrolysis. Pyrolysis (heating of organic materials under conditions of limited or zero oxygen) is the thermo-chemical decomposition of organic waste under different temperatures, in presence of little or no oxygen (Lehmann, 2007). This can be achieved in several different ways. Basically, pyrolysis can be slow or fast, yielding different quality of products. The relative quality of biochar as a soil amendment (McClellan *et al*. 2007) is solely dependent on the type of organic matter (or feedstock) that is used and the conditions under which the biochar is produced. In rating the quality of biochar, several workers (Liang *et al*. 2006, McClellan *et al*. 2007, McLaughlin *et al*. 2009) have determined that high adsorption and cation exchange capacities and low levels of mobile matter (tars, resins, and other short-lived compounds) are the most important factors in determining the quality of biocahar. These measures have a lot to do with its nutrient retaining capacity for sustainable release over a longer period of time.

Effa, Emmanuel Bassey, Department of Crop Science, University of Calabar, Calabar
Otie, Victoria Oko, Department of Soil Science, University of Calabar, Calabar

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During the production of biochar, the process generally releases more energy than is consumed, depending on the moisture content of the feedstock (Lehmann 2007). Heat, oil and gas that are released can be recovered for other uses, including the production of electricity. A sustainable model of biochar production primarily uses waste biomass, such as green-waste from municipal landscaping, forestry, or agriculture (for example, bagasse and other refuse materials from processing of agricultural value commodities). Biochar is fast assuming the position of a one stop solution to all soil degradation problems associated with the sustainable management of plant nutrients for strategic increases in crop yields. This calls for a careful examination of the benefits and definite drawbacks of biochar.

STATE OF BIOCHAR IN SOIL: effects on soil acidity and other physicochemical properties

The quality attributes of biochar are specifically dependent on several factors, such as the soil type, presence of metals and the raw materials used for carbonization, the conditions under which pyrolysis is carried out, and the volume of biochar applied to the soil (Debela *et al*., 2012) and perhaps, the methods of application. In addition, the biochar amendment to the soil proved to be beneficial to improve soil quality and retain nutrients, thereby enhancing plant growth (Bonanomi *et al*., 2017). Since biochar contains organic matter and nutrients, its addition increases soil pH and reduces acidity and electric conductivity (EC). The organic carbon (C), total nitrogen (TN), available phosphorus (P), and the cation exchange capacity (CEC) are similarly enhanced (Dume *et al*., 2016). Biocahar therefore has liming potentials and with its sponge effect can supply nutrients for a long time in a modified environment that enhances plant uptake. Nigussie *et al*. (2012) reported that the improvement of soil properties as a result of biochar application and the increase in the absorption of nutrients by plants in soils treated with biochar can be traceable to factors such as; the availability of plant nutrients and ash in the biochar and its large surface area, porous nature, and the potential ability of biochar to behave as a medium for microorganisms. According to Chan *et al*. (2008), when biochar was applied, there was a decrease in soil core tensile strength, indicative of the fact that the use of biochar can reduce the risk of soil compaction. Biochar in the soil can be extremely useful to improve its quality and stimulate plant growth. Placek *et al*. (2016) had articulated several uses and positive effects of biochar amendment as an effective method to reclaim soil that has suffered nutrient loss and contamination and to achieve high crop yields without causing harm to the natural environment. Similarly, Rawat *et al*. (2019) reported the positive influences of biochar on soil quality and growth of plants and suggested that using biochar could be a good way to overcome nutrient deficiency, and a suitable technique to improve farm-scale nutrient cycles.

EFFECTS OF BIOCHAR ON CROP YIELD

One of the strategic means of improving energy efficiency of agricultural systems globally is by returning crop waste into the soil, either without processing or through organic additives to combat soil degradation phenomena. Use of biochar in agricultural practices has improved soil quality and enhanced agricultural sustainability through its capability in enhancement of nutrient uptake from the soil, improvement of soil physical properties, reduction of soil compaction and carbon sequestration among others. Recently, studies on biochar and its effects on crop yield have been on the increase. According to Singh *et al*. (2019), amendment of agricultural soils with biochar facilitated significant yield increases as a result of greater productivity from continuous land use. Another study (Yu *et al*., 2019) reported significant improvement in plant growth and yield when biochar was combined with inorganic fertilizers. The relationship between biochar and productivity of rice, wheat and maize was evaluated. It was discovered that biochar boosted the productivity of these crops substantially by 16, 17 and 19 %. This could be associated with its liming effect, water holding capacity and nutrient retention in the soil (Fischer *et al*., 2019; Jeffery *et al*., 2015). It was also reported that biochar has N content within the range of 0.04 to 2.4 % and is capable of reducing compost and soil N losses through reduction in NH_3 volatilization, N_2O emissions and N leaching (Al-Wabel *et al*., 2018). The low N_2O emissions could be attributed to a better soil aeration as a result of an increase in soil pH and nitrate adsorption (Cornelissen *et al*., 2013; Van-Zwieten *et al*., 2014).

The positive response of crops to biochar application could be attributed to its significant influence on soil parameters and plant growth. In Kannan *et al*. (2016), the application of red gram stalks of biochar at 5 tons ha^{-1} increased the dry matter production and groundnut pod yield in acidic red soil. Also, Hussain *et al*. (2017) reported that the combination of biochar at the rate of 25 tons ha^{-1} with farm yard manure at 10 tons ha^{-1} along with 30 kg ha^{-1} of N improved mung bean growth and yield. There was a significant increase in the above ground biomass and grain yield of durum wheat as compared with the control when treated with biochar (Steiner *et al*., 2007). Wheat straw biochar in combination with NPK 80:80:80 kg ha^{-1} was reported to increase maize yield in *Inceptisol* (Purakayastha, 2010).

Biochar has a promising role in recent environmental management strategies. As a soil amendment utilized on a large scale, it has the capacity to be used as a promising resource for environmental technology because of its high economic and environmental benefits. Therefore, the need to emphasize on the importance of biochar and its gainful relevance in crop production cannot be overemphasized.

ROLES OF BIOCHAR IN CARBON SEQUESTRATION AND CLIMATE CHANGE MITIGATION IN SOIL

Sequestration of carbon involves the seizure and storage of carbon in soil to prevent its emission in the atmosphere (Duku *et al*., 2011). According to IPCC (2019), about 72 % of global warming is caused by carbon-dioxide as a major greenhouse gas. However, other gases like CH_4, N_2O and F-gases also contribute as well, but with minimal rates of 20 %, 5 % and 3 %, respectively. It is estimated that use of this method to “tie up” carbon has the potential to reduce current global carbon emissions by as much as 10 percent (Woolf *et al*. 2010). Application of organic fertilizers and charcoal increased nutrient stocks in the rooting zone of crops, reduced nutrient leaching and thus, improved crop production on acid and highly weathered tropical soils (Steiner, 2007).

The sequestration of carbon in soil is a potent option for the mitigation of climate change. Recently, the awareness of sequestrating atmospheric carbon into biochar and its application to soil is on the increase. Soil amendment with biochar is a great remedy for mitigation of climate change through the sequestration of carbon which promotes other beneficial effects in agriculture and the environment at large. Soil incorporated biochar also reduce N_2O and CH_4 emissions from the soil. It provides suitable management options for agricultural wastes, enhances sustainability of soil, reduces the requirement for fertilizers and several other potential benefits (Majumder *et al*., 2019 and Wang *et al*., 2019).

When plants assimilate carbon-dioxide through photosynthesis, it is stored in the above and below-ground biomass, and also absorbed in soil for improvement of organic carbon. This process is termed carbon sequestration. Naturally, organic carbon accumulation in soil is very slow and prone to reduction through soil erosion and continuous cultivation. Therefore, land-use systems that involve the utilization of large amount of carbon within a short period of time, while its storage stands for a longer time span are better options for minimizing carbon-dioxide concentration in the atmosphere, as well as global warming and climate change mitigation.

SEQUESTRATION OF OTHER GREENHOUSE GASES (GHGs) BY BIOCHAR

The accumulation of greenhouse gases (GHGs) from the atmosphere, such as carbon-dioxide, methane, nitrous oxide and fluorinated gases as a result of excessive anthropogenic activities are the major causes of global warming. There is serious need to reduce the increasing effects of GHGs to minimize global warming. Despite several other means of GHGs mitigation, incorporating biochar into the soil is becoming globally acceptable due to its edge over other soil conditioners. Application of biochar to soil increases crop productivity, improves nutrient and water uptake, as well as several other environmental benefits (Chia *et al*., 2015). Apart from carbon sequestration, the incorporation of biochar into the soil also provides a better means for the utilization of agricultural wastes. Van Zwieten *et al*. (2009) reported that the priming effect of biochar has the capacity to reduce considerable quantity of methane and nitrogen (iv) oxide emissions from agricultural sites.

There is serious need for the mitigation of greenhouse gases due mainly to the increasing rate of global warming across the globe. Carbon-dioxide, methane and nitrous oxide are the three main GHGs that cause 90 % of anthropogenic climate change (IPCC, 2013). Managing the environment through greenhouse gas (GHG) mitigation includes the total avoidance of these emissions and total eradication of the gases existing in the atmosphere (Smith *et al*., 2007). Biochar can reduce GHG emissions from the soil through its direct and indirect influence on soil properties to enhance agricultural production and eliminate GHGs. When applied on forested soils at 30 ton/ha showed a significant reduction of about 31.5 % in CO_2 emission (Sun *et al*., 2014). More so, it suppressed N_2O in the continuous cropping of maize, whereas, no effect on CO_2 emission was recorded (Fidel *et al*., 2019). These proved that both temperature and soil moisture played a prominent role in CO_2 and N_2O emissions.

The reduction of N_2O emission in soil when biochar was applied could be as a result of increased oxygen supply through soil aeration. This will limit denitrification that usually occurs during low oxygen condition by soil microbes (Hale *et al*., 2012). Biochar enabled the availability of inorganic forms of N (NH_4^+, NO_3^- etc.), which in turn reduced the availability of N for nitrifiers and de-nitrifiers, and limited N_2O emission (Cornelissen *et al*., 2013b; Clough *et al*., 2013). Increased N_2O emissions could be mainly due to increased water content in the soil as a result of the added biochar that facilitated the denitrification process. The emission of soil CH_4 was reduced when amended with biochar because of its significant efficiency in uptake of CH_4, irrespective of the rates of application (Xiao, 2016).

The sustainability impact of biochar has greatly improved problematic soils by boosting its fertility and productivity. Crop productivity is highly facilitated by biochar due to its porous characteristics that uphold soil properties. The bio-remediating role of biochar increases surface area of soil for good water and nutrient capacities. These tendencies of biochar are known to further reduce the emissions of greenhouse gases (Mate *et al*., 2015).

DRAWBACKS OR DELETERIOUS EFFECTS OF BIOCHAR

The influence of untreated or uncharged biochar applied to soil in the short term maybe detrimental to plants, by initial nutrient immobilization. This is similar to the influence of bacteria or micro-organisms in poorly treated composts or farm yard manure that has not undergone adequate curing. These microbes can mobilize all available nutrients to synthesize their flora, leaving the plants in short supply of critical nutrients for a while before nitrogen fixation commences. Biochar with a high sorption capacity may adsorb nutrients and make them temporarily unavailable in the short term or for short gestation plants, except it is charged. However, in the long term, the sponge effect of biochar could benefit long season growing plants and improve soil chemical properties. Further research is ongoing on the sponge effect of biochar in crops in short and long term applications. Amoah-Antwi *et al*., (2020) suggested that soil applications of carbonized waste organic materials, including biochar could hold substantial prospects for the restoration of soil quality and attainment of food security across the globe.

CONCLUSION

There is scientific evidence that proved the efficacy of biochar as a useful material for the remediation of declining soil nutrients. The informed and careful use of biochar through incorporation into the soil, may provide a much-needed solution for the recovery of nutrients and increase in crop yield. This review therefore points to the need for carrying out actual field experiments and numerical studies to ascertain the efficacy of biochar, the best methods and rates of application that will bring maximum gains in production.

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