International Journal of Chemical Studies

P-ISSN: 2349–8528
E-ISSN: 2321–4902
IJCS 2017; 5(6): 1947-1950

Received: 26-09-2017
Accepted: 27-10-2017

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Ameliorating chemical properties of acid soils with biochar-A review

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Abstract

Amelioration of acid soil is a challenging task for the scientific community to mitigate the rising concentration of H^+ and Al^{3+} ion. Biochar used as a liming material in acid soil due to its high soil organic matter contents and soil fertility. Therefore, we reviewed the available information about the chemical properties of biochar as affected by different combustion procedures, and the effects of its application in agricultural fields on nutrient retention and crop production. Global production of black carbon has been reported between 50 and 270 Tg yr^{-1}, with as much as 80% of this remaining as residues in the soil. Biochar mitigate the elevated atmospheric CO2 due to its slow decomposition rate in soil. Biochar with combination of some fertilizers can produce significant benefits when applied to agricultural.

Keywords: Biochar, acid soil, soil productivity, soil amelioration, soil pH

Introduction

The term 'biochar' denotes black carbon formed by the pyrolysis of biomass, i.e. by heating biomass under oxygen-free or stress environment, so that it is not subject to complete combustion. The global production of black carbon has been estimated to be between 50 and 270 Tg yr^{-1}, with as much as 80% of this remaining as residues in the soil Lehmann *et al* (2003) [1]. estimated that a total of 9.5 billion tonnes of carbon could potentially be stored in soils by the year 2100 using a wide variety of biochar application programmes. The application of biochar to the soil is proposed as a novel approach to establish a significant long-term sink for atmospheric carbon dioxide (CO2) in terrestrial ecosystems Lehmann *et al* (2003) [1]. Biochar application has received a growing interest as a sustainable technology to improve highly degraded soils (Lehmann and Rondon, 2006) [7]. Biochar can enhance plant growth by improving soil chemical characteristics (i.e., nutrient retention, nutrient availability), soil physical characteristics (i.e., bulk density, water holding capacity, permeability), and soil biological properties, all contributing to an increased crop productivity (Glaser *et al*., 2002; Lehmann and Rondon, 2006; Yamato *et al*., 2006) [8, 7, 23]. In addition, biochar is highly recalcitrant to microbial decomposition and thus guarantees a long term benefit for soil fertility (Steiner *et al*., 2007) [6].

Biochar has the potential to increase conventional agricultural productivity and enhance the ability of farmers to participate in carbon markets beyond the traditional approach by directly applying carbon into the soil. The use of biochar as soil amendment is proposed as a new approach to mitigate man-induced climate change along with improving soil productivity. The use of biochar in agriculture is not new; in ancient times farmers used it to enhance the production of agricultural crops. One such example is the slash and burn cultivation, which is still being practiced in some parts of North East India. It has been suggested by many authors4,6 that the use of biochar as soil amendment meets the above requirements; since the biomass is protected from further oxidation from the material that would otherwise have degraded to release CO_2 into the atmosphere. When biochar applied as a soil amendment, it improves crop yield bystimulation of beneficial soil microbes such as mycorrhizalfungi (Warnock *et al*., 2007) [2],improves water holding capacity, and soil physical properties, (Kramer *et al*., 2004; Liang *et al*., 2010; Ogawa and Okimori, 2010) [24], and store carbon for long time, ameliorates degraded soils and reduces soil acidity (Major *et al*., 2010) [3] and it can increase available nutrient larger potassium, phosphorus, and zinc availability, and to a lesser extent, calcium and copper (Lehmann *et al*.,2003) [1] increases of soil base saturation (Glaser *et al*., 2002; Major *et al*.2010) [3] Biochar applied in typical Ultisol, increases soil pH and cation exchange capacity (CEC) (Peng *et al*., 2011; Yuan and Xu (2011) [18, 20, 21].The soil pH increased from 4.33 pH to 5.38, when biochar was added (Cheng *et al*., 2006) [13].The biochar produced from corn straw, peanut straw, and soybean straw at a 3000C temperature were all alkaline, but the pH of biochar from canola straw, wheat straw, and hull straw was 6.48, 6.42 and 6.43, respectively (Yuan *et al*., 2011) [20, 21].

Characteristics of biochar

The net ability of biochar to enhance ecosystem services depends, in part on the specific qualities of the biochar and site conditions. According to different literatures there was little uniformity on the production method of biochar, materials were created in a range of pyrolyzers from highly sophisticated industrial equipment to primitive earthen mounds. Due to the variation of feedstock source, time and temperature of pyrolysis, kiln type also varies the pH, C:N ratio, and different nutrient contents of the biochars. (Table 1)Kajsa *et al* observed the nutrient concentration in biochar produced from different plant materials.

Table 1: Carbon and Macronutrient concentration (%) in biochar from different plant materials

Plant Material	C	N	P	K	Ca	Mg
Fresh Banana leaves	51.2	1.05	0.16	8.68	1.83	0.76
Maize stovers	52.2	0.58	0.10	1.03	0.64	0.50
Wilted Banana leaves	54.0	1.37	0.12	0.55	4.13	0.72
Coffee leaves	54.1	2.63	0.27	4.80	3.33	1.01
Coconut leaves	61.0	0.47	0.10	3.00	1.29	0.55
Cassava	60.8	1.73	0.31	4.01	3.22	0.99

Biochar used as soil conditioner

Biochar as soil conditioner are warranted, obviously due to carbon sink function, but also, because of potential for increased nutrient use efficiency in farming (Brandstaka *et al*., 2010) [12].Major *et al*., (2010) [3] studied the effect of biochar application on crop yield. They concluded that the crop yield, nutrient uptake and availability of Ca and Mg were greater in soil where biochar was applied.

Impact of biochar on crop productivity

The application of biochar promote plant prouctivityand yield through several mechanisms.Physical conditions change with biochar, it's dark colour alters thermal dynamics and facilitates rapid germination and increase growth.

Effect of biochar on productivity of cassava based cropping system evaluated by Islami *et al*., (2011) [15]. The application of biochar increases in yield of cassava and maize (15 Mg ha–1). In an experiment conducted by Southavong *et al*., (2011) [25] the effect of two types of biochar (Downdraft Gasifier or Updraft Gasifier Stove) were evaluated at different levels on productivity of rice plants in acid soil. Biochar raised soil pH from 4.5 to 5.13 and 5.40 with the higher value for stove biochar. The level of biochar was raised from 0 to 24% showed a curvilinear increasethe biomass growth of rice (over 30 day period from planting) followed by a slight decline at higher levels. The biochar and FYM applications at the rate of 25t and 5t ha-1 are recommended for improving maize growth and efficient weed control (Arif *et al*., 2012) [11].Zhang *et al*., (2013) [22] used four biochar samples and studied their chemical properties. The results showed that wood biochar and bamboo biochar samples were 60%-80% more hydrophobic and better sorptive, aromatic, and humification properties than those of rice husk biochar and rice husk ash. Therefore it may be used as a bulking agent and a composting amendment during the solid waste

composting process.Cornelissen *et al*., (2014) studied that the effect of maize and wood biochar on maize yields. In sandy acidic soils, they reported that CF (Conservation Farming) and biochar amendment can be a promising combination for increasing harvest yield. Moderate but non-significant effects on yields were observed for maize and wood biochar in a red sandy clay loam

Prabha *et al*., (2013) [19] opined that the biocharapplication considerably influenced the growth profile and grain yield of the rice plants compared to other amendments and showed positive response.Hseu *et al*.,(2014) studied the effect of biochar application produced from rice hull on changes of physiochemical characteristics and erosion potential of a degraded slopeland soil. They concluded that available water contents significantly increased in the amended soils and biochar application could availably raise soil quality and physical properties for tilth increasing in the degraded mudstone soil.Also, biochar can stabilize carbon belowground and potentially increase agricultural and forest productivity (Krishnakumar *et al*., 2014) [17].

Impact of biochar on soil health

It is well known that biochar affects on microbial populations soil physico-chemical properties.Both biochar and mycorrhizal association, a symbiotic association in terrestrial ecosystems, are potentially important in various ecosystem services provided by the soil, contributing to sustainable plant production, ecosystem restoration, soil-carbon sequestration and hence mitigation of global climate changes (Warnock *et al* 2007) [2]. Through the application of biochar increasing SOC content and water retention as well as providing a habitat for microbes. Adding of biochar to soil can significantly increase seed germination, plant growth, and crop yields Chidumayo (1994) [27]. The application of charcoal can increase the pH and decrease the Al saturation of acid soils, which often are major constraints for productive cropping in highly weathered soils of the humid tropics (Cochrane and Sanchez 1980).Biochar also adds some macro- and micronutrients (Steiner *et al* 2008) [5]. Not only the nutrient contents but also the nutrient retention can be improved with biochar additions to soil. The accumulation of the ashes from burned biomass and its effect on soil pH is a well-documented mechanism for improving soil fertility (Sanchez *et al*.1983) [29].

Effect of biochar on environment

Biochar can be a simple yet powerful tool to combat climate change. As organic materials decay, green house gases such as carbon dioxide and methane which is 21 times more potent as a greenhouse gas than CO_2, are released into the atmosphere. By charring the organic material, 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.

Biochar addition seems to generally enhance plant growth and soil nutrient status and decrease nitrous oxide (N_2O) emissions. Biochar can use as soil amendment for improving soil quality and soil-carbon sequestration, implications of long-term biochar application on environmental conditions need to be assessed. Biochar additions suppressed N_2O production. Biochar additions also significantly suppressed ambient CH_4 oxidation at all levels compared to unamended soil. The recalcitrance of the biochar suggested that it could be a viable carbon sequestration strategy, and might provide substantial net greenhouse gas benefits if the reductions in N_2O production are long-lasting. Cao *et al* (2009) [10]. evaluated the ability of dairy manure-derived biochar to sorb heavy metal, Pb and organic contaminant, atrazine.

For future research interventions

The basic mechanisms of biochar could provide beneficial functions to the soil, crop productivity and the agro-ecosystem. We can use biochar as a large-scale for agriculture purposes because the amount of carbon sequestered in the biochar biomass must take into account of net carbon balance, i.e. the amount of CO_2 evolved for producing biochar must be considerably less than the amount of carbon sequestered in charcoal. There must be positive carbon balance for producing biochar biomass. As we know the decomposers present in the soils derive energy from the breakdown of SOM, particularly the soil heterotrophs. Thus their dynamics under the presence of non-degrading carbon source must be fully understood. Otherwise it may have some adverse effect on the soil ecological settings.

Conclusion

Aplication of different types of biochar materials,which prepared from local resources, shows promise as ecologically sound technology. Biochar helps for improving in soil physical, chemical, biological as well as crop productivity. However, the absence of the significant alternative, uses of biochar as an energy source constitute a major economic constraint to the practical application in acid soils. Biochar could be the panacea to mitigate the increasing CO2 concentration in the environment provided its rate of application and mechanism of action are fully understood.

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