International Journal of Applied
and Natural Sciences (IJANS)
ISSN(P): 2319-4014; ISSN(E): 2319-4022
Vol. 7, Issue 5, Aug - Sep 2018; 109-122

International Academy of Science, Engineering and Technology
Connecting Researchers; Nurturing Innovations

POTENTIAL OF ENGINEERED PYROGENIC CARBON IN REVITALIZING FERTILITY OF SUB-SAHARAN AFRICAN SOILS: A REVIEW

A. Ibrahim[1], E. E. Okorie[2] & M. L. Bubarai[3]

[1,2]Department of Soil Science, Modibbo Adama University of Technology, Yola, Nigeria

[3]Department of Agronomy, Sam Higginbottom University of Agriculture, Technology and Sciences, Allahabad, Uttar Pradesh, India

ABSTRACT

The soils of Sub-Saharan Africa are generally relatively of low inherent fertility status because of the nature of the soils, climatic conditions and scanty vegetation cover that facilitate intensive degradation and perennial loss of topsoil coupled with poor soil management practices. These factors lead to poor crop yields, hunger and food insecurity in the region. Being an organic based soil nutrient management systems, engineered pyrogenic carbon could be a reliable soil management strategy for Sub-Saharan African. Pyrogenic carbon may not be a silver bullet that will solve environmental problems without a much wider and far-reaching strategy. But it can provide an important tool for addressing a wide range of the major challenges bordered around soil degradation and food insecurity, climate-smart agriculture, and waste management. This review therefore, synthesizes current knowledge regarding the behavior of engineered pyrogenic carbon as a soil amendment in order to highlight its prospects for revitalizing the low fertility status of the soils of Sub-Saharan Africa. Studies show strong evidence that engineered pyrogenic carbon, especially the cost-effective biochar, retains recalcitrant carbon in the soil that could improve soil structure, increase nutrient retention and availability, prevent loss of nutrients, support crop growth and increase crop yields. It is imperative therefore, that the ability to revitalize the low fertility status of Sub-Saharan soils lies on biochar, a cost-effective engineered pyrogenic carbon that smallholder African farmers can afford.

KEYWORDS: *Degradation and Food Insecurity, Nutrient Dynamics of the Amazonian Terra Preta*

Article History

Received: ***01 Aug 2018*** **|** ***Revised:*** ***07 Aug 2018*** **|** ***Accepted:*** ***18 Aug 2018***

INTRODUCTION

Pyrogenic carbon is the pyrolyzed carbon component of any carbonaceous material which has undergone incomplete combustion. It is inclusive of many other terms, including soot, char, black carbon, charcoal, biochar, micro graphite and a range of other compounds of pyrogenic origin whether they are naturally made result of anthropogenic activity. In a bid to differentiate between the carbon component and the organic material itself, different researchers have come up with terms such as pyrogenic organic matter while referring to the organic materials which have undergone pyrolysis, strictly using the term "pyrogenic carbon" for the carbon component alone.

The term "engineered pyrogenic carbon" was coined to differentiate between pyrogenic carbon formed not from natural occurrences or wildfire but from the carefully prescribed process of burning that consciously excludes oxygen in order to obtain pyrogenic carbon similar to those native to our environment. Biochar and activated charcoal therefore, fall under this category. Seeing that biochar is more cost effective and therefore suitable for agricultural production (Fengjie*et al*., 2015), the term engineered pyrogenic carbon in this paper refers to biochar.

In the past decade, it has been recognized that pyrogenic carbon is a significant component of the anthropogenic, highly fertile, Amazonian dark soil, terra preta (Glaser *et al.,* 2001). This observation has stimulated interest in biochar as a tool for improving soil fertility and crop yields and, as a result of its apparent environmental stability (Sohi*et al*., 2010; Kuzyakov*et al*., 2014), to provide significant long-term soil sequestration of carbon to offset a significant fraction of anthropogenic emissions (Lehmann, 2007 and Woolf *et al*., 2010).

True to these assumptions, biochar has shown close similarity to the pyrogenic carbon of the Amazonian terra preta and the incorporation of biochar into the soil has been shown to have many beneficial effects, such as increasing crop yield and mitigating soil nutrient losses (Sohi*et al.,* 2010; Spokas*et al*., 2012; Clough *et al.,* 2013). Therefore, interest in the use of biochar as a soil additive has been expanding because of its dual benefits of carbon sequestration and soil fertility improvement (Sohi*et al.,* 2010).

The prospects that biochar presents for soil management, soil quality improvement and long-term climate change mitigation has provided a recent stimulus to research factors controlling pyrogenic carbon stability, degradation potential and interactions between pyrogenic carbon and the environment. This review therefore, synthesizes current knowledge regarding the behavior of engineered pyrogenic carbon (biochar) as a soil amendment and its potential in revitalizing low fertility Sub-Saharan African soils.

Statement of the Problem: It is a common fact that the soils of Sub-Saharan region have relatively low inherent fertility due to degradation and loss of topsoil to wind erosion and desertification resulting in reduced accumulation or low level of organic matter coupled with poor soil management practices of the fragile soils (Omotayo and Chukwuka, 2009).

The present problem of soil nutrient depletion and degradation have been considered serious threats to agricultural productivity and have been identified as major causes of decreased crop yields and per capita food production in Sub-Saharan Africa (Henao and Baanante, 2006).

Omotayoand Chukwuka (2009) in their review identified the utilization of organic based soil nutrient management systems as a reliable soil management strategy for Sub-Saharan African Soils, the incorporation of the cost-effective biochar presents a massive opportunity for the management of these low fertility African soils while also advancing climate-smart agriculture.

The objectives of this review are to explain the mechanism of engineered pyrogenic carbon for soil fertility improvement and to expose the prospects of engineered pyrogenic carbon in managing low fertility soils.

The Amazonian Terra Preta: The Amazonian terra pretta otherwise known as the Amazonian Dark Earth is the local name given to the dark-colored soils that have been discovered in the Brazilian Amazon region and in several countries in South America. The origin of the terra preta is not entirely clear because there remain unanswered questions regarding their origin, properties and their distribution. It has been proposed however that these dark soils were most likely created by the pre-Columbian Indians living in the area before the invasion by the Europeans.

Irrespective of the conflicting theories that have been presented about the terra preta, the fact that has survived the arguments and received wide acceptance is that these dark earth are highly fertile and were a product of indigenous soil management in the region (Lehmann, 2007).

The Amazonian terra preta although differing in features in different locations is characterized by high soil organic matter and higher cation exchange capacity, base saturation and pH than surrounding soils lacking in that distinctive color (Liang *et al.,* 2006)… It has also been found that terra preta has a high phosphorus content of about 200-400mg/kg (Glaser *et al*., 2009;Lehmann *et al.,* 2004) These impressive characteristics obviously imply that the dark soils of the Amazon are highly fertile.

Soil Organic Matter Content of Amazonian Terra Preta: High black carbon content is the most important property of the Amazonian terra preta and it is this property that influences carbon dynamics and stability in these soils. The Amazonian terra preta has been found to have carbon content up to 150g C/kg in comparison to the soils surrounding it with a carbon content of 20-30g C/kg soil (Glaser *et al*., 2001). In addition, the horizons which are enriched with organic matter are not just 110-20cm deep which is a common sight in several soil types. In the case of the terra preta, the organic matter horizon can go as deep as 1-2m (Solomon *et al.,* 2007, Liang *et al.,* 2008).

Furthermore, the organic matter content in the dark soil is highly persistent backed by the fact that these elevated carbon contents were discovered hundreds of years after they were abandoned. The reason for this high stability is currently being studied by several researchers (Mao *et al*, 2012).

Nutrient Dynamics of the Amazonian Terra Preta: The Amazonian terra preta has been analyzed in comparison to adjacent soils with relation to nutrient dynamics, crop production, nutrient leaching and nutrient availability.

Major (2005) reported that maize yield on terra preta plots was 63 times greater than corresponding adjacent soils without fertilizer additions. The research also revealed that location averages varied from 0-3.15t/ha for the terra preta plots. Also, the Amazonian terra preta exhibited species richness which was 11 times greater than corresponding adjacent soil with the terra preta plots accommodating about 4-14species of weeds while the adjacent soil exhibited only 1-8 species. An experiment was also conducted by Lehmann *et al.* (2003) to determine the soil fertility and nutrient leaching losses of Amazonian terra preta in comparison with a Xanthic Ferralsol from the region. This experiment which was conducted on cowpea (*Vigna unguiculata*) and rice (*Oryza sativa*) showed significantly higher P, Ca, Mn, and Zn availability for the Amazonian terra preta than the Ferraslsol increasing biomass production and yield by 38-45% without any addition of fertilizer. Lehmann *et al.* (2003) also identified higher soil N in the terra preta although the wide C: N ratio may have led to lower foliar N contents of the crops. Interestingly, with a generally high nutrient content and availability, leaching was minimal.

These studies provided explanations for the sustainable fertility of the Amazonian terra preta and it is on this basis that studies to promote engineered pyrogenic carbon that would exhibit the same properties as the terra preta for soil improvement and climate change mitigation are being advanced.

Frontier Research

Research on pyrogenic carbon whether natural or engineered, has been met with interest by different scientific communities and stakeholders, hoping to explore the exciting perspective of waste and biomass management for the future economy. By exploring the precedent set by naturally occurring terra preta, insight to combine waste management, bio-energy production, climate change and pollution mitigation and sustainable agriculture into one approach using the engineered pyrogenic carbon has been pursued by several researchers. This synergism however, is possible upon the adequate study of the characteristics and behavior of the natural pyrogenic carbon.

The frontier research in this area therefore, involves the adequate study of the Amazonian terra preta, its distribution, properties, and behavior; the development of the man-made alternative to the natural terra preta and the development of a strategic approach that would make such innovation highly beneficial in waste management, climate change and pollution mitigation and sustainable agriculture. Presently, it has been found that there is a structural similarity between the pyrogenic carbon in the Amazonian terra preta and that found in biochar. This has led scientist to assume that accumulation or purposeful application of organic carbon from incomplete combustion may have been the primary reason for the high carbon contents and fertility of these soils (Glaser *et al.,* 2001).

This is a theory that had been proposed, but whether all or some of these soils were actually created by char applications to improve soils for agriculture has still to be demonstrated adequately. Nevertheless, there is a huge potential in the theory that the terra preta was formed from the incomplete combustion of biomass during a forest fire or similar occurrence.

Natural vs. Engineered Pyrogenic Carbon: Natural pyrogenic carbon found in the soil is produced from biomass and fossil fuels. Biomass-derived natural pyrogenic carbon can originate from wildfires, prescribed burnings for agricultural and forest management, and other human practices which may include cooking activities and metallurgy (Norwood *et al.,* 2013). In natural fire-prone ecosystems like grasslands, open woodlands, and forests, wildfires are often the most important source of pyrogenic carbon (Nocentini*et al.*, 2010). Historically, burning post-harvest agricultural residues from crop cultivation and weeds was a common agricultural practice (Thevenon*et al.,* 2010), therefore, it is the primary pathway through which pyrogenic carbon was introduced into agricultural soils. In the 1990s it was estimated that, globally, at least 25% of agricultural wastes such as sugarcane trash and crop straw were burned, producing pyrogenic carbon (Crutzen and Andreae, 1990). Fossil fuel (diesel and coal) combustion is another source of pyrogenic carbon which is presumed to play a greater role in industrial coal mining regions and urban areas than pyrogenic carbon generation from biomass source (Knicker, 2011).

Thermochemical techniques for the production of biochar, an engineered pyrogenic carbon, include slow and fast pyrolysis, gasification, microwave conversion, flash carbonization, Torre faction and hydrothermal carbonization (Xu*et al.,* 2012, Tan *et al*., 2015). Among them, slow pyrolysis, ranging from hours to days, and generally with relatively lower peak temperatures (Woolf *et al*., 2010), is most often used for biochar production (Xu*et al*., 2012). Unlike soil native pyrogenic carbon that is historically formed in uncontrolled natural conditions, biochar is purposely manufactured and its properties can be tailored under well-controlled conditions to satisfy specific applications. Pyrolysis kiln temperature is regarded as the most significant process parameter and is typically controlled within 200-900 ˚C (Ahmad *et al.,* 2014). The atmosphere of a biochar production chamber is normally controlled by the absence, or minimal oxygen to favor high biochar yield. Typically, biochar yields from slow pyrolysis, fast pyrolysis, and gasification are 30%, 12% and 10%, respectively (Inyang and Dickenson, 2015). Pyrolysis provides a means of value added management of biomass wastes such as livestock manures for which there are an estimated 80 million tonnes awaiting proper handling or land application. In addition, compared to conventional waste management methods such as direct application to soils or composting, application of biochar decreases carbon degradation speed and greenhouse gas emissions. Furthermore, compared to activated carbon production, it is often more cost-effective to produce biochar because of lower production temperatures and the activation process which is left out.

Table 1 below shows the high variability among the different types of pyrogenic carbon and their feedstock. The wildfire charcoal does not only differ from the man-made biochar, but also the biochar characteristics vary depending on the production temperature (Satin *et al.*, 2013).

Table 1: Characteristics of Original Material (feedstock) and Derived Pyrogenic Carbon From it

	Conversion (% Original Weight)	C (%)	N (%)	C/N	δ13C (‰)
Feedstock	-	40.5	1.0	39.6	-28.1
WildfireCharcoal	30	54.7	1.3	44.7	-29.0
Biochar 350 °C	62	58.3	1.7	33.5	-29.4
Biochar 500 °C	46	64.6	1.8	35.0	-29.2
Biochar 600 °C	40	64.3	1.3	49.3	-29.3

Source: Satin *et al.* (2013)

Properties and Behavior of Pyrogenic Carbon in Soil: Pyrogenic carbon is generally dominated by polycyclic aromatic hydrocarbons (PAHs); the size of PAH clusters increases with temperature (Mc Beath and Smernik, 2009), leading ultimately to the formation of micro graphitic sheets (Schmidt andNoack, 2000). Pyrogenic Carbonaceous Materials formed by biomass burning are often heterogeneous in nature, with both organized micro graphitic domains and disorganized domains of variably thermo-chemically altered organic material (Cohen-Ofri*et al.*, 2006). This continuum of potential thermo chemical reorganization confers a variable degree of stability to subsequent degradation. At one end of the pyrogenic carbon continuum, small PAHs are readily degradable by microorganisms, whereas at the other end, microcrystalline graphite is likely to be highly resistant to degradation by any mechanism operating in the surficial environment.

Thus it is appropriate to conclude that, there is a pyrogenic carbon degradation continuum. Therefore, the assumption that pyrogenic carbon is an inert and environmentally recalcitrant form of carbon has been replaced over the past decade by a more pronounced understanding that pyrogenic carbon represents a range of materials with a range of degradation potentials by a range of mechanisms (Birds *et al*, 2015).

It is more appropriate to consider pyrogenic carbon in the context of a degradation continuum ranging from relatively degradable lightly charred materials to highly condensed aromatic materials that are indeed likely to persist in the environment for millennia. Evidence that at least a component of pyrogenic carbon is not inert comes from observations of loss of this carbon from soils over time (Hammes*et al.* 2008), changes to the surface functionality of pyrogenic carbon (Cheng *et al.* 2006), and changes in susceptibility of environmentally exposed pyrogenic carbon to dissolution (Braadbaart*et al.,* 2009, Ascough*et al.,* 2011); from a large number of studies that have shown that pyrogenic carbon can support microbial respiration (Kuzyakov*et al.* 2014); and from the detection of molecules of original pyrogenic origin in soil humus(Jaff´e*et al.,* 2013). The degree to which pyrogenic carbon is susceptible to any of these processes is dependent on the nature of the material itself (material pyrolyzed, particle size, temperature, time of pyrolysis) and local environmental conditions (such as soil type, land use, temperature, moisture).

The physicochemical characteristics of pyrogenic carbon are complex and highly variable, dependent on the organic precursor and the conditions of formation. A component of pyrogenic carbon is highly recalcitrant and persists in the environment for millennia. However, it is now clear that a significant proportion of pyrogenic carbon undergoes transformation, translocation, and mineralization on comparatively short timescales (Bird *et al.,* 2015)

After formation, the environmental temperature where sufficient moisture is available is directly and positively related to carbon dioxide (CO_2) production from pyrogenic carbon (Cheng *et al.,* 2006, Zimmermann *et al.*, 2012). Soil conditions also influence the mineralization of pyrogenic carbon, directly through control of moisture and oxygen availability as well as indirectly and interactively through parameters that influence the activity of microbial communities and organomineral interactions (Hockaday*et al.* 2007). For the above reasons, identifying a simple rate constant for pyrogenic mineralization is difficult.

Effect of Biochar Addition on Soil Organic Matter: Two major mechanisms have been proposed to explain the short-term priming effects of biochar on soil organic matter decomposition, both concerning the labile components of biochar. The first mechanism is co-metabolism, where the labile carbon in biochar activates soil microorganisms decomposing soil organic matter (Hamer*et al*., 2004; Luo*et al*., 2011; Zimmerman *et al*., 2011; Maestrini*et al*., 2015). The labile components of biochar, which make up about 3% of total biochar-carbon with a mean residence time of 108 days as estimated byWang *et al.* (2016), are presumably water-soluble C (Luo*et al*., 2011) and largely composed of non-aromatic substances (Singh *et al*., 2012). Generally, this labile carbon is intensively mineralized in the initial few days to weeks following amendment to the soil (Kuzyakov*et al*., 2009; Keith*et al*., 2011; Singh and Cowie, 2014), leading to the strongest priming effects in the first 20 days (Maestrini*et al*.,2015).

For the second mechanism, microbes may switch their carbon sources from the recalcitrant soil organic matter to the easily available carbon in biochar, thereby resulting in negative priming effects on soil organic matter mineralization (Wang*et al*., 2016). In addition, a few studies have found that carbonates contained in biochar may contribute to the initial CO2 flush following biochar addition (Jones *et al*., 2011; Bruun*et al*., 2014). This abiotic mechanism, although not a major pathway of CO2 release from low-temperature biochar, as suggested by Bruun*et al.*(2014), might still lead to an overestimation of biochar decomposition and should be considered when evaluating biochar-induced priming of SOM decomposition.

According to reports by Cui *et al* (2017) during the first month of incubation, when the rate of biochar decomposition was highest, the priming effects were largely negative or slightly above zero suggesting a preferential microbial utilization of labile carbon in biochar rather than co-metabolism, given that strong mineralization of biochar occurred during this period. Consistent with the above observation is the results of the meta-analysis performed by Maestrini*et al.* (2015), which showed that many studies reported negative priming effects on SOM by biochar in the first 20 days of incubation. An initial preferential use of exogenous labile carbon inputs by microbes was also noted by Kuzyakov and Bol (2006).

The Role of Pyrogenic Carbon in Soil Fertility Improvement: The soil fertility benefits of Pyrogenic Carbon rest on two major pillars which include the high nutrient affinity of the carbon and its persistence. All organic matter added to soil significantly improves various soil functions, not the least the retention of several nutrients that are essential to plant growth. What is special about pyrogenic carbon is that it is much more effective in retaining most nutrients and keeping them available to plants than organic matter from other sources such as leaf litter, compost or farm manures. Interestingly, this is also true for phosphorus which is not at all retained by 'normal' soil organic matter (Lehmann, 2007).

It is also undisputed that pyrogenic carbon is much more persistent in soil than any other form of organic matter that is commonly applied to soil. Therefore, associated benefits with respect to nutrient retention and soil fertility are longer lasting than with alternative management.

Nevertheless, biochar amendment has been found to induce changes in the decomposition of soil organic matter (Kuzyakov, 2010). By synthesis of results from soil incubations with biochar, Maestrini*et al.* (2015) suggested that the addition of biochar resulted in a short-term positive priming effect (mineralization) of soil organic matter.

The short-term priming of soil C mineralization as a result of biochar addition was generally related to the labile C fraction of biochar (Cross and Sohi, 2011; Maestrini*et al*., 2015; Wang *et al*., 2016), which would lead microbes to switch their food sources from soil organic matter to the new carbon inputs, thereby resulting in a negative priming effect (Whitman *et al*., 2014). Alternatively, the labile C of biochar may benefit microbes capable of decomposing SOM and thus lead to positive priming effects (Singh and Cowie, 2014). Cui *et al.* (2017) in their study on the interaction between and biochar and litter priming also confirmed that addition of biochar brought about a priming effect. This priming effect was reported to be more in the biochar alone than in the mixture of biochar and litter. Nevertheless, more than 60% of the total CO2 produced from biochar alone was mineralized within 31days.

These studies clearly explain the nutrient availability in biochar treated soil. Although the pyrogenic carbon is said to be persistent and stable, it is still able to mineralize and release nutrients from the biochar or from soil organic matter especially at the early period of its application due to its labile fraction and afterwards play a greater part of retaining these available nutrients due to its recalcitrant component with highly reactive surface.

Biochar addition alone has been reported to significantly increase microbial biomass and enhanced soil mineral N contents by 274% (Cui *et al*, 2017). The increased mineral N might partly originate from biochar itself (Maestrini*et al*., 2014), but should be mainly released when soil microbes mined SOM for carbon and nutrients as primed by the labile carbon inputs from biochar (Nelissen *et al*., 2012; Maestrini *et al*., 2014). The latter mechanism is facilitated by the feedstock of the biochar since certain feedstock such as woody biomass tends to suppress soil N mineralization compared to straw-made biochar ((Prendergast- Miller *et al*., 2014; Hansen *et al*., 2016). Biochar amendment also induces some lasting changes in soil, such as improved aeration and higher water holding capacity (Herath *et al*., 2013), and alterations to enzymatic activities or microbial biomass (Lehmann *et al*., 2011). In another study, biochar has been found to correct undesirable pH similar to lime (Lehmann and Joseph, 2009) and can therefore, be of value to improve acid soils. However, there is a need to conduct more studies in other to ascertain the mechanism and to fully understand the process.

Other Soil Associated Roles: Apart from soil fertility improvement, engineered pyrogenic carbon plays other major roles in the soil and very popular one among these is the reduction in the net emission of carbon dioxide and other greenhouse gases that would ordinarily follow the carbon pathway.

The long persistence of pyrogenic carbon in the soil makes it a prime candidate for the mitigation of climate change as a potential sink for atmospheric carbon dioxide. The success of effective reduction of greenhouse gases depends on the associated net emission reductions through carbon sequestration. A net emission reduction can only be achieved in conjunction with sustainable management of biomass production. During the conversion of biomass to pyrogenic carbon about 50% of the original carbon is retained in the carbon, which offers a significant opportunity for creating such a carbon sink (Lehmann, 2007).

Pyrogenic carbon also plays a significant role in the immobilization of contaminants including heavy metals which may have a phytotoxic effect on plants (Fangjie*et al*., 2017). This is as a result of their reactive surface and their sorptive property. Biochar also has a strong affinity for the pesticide. Several studies have since confirmed reductions in the efficacy of pesticides in the presence of combustion residues in soil (Nag *et al*. 2011; Graber *et al*. 2012). Yang *et al*. (2006) observed that even doubling the application rate of diuron failed to control weed growth in the presence of 0.5% of wheat char in the soil. Graber *et al*. (2012) also noted that although weed control and herbicide efficacy were hindered in the presence of biochars, the effect depended upon the specific surface area of biochars, with higher specific surface area resulting in poorer weed control. This is an obvious indicate of agronomic or economic implications, in terms of increased input cost of pesticides to the grower, if herbicide application rates need to be adjusted for biochar-amended soils. However, decreased efficacy of pesticides has been observed only with freshly applied biochars in the soil. It has been suggested that after application to soil, biochar may rapidly lose its sorption capacity for herbicides (Martin *et al*. 2012). Further research is needed to investigate this aspect thoroughly, especially under field condition.

Engineered PyC and its Prospects for Low Fertility Sub-Saharan Soils: Sub-Saharan soils are characterized by relatively low soil fertility as a result of their inherent characteristics and most times as a result of soil degradation caused by years of inadequate soil management. This is evidenced by poor yield which contributes a major constraint to agricultural productivity for smallholder farmers in the Sub-Sahara especially in the semi-arid regions (Mukome*et al*., 2013). However, current efforts have focused on improving soil fertility through the use of synthetic fertilizer alone (Rockstrom*et al*., 2009). Omotayo and Chukwuka (2009) having identified the utilization of organic based soil nutrient management systems as a reliable soil management strategy for Sub-Saharan African Soils, the incorporation of the cost-effective biochar presents a massive opportunity for the management of these low fertility African soils.

Inspired by the Amazonian Terra Preta, engineered pyrogenic carbon (especially biochar) has been identified as a soil amendment that has the potential to change the concept of soil management. Several studies seem to agree that biochar application to soil improves nutrient availability and minimal leaching despite the high nutrient availability while also encouraging the significant increase in crop yield, improved pasture and native savanna (Major *et al*. 2010ab). It also has the potential to control certain problem soils such as acid soils by acting as a lime (Lehmann and Joseph, 2009).

The improvements in soil quality associated with biochar application have often resulted in enhanced seed emergence, crop growth, and productivity. Biochar application has been reported to enhance crop emergence and establishment. Solaiman*et al*. (2012) showed in their study that wheat seed germination was increased with a single dose (10 ton/ha) of paper mill biochar. The mechanisms involved may include improved moisture retention and availability, and reduced soil bulk density. Therefore, biochar application may overcome poor emergence and crop establishment caused by soil crusting, and sealing, and inadequate soil moisture, all which are conditions prevalent in several parts of Sub-Saharan Africa.

Biochar can also play a critical role in the area of low and declining soil fertility, unavailability of fertilizers and limited soil moisture caused by mid-season dry spells and droughts, directly increasing crop yield. Cornelissen*et al*. (2013) reported an increase in maize yield by 80% to 400% relative to the control after amending a soil in Zambia with Biochar. Other studies have also reported yield increase following biochar application (Kimetu*et al*., 2008; Utomo*et al*., 2011). In Ghana, Yeboah*et al*. (2009) reported up to 5% increase in N recovery when biochar was applied to maize fields on a sandy soil. This was attributed to nutrient retention.

Given that carbon in biochar is not directly taken up by plants, the impact of biochar on crop productivity is largely through improvements in soil physical, chemical and biological properties and appears to be a comprehensive soil management system that Sub-Saharan Africa soils need.

CONCLUSIONS

Pyrogenic carbon is not a silver bullet that will solve environmental problems without a much wider and far- reaching strategy, but it can provide an important tool to addressing a wide range of the major challenges bordered around soil degradation and food insecurity, climate-smart agriculture and waste management. While this prospect has been embraced by people in other parts of the world such as in America and in Europe where the use of biochar has become quite popular, not much effort has been made in advancing this new soil management concept in Sub-Saharan Africa when in actual sense it the Sub-Saharan Africa that needs it the most. Studies conducted both outsides and within the Sub-Saharan region of Africa show strong evidence that engineered pyrogenic carbon, especially biochar retain recalcitrant carbon in the soil that could improve soil structure, improve nutrient availability.

REFERENCES

1. *Ahmad M., Rajapaksha AU, Lim JE, Zhang M, Bolan N, Mohan D, Vithanage M, Lee SS, Ok YS (2014). Biochar as a sorbent for contaminant management in soil and water: a review. Chemosphere 99, 19-33.*
2. *Ascough PL, Bird MI, Francis SM, Lebl T. (2011). Alkali extraction of archaeological and geological charcoal: evidence for diagenetic degradation and formation of humic acids. J. Archaeol. Sci. 38:69–78*
3. *Azargohar R, Dalai AK, (2006). Biochar as a precursor of activated carbon. Appl. Biochem. Biotechnol. 131, 762–773.*
4. *Bird M I., Jonathan, Wynn G, Gustavo Saiz, Christopher M. Wurster, and Anna McBeath(2015) The Pyrogenic Carbon Cycle. Annual Review of Earth and Planetary Sciences. 43:9.1–9.26*
5. *Braadbaart F, Poole I, Van Brussel AA. (2009). Preservation potential of charcoal in alkaline environments: an experimental approach and implications for the archaeological record. J. Archaeol. Sci. 36:1672–79.*
6. *Bruun, S., Clauson-Kaas, S., Bobulska, L., Thomsen, I.K., (2014). Carbon dioxide emissions from biochar in soil: role of clay, microorganisms and carbonates. European Journal of Soil Science 65, 52-59.*
7. *Cheng CH, Lehmann J, Thies JE, Burton SD, Engelhard MH (2006) Oxidation of black carbon by biotic and abiotic processes. Org. Geochem. 37:1477–88*
8. *Clough, T.J., Condron, L.M., Kammann, C., Müller, C., (2013). A review of biochar and soil nitrogen dynamics. Agronomy 3, 275-293.*
9. *Cohen-Ofri I, Weiner L, Boaretto E, Mintz G, Weiner S. (2006). Modern and fossil charcoal: aspects of structure and diagenesis. J. Archaeol. Sci. 33:428–39*
10. *Cornelissen, G.V., Martinsen, V., Shitumbanuma, V., Alling, G.D., Breedveld, D.W., Rutherford, M., Sparrevik, M., Hale, S.E., Obia, A., Mulder, J., (2013) Biochar effect on maize yield and soil characteristics in five conservation farming sites in Zambia. Agronomy 3 (2), 256-274*

11. *Cross, A., Sohi, S.P., (2011). The priming potential of biochar products in relation to labile carbon contents and soil organic matter status. Soil Biology & Biochemistry 43, 2127-2134.*
12. *Crutzen P. J., Andreae M. O. (1990). Biomass Burning in the Tropics: Impact on Atmospheric Chemistry and Biogeochemical Cycles. Science 250, 1669-1678.*
13. *Cui Jun, TidaGe, YakovKuzyakov, Ming Nie, Changming Fang, Boping Tang, Chunlin Zhou (2017) Interactions between biochar and litter priming: A three-source 14C and d13C partitioning study. Soil Biology & Biochemistry 104, 49-58*
14. *Dickens A. F., Gélinas Y., Hedges J. I. (2004). Physical separation of combustion and rock sources of graphitic black carbon in sediments. Marine Chemistry 92, 215-223.*
15. *Fangjie Qi, Saranya Kuppusamy, Ravi Naidu, Nanthi S Bolan, Yong Sik Ok, Dane Lamb, Yubiao Li, Linbo Yu, Kirk T Semple & Hailong Wang (2017): Pyrogenic Carbon and Its Role in Contaminant Immobilization in Soils. Critical Reviews in Environmental Science and Technology, DOI: 10.1080/10643389.2017.1328918*
16. *Glaser B, Haumaier L, Guggenberger G, Zech W. (2001). The 'Terra Preta' phenomenon: a model for sustainableagriculture in the humid tropics. Naturwissenschaften88:37–41*
17. *Glaser, B., Parr, M., Braun, C., Kopolo, G., (2009) Biochar is carbon negative. Nat. Geosci. 2, 2.*
18. *Graber ER, Tsechansky L, Gerstl Z, Lew B (2012) High surface area biochar negatively impacts herbicide efficacy. Plant and Soil 353, 95–106. doi:10.1007/s11104-011-1012-7*
19. *Gupta, R.K., Dubey, M., Kharel, P., Gu, Z., Fan, Q.H., (2015) Biochar activated by oxygen plasma for supercapators. J. Power Sources 274, 1300–1305.*
20. *Hamer, U., Marschner, B., Brodowski, S., Amelung, W (2004). Interactive priming ofblack carbon and glucose mineralisation. Organic Geochemistry 35, 823-830.*
21. *Hammes K, Torn MS, Lapenas AG, Schmid MWI. (2008). Centennial black carbon turnover observed in a Russian steppe soil. Biogeosciences5:1339–50*
22. *Henao J, Baanante C (2006). Agricultural production and soil nutrient mining in Africa: Implication for resource conservation and policy development. IFDC Tech. Bull. International Fertilizer Development Center. Muscle Shoals, Al. USA.*
23. *Hansen, V., Müller-St€over, D., Munkholm, L.J., Peltre, C., Hauggaard-Nielsen, H., Jensena, L.S., (2016). The effect of straw and wood gasification biochar on carbon sequestration, selected soil fertility indicators and functional groups in soil: an incubation study. Geoderma 269, 99-107.*
24. *Herath, H.M.S.K., Camps-Arbestain, M., Hedley, M., (2013). Effect of biochar on soil physical properties in two contrasting soils: an Alfisol and an Andisol. Geoderma209-210, 188-197.*
25. *Hockaday WC, Grannas AM, Kim S, Hatcher PG. (2007). The transformation and mobility of charcoal in a fire-impacted watershed. Geochim. Cosmochim. Acta71:3432–45*

26. *Inyang M., Dickenson E. (2014). The potential role of biochar in the removal of organic and microbial contaminants from potable and reuse water: A review. Chemosphere 134, 232-240.*
27. *Jaff ´e R, Ding Y, Niggemann J, V¨ah¨atalo AV, Stubbins A (2013). Global charcoal mobilization from soils via dissolution and riverine transport to the oceans. Science 340:345–47*
28. *Jones, D.L., Murphy, D.V., Khalid, M., Ahmadd, W., Edwards-Jones, G., DeLuca, T.H., (2011). Short-term biochar-induced increase in soil CO2 release is both bioticallyand abiotically mediated. Soil Biology & Biochemistry 43, 1723-1731.*
29. *Kanaly RA, Harayama S. (2000). Biodegradation of high-molecular-weight polycyclic aromatic hydrocarbons by bacteria. J. Bacteriol. 182:2059–67*
30. *Keith, A., Singh, B., Singh, B.P., (2011). Interactive priming of biochar and labile organic matter mineralization in a smectite-rich soil. Environmental Science &Technology 45, 9611-9618.*
31. *Knicker H. (2011). Pyrogenic organic matter in soil: Its origin and occurrence, its chemistry and survival in soil environments. Quaternary International 243, 251-263.*
32. *Kimetu, J.M., Lehmann, J., Ngoze, S.O., Mugendi, D.N., Kinyangi, J.M., Riha, S., Verchot, L., Recha, J.W., Pell, A.N.(2008). Reversibility of soil productivity decline with organic matter of differing quality along a degradation gradient. Ecosystems 11, 726-739*
33. *Momo Lokko, C. N., & Lokko, F. (2016). Clinical Presentation and Management of Human Ebola Virus Disease in Sub-Saharan Africa.*
34. *Kuzyakov, Y., Bol, R., (2006). Sources and mechanisms of priming effect induced in two grassland soils amended with slurry and sugar. Soil Biology & Biochemistry 38, 747-758.*
35. *Kuzyakov, Y., (2010). Priming effects: interactions between living and dead organic matter. Soil Biology & Biochemistry 42, 1363-1371.*
36. *Kuzyakov, Y., Bogomolova, I., Glaser, B., (2014). Biochar stability in soil: decomposition during eight years and transformation as assessed by compound-specific 14C analysis. Soil Biology & Biochemistry 70, 229-236.*
37. *Lehmann J, da Silva Jr. JP, Steiner C, Nehls T, Zech W and Glaser B (2003) Nutrient availability and leaching in an archaeological Anthrosol and a Ferralsol of the Central Amazon basin: fertilizer, manure and charcoal amendments. Plant and Soil 249: 343-357.*
38. *Lehmann, J., (2007). A handful of carbon. Nature 447, 143-144.*
39. *Lehmann J (2007) Bio-energy in the black. Frontiers in Ecology and the Environment 5, 381-387.*
40. *Lehmann J and Joseph S (2009) Biochar for Environmental Management: Science and Technology. Earthscan, London.*
41. *Liang B, Lehmann J, Solomon D, Kinyangi J, Grossman J, O'Neill B, Skjemstad JO, Thies J, Luizão FJ, Petersen J and Neves EG (2006) Black carbon increases cation exchange capacity in soils. Soil Science Society of America Journal 70: 1719-1730.*

42. *Liang B, Lehmann J, Solomon D, Sohi S, Thies JE, Skjemstad JO, Luizão FJ, Engelhard MH, Neves EG and Wirick S (2008) Stability of biomass-derived black carbon in soils. GeochimicaetCosmochimicaActa 72, 6096-6078.*

43. *Luo, Y., Durenkamp, M., Nobili, M.D., Lin, Q., Brookes, P.C., (2011). Short term soil priming effects and the mineralisation of biochar following its incorporation to soils of different pH. Soil Biology & Biochemistry 43, 2304-2314.*

44. *Maestrini, B., Herrmann, A.M., Nannipieri, P., Schmidt, M.W.I., Abiven, S., (2014). Ryegrass-derived pyrogenic organic matter changes organic carbon and nitrogen mineralization in a temperate forest soil. Soil Biology & Biochemistry 69, 291-301.*

45. *Maestrini, B., Nannipieri, P., Abiven, S., (2015). A meta-analysis on pyrogenic organic matter induced priming effect. GCB Bioenergy 7, 577-590.*

46. *Masiello CA, Druffel ERM.(2003). Organic and black carbon 13C and 14C through the Santa Monica Basin oxic–anoxic transition. Geophys. Res. Lett. 30:1185*

47. *Major J, DiTommaso A, Lehmann J and Falcão NPS (2005). Weed dynamics on Amazonian Dark Earth and adjacent soils of Brazil. Agriculture, Ecosystems and Environment 111: 1-12.*

48. *Major J, Lehmann J, Rondon M and Goodale C (2010) Fate of soil-applied black carbon: downward migration, leaching and soil respiration. Global Change Biology 16: 1366-1379.*

49. *Major J, Rondon M, Molina D, Riha S and Lehmann J (2010) Maize yield and nutrition during 4 years after biochar application to a Colombian savanna oxisol.Plant and Soil 333, 117-128.*

50. *Mao JD, Johnson RL, Lehmann J, Olk DC, Neves EG, Thompson ML, Schmidt-Rohr K (2012) Abundant and Stable Char Residues in Soils: Implications for Soil Fertility and Carbon Sequestration. Environmental Science & Technology 46: 9571-9576*

51. *Martin SM, Kookana RS, Van Zwieten L, Krull E (2012) Marked changes in herbicide sorption–desorption upon ageing of biochars in soil. Journalof Hazardous Materials 231, 7–78.*

52. *McBeath AV, Smernik RJ. (2009). Variation in the degree of aromatic condensation of chars. Org. Geochem.40:1161–68*

53. *Mohan D., Sarswat A., Ok Y. S., Pittman Jr C. U. (2014). Organic and inorganic contaminants removal from water with biochar, a renewable, low cost and sustainable adsorbent – A critical review. Bioresource Technology 160, 191-202.*

54. *Mukome, F.N., Six, J., Parikh, S.J., (2013). The effects of walnut shell and wood feedstock biochar amendments on greenhouse gas emissions from a fertile soil. Geoderma 200, 90-98.*

55. *Nag SK, Kookana RS, Smith L, Krull E, Macdonald LM, Gill G (2011) Poor efficacy of herbicides in biochar-amended soils as affected by their chemistry and mode of action. Chemosphere 84, 1572–1577.*

56. *Nelissen, V., Rütting, T., Huygens, D., Staelens, J., Ruysschaert, G., Boeckx, P., (2012). Maize biochars accelerate short-term soil nitrogen dynamics in a loamy sand soil. Soil Biology & Biochemistry 55, 20-27.*

57. *Nocentini C., Certini G., Knicker H., Francioso O., Rumpel C. (2010). Nature andreactivity of charcoal produced and added to soil during wildfire are particle-size dependent. Organic Geochemistry 41, 682-689.*
58. *Norwood M. J., Louchouarn P., Kuo L.-J., Harvey O. R. (2013). Characterization and biodegradation of water-soluble biomarkers and organic carbon extracted from low temperature chars. Organic Geochemistry 56, 111-119.*
59. *Omotayo O. E. and Chukwuka K. S (2009). Soil fertility restoration techniques in sub-Saharan Africa using organic resources African Journal of Agricultural Research Vol. 4 (3), pp. 144-150*
60. *Prendergast-Miller, M.T., Duvall, M., Sohi, S.P., (2014). Biochar-root interactions are mediated by biochar nutrient content and impacts on soil nutrient availability. European Journal of Soil Science 65, 173-185.*
61. *Rockstrom, J., Kaumbutho, P., Mwalley, J., Nzabi, A.W., Temesgen, M., Mawenya, L., € Barron, J., Mutua, J., Damgaard-Larsen, S., (2009). Conservation farming strategies in East and Southern Africa: yields and rain water productivity from on-farm action research. Soil Tillage Res. 103, 23-32.*
62. *Santin Christina, Stefan h. Doerr and Agustín Merino (2014) Comparing carbon sequestration potential of pyrogenic carbon from natural and anthropogenic sources Geophysical Research Abstracts Vol. 16, EGU2014-2395*
63. *Singh, B., Cowie, A., Smernik, R., (2012). Biochar carbon stability in a clayey soil as a function of feedstock and pyrolysis temperature. Environmental Science & Technology 46, 11770-11778.*
64. *Singh, B.P., Cowie, A.L., (2014). Long-term influence of biochar on native organic carbon mineralisation in a low-carbon clayey soil. Scientific Reports 4, 3687*
65. *Sohi, S.P., Krull, E., Lopez-Capel, E., Bol, R., (2010). A review of biochar and its use and function in soil. Advances in Agronomy 105, 47-82.*
66. *Solaiman, S.M., Murphy, D.V., Abbott, L.K., (2012). Biochars influence seed germination and early growth of seedlings. Plant Soil.http://dx.doi.org/10.1007/s11104- 011-1031-4*
67. *Solomon D, Lehmann J, Thies J, Schäfer T, Liang B, Kinyangi J, Neves E, Petersen J, Luizão F and Skjemstad J (2007) Molecular signature and sources of biochemical recalcitrance of organic C in Amazonian Dark Earths. GeochimicaetCosmochimicaActa 71, 2285-2298.*
68. *Spokas K. A. (2010). Review of the stability of biochar in soils: predictability of O: C molar ratios. Carbon Management 1, 289-303.*
69. *Spokas, K.A., Cantrell, K.B., Novak, J.r. M., Archer, D.W., Ippolito, J.A., Collins, H.P., Boateng, A.A., Lima, I.M., Lamb, M.C., McAloon, A.J., Lentz, R.D., Nichols, K.A., (2012). Biochar: a Synthesis of its agronomic impact beyond carbon sequestration. Journal of Environmental Quality 41, 973-989.*
70. *Ssali H., Ahn P. M., Mokwunye A. (1986) Fertility of soils of tropical Africa: a historical perspective. In: Mokwunye A.U., Vlek P. L. G. (eds) Management of nitrogen and phosphorus fertilizers in Sub-Saharan Africa. Developments in plant and soil sciences, vol 24. Springer, Dorrdrecht*

71. *Tan X., Liu Y., Zeng G., Wang X., Hu X., Gu Y., Yang Z. (2015). Application of biochar for the removal of pollutants from aqueous solutions. Chemosphere 125, 70-85.*

72. *Thevenon F., Williamson D., Bard E., Anselmetti F. S., Beaufort L., Cachier H. (2010). Combining charcoal and elemental black carbon analysis in sedimentary archives: Implications for past fire regimes, the pyrogenic carbon cycle, and the human–climate interactions. Global and Planetary Change 72, 381-389.*

73. *Utomo, W.H., Kusuma, Z., Nugroho, W.H., (2011). Soil fertility status, nutrient uptake, and maize (Zea mays L.) yield following biochar and cattle manure application on sandy soils of Lombok, Indonesia. J. Trop. Agric. 49 (1/2), 47-52.*

74. *Wang, J., Xiong, Z., Kuzyakov, Y., (2016). Biochar stability in soil: meta-analysis of decomposition and priming effects. GCB Bioenergy 8, 512-523.*

75. *Whitman, T., Enders, A., Lehmann, J., (2014). Pyrogenic carbon additions to soil counteract positive priming of soil carbon mineralization by plants. Soil Biology & Biochemistry 73, 33-41.*

76. *Woolf D., Amonette J. E., Street-Perrott F. A., Lehmann J., Joseph S. (2010). Sustainable biochar to mitigate global climate change. Nature Communications 1, 56.*

77. *Xu, Lv Y., Sun J., Shao H., Wei L. (2012). Recent advances in biochar applications in agricultural soils: Benefits and environmental implications. CLEAN–Soil, Air, Water 40, 1093-1098.*

78. *Yang YN, Sheng GY, Huang MS (2006) Bioavailability of diuron in soil containing wheat-straw-derived char. The Science of the Total Environment 354, 170–178. doi:10.1016/j.scitotenv.2005.01.026*

79. *Yeboah, E., Ofori, P., Quansah, G.W., Dugan, E., Sohi, S.P., (2009). Improving soil productivity through biochar amendments to soils. Afr. J. Environ. Sci. Technol. 3 (2), 034-041*

80. *Zimmerman, A.R., Gao, B., Ahn, M.-Y., (2011). Positive and negative carbon mineralization priming effects among a variety of biochar-amended soils. Soil Biology & Biochemistry 43, 1169-1179.*

81. *ZimmermannM, BirdMI, Wurster C, Saiz G, Goodrick I (2012). Rapid degradation of pyrogenic carbon. Glob. Change Biol. 18:3306–16*