

Biochar Application to Soil for Increased Resilience of Agroecosystems to Climate Change in Eastern and Southern Africa



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Abstract With the current unreliable rainfall pattern, which is expected to worsen due to climate change, agricultural production might become more challenging especially among resource-poor farmers in Eastern and Southern Africa. This calls for adaptation of farming systems to overcome this emerging challenge. Biochar, a product of biomass pyrolysis, with long-term evidence from Amazonia, might contribute to a climate-resilient farming system. This is due to its positive effects on soil chemical and physical properties resulting in increased crop yields, which has been experimentally demonstrated largely within the last two decades. In acidic low cation exchange capacity (CEC) soils, biochar derived from corncob at 5% application rate, for example, increased pH by ≥ 1 unit and CEC by ≥ 2 $\text{cmol}_c \text{ kg}^{-1}$ in addition to direct nutrient supply. Increased CEC may be linked to the observed increase in soil organic carbon content (biochar carbon/sequestered carbon) due to biochar addition. Sequestration of carbon due to biochar has been reported to be stronger in soils that have low pH and low carbon contents, with greater effects from biochars

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produced from woody materials or those produced at high temperature. Such soils with low pH and carbon contents are common in tropical areas. Another effect of biochar at field-relevant doses of $\leq 5\%$ is the improvement of physical properties such as increased aggregate stability by up to 7%, increased aggregate mean weight diameter by 8–13%, increased soil water contents and reduced soil temperature fluctuations. Similar changes to soil properties have been found to increase yield by 10% based on global dataset, but up to fourfold increases have also been reported for acidic low CEC soils. One key challenge to implementation of biochar technology for increased yields is probably the unavailability of large quantity of biochar often in tens of Mg ha^{-1} that is required for field application. Conservation agriculture (CA) with its three principles of minimum tillage, residue retention and crop diversification may partly address this key challenge of biochar implementation. This can be achieved by applying biochar only in the tilled part of land in a minimum tillage operation, which can be only 10% of the land surface. In this way, biochar may increase the positive attributes of CA such as increased rainwater harvesting and crop yields. Further solution to the quantity of biochar material for field application is the application of limited quantity of biochar in combination with traditional amendment such as manures either in mixtures or after co-composting. In this way, biochar is expected to deliver its benefits to manure resulting in improved soil properties and increased yields. Overall, incorporation of biochar in CA-based farming system alone or in combination with manures might contribute to building of climate-resilient agroecosystem.

Keywords Biochar · Conservation agriculture · Tropical soils · Climate resilient farming systems · Crop yields

1 Introduction

Biochar is a type of charcoal produced from various biomass feedstocks such as crop residues, manure and waste from agro-industries under low or no oxygen availability, a process called pyrolysis for the purpose of application to soil. Recent interest in biochar research stems mainly from work that has been conducted in Amazonia. A number of areas in Amazonia have black-earth-like “man-made” soils (Anthrosols) containing charcoal (Glaser et al. 2001). These man-made soils are also called Terra Preta or Amazonian Dark Earth. Terra Preta soils are characterized by greater content of soil organic carbon and higher pH, cation exchange capacity (CEC), nutrient availability and water holding capacity compared to surrounding soils with similar texture and mineralogy, resulting into an overall enhanced soil fertility and productivity (Glaser et al. 2001; Lehmann et al. 2003; Novotny et al. 2009). Biochar with evidence from Amazonia has been found to last in the soil for hundreds to thousands of years. Depending on the proportion of stable and degradable carbon in biochar (Spokas 2010; Lal 2016), biochar may lock up carbon in the soil for a longer timescale not comparable to

any carbon sequestration approach such as afforestation currently in practice (Lehmann 2007). This soil productivity improvement and carbon sequestration potentials are important given the “low-tech” nature of the overall biochar technology (Renner 2007).

So far few studies have assessed the potential of biochar in Southern Africa (Gwenzi et al. 2015). However, the observed benefits of biochar in Amazonia, which date up to over 1000 years, can be expected in Eastern and Southern Africa given the similar geographical placement in the tropics. Tropical soils are generally low in soil organic matter, pH, CEC, nutrients and water holding capacity largely due to advanced weathering status. Biochar, generally having greater pH, CEC, nutrients and water holding capacity (Martinsen et al. 2015; Revell et al. 2012), can therefore be used to improve tropical soils and hence resilience of agroecosystems to climate change. This improved resilience to climate change will definitely contribute to increase in crop yields (Jeffery et al. 2011). Now and in the future, the importance of this lies in the ever-challenging need to feed the rapidly growing human population.

Feedstock for biochar production can be from any biomass, but this should be restricted to agricultural and forest/wood product wastes and not cutting of trees for biochar production. The choice of feedstock depends on local availability and costs of acquisition (Gwenzi et al. 2015) and can include manures and agricultural waste such as corncobs (*Zea mays*), groundnut (*Arachis hypogaea*) shells and rice (*Oryza sativa*, L.) husks. However, for large-scale implementation, crops with large amounts of biomass wastes such as pigeon pea (*Cajanus cajan*) may be preferred. Production of biochar can take different forms such as traditional earth mounds, drum/Adam retort kiln, flame curtain/Kon-Tiki technique and a number of advanced techniques that may not be relevant to small-scale rural farmers in Eastern and Southern Africa. Traditional earth mound is unhealthy as it emits large amounts of toxic gases to the air, while retort kilns may be costly and require technical know-how for its construction and operation (Sparrevik et al. 2013, 2015). Flame curtain kiln, which can be a conical hole in the ground (Fig. 1) or metallic, is cheap and low-tech (Schmidt and Taylor 2014). It has been found to produce large quantity of high-quality biochar in a short time with low emission of toxic gases (Cornelissen et al. 2016; Pandit et al. 2017). The low emissions during production of biochar with such a kiln is however outweighed by the carbon sequestration if the biochar is used as a soil amendment, leaving a neutral environmental impact (Smebye et al. 2017). Flame curtain kiln is perhaps the best technique for biochar production in rural areas much as production procedure is non-standardized with no control on production temperature and oxygen concentration, which may result in variation in char quality.

The objective of this chapter is to assess the potential of biochar application to soils for increased resilience of agroecosystems to climate change in Eastern and Southern Africa. We review studies on effects of biochar and biochar formulations on soil physical and chemical properties and crop yield under different management practices including conservation farming.



Fig. 1 Pyrolysis in flame curtain kiln in Zambia. (Photo: Left, corncob by A. Obia; right, pigeon pea by G. Cornelissen)

2 Vulnerability of Eastern and Southern Africa Agriculture to Climate Change

The economies of countries in Eastern and Southern African countries are predominantly based on agriculture. In these countries, agricultural growth rate has generally remained low at less than 1% per year in the last 50 years (Chauvin et al. 2012). Yet population growth rate for a number of these countries far exceeds 1%. For example, Zambia had a population of only 2.3 million people in 1950, which had increased to 17.1 million by 2017 and is expected to further grow to 41 million people by 2050 (United Nations Department of Economic and Social Affairs Population Division 2017). The increasing population presents a challenge of food insecurity, which is likely to remain into a distant future unless drastic measures are carried out.

The food insecurity has been and will be compounded by land degradation and climate change, which are interlinked (Lal 2013). Agricultural-based degradation such as soil erosion, compaction, soil acidification and pollution is widespread. In addition, most of the lands in Eastern and Southern Africa are characterized as drylands, where evapotranspiration exceeds precipitation in some parts of the year, making the lands inherently vulnerable to degradation by erosion. Common drylands are dry sub-humid, semi-arid and arid areas. Besides being dry during part of the year with significantly reduced vegetation cover, other socio-economic factors are also driving people to continuously remove vegetation cover to provide energy for cooking. This is due to either lack of clean energy sources or clean energy sources are simply too expensive for many households.

With climate change, real or merely perceived, agricultural droughts are increasingly becoming more common due to soil degradation (Cornelis et al. 2013) and

will necessitate adaptation of farming systems to reduce impact on productivity. Such adaptation may involve the use of long-established technologies such as incorporation of manures and other agronomic practices such as conservation agriculture (Farooq and Siddique 2015). Meanwhile, completely degraded agricultural areas may require restoration using afforestation with appropriate vegetation type. In addition to traditional soil amendments such as poultry manure and farm yard manure, biochar, due to its long resident time in soil, may offer sustained benefits for improved soil productivity. Among the benefits that can reduce vulnerability to climate change are the improved soil water retention and chemical properties, including direct addition of nutrients (Obia et al. 2016; Martinsen et al. 2014).

3 Effect of Biochar to Soil Physical Properties

Soil is composed of solid matter (organic and inorganic) and pore space, which can be filled with water and/or air. The proportion and composition of the solid matter and pore space determine the physical characteristics. Characteristics that are important for crop production are structural/mechanical, hydraulic and thermal/soil temperature. These soil characteristics are interdependent such that the effect of biochar on one may influence the other.

In Eastern and Southern Africa, studies exist showing that biochar can improve soil structure (Obia et al. 2016; Fungo et al. 2017), especially when applied in combination with fertilizer. Such improvement in soil structure may be attributed directly to biochar or indirectly to increased biomass production and microbial activities due to both biochar and fertilizer. Increased biomass production may be related to increased root exudates that promote aggregation. The changes in soil structure after biochar application have been assessed in terms of soil aggregation (aggregate size distribution and aggregate stability), porosity and pore-size distribution, bulk density and penetration resistance. Biochar produced from corncob has been found to increase aggregate stability by 2.5–7.0% per percent biochar, added in a sandy loam Acrisol in Zambia (Obia et al. 2016), while aggregate mean weight diameter increased by 8–13% in a similar soil type (Ultisol \approx Acrisol) in Kenya only when biochar was combined with other amendments (Fungo et al. 2017). In a sandy loam Acrisol in Zambia, porosity significantly increased by 1.2% per percent biochar, and the increase was mainly associated with increase in large pores with sizes $>100 \mu\text{m}$. Increase in porosity coupled with the light weight of biochar relative to soil reduced the bulk density of the soil after biochar application. In sandy Arenosol, biochar increased porosity due to its high porosity and reduced bulk density due to weight dilution (Obia et al. 2016). The reduction in bulk density was in the range of $0.02\text{--}0.06 \text{ g cm}^{-3}$ per percent biochar added. In another study in Zambia (Obia et al. 2017), biochar reduced soil penetration resistance in a loamy sand Acrisol by $2.1\text{--}2.9 \text{ N cm}^{-2}$ per percent biochar added, while no effect was observed in sand. The reduction in penetration resistance was found to be due to the initiation of structural development (i.e. aggregation).

Soil structure, a dynamic soil property, is a key determinant of soil porosity and pore structure. Soil pores provide space through which fluids (water and air) are transported and stored in soil. Pore size distribution determines the proportion between water and air in soil, because large pores normally drain fast and fill with air. The effect of biochar on water transport commonly measured in terms of hydraulic conductivity has shown mixed results depending on soil type/texture, biochar type and particle size (Obia et al. 2017). In Zambia, a reduction in saturated hydraulic conductivity by 0.17 cm h^{-1} per percent biochar added was observed in sandy loam Acrisol, while no effect was observed in sandy Arenosol after application of biochar derived from corncob (Obia et al. 2017). The reduction in hydraulic conductivity was likely due to clogging of water-conducting macro-pores and introduction of micro-pores by biochar, which need to be filled first before water transport. The reduction in conductivity was not related to the water-repellent nature of the biochar, because the hydrophobic biochar did not affect the water repellency of the non-repellent soil after 1 year of experiment. Water repellency of biochar may be due to surface coating by semi-volatile organic compounds (Yi et al. 2015) or due to alkyl groups on BC surfaces (Kinney et al. 2012). However, such hydrophobic compounds can be rapidly lost from biochar upon mixing with soil to percolating water as suggested by Yi et al. (2015). In addition, in these coarse-textured Zambian soils, biochar generally increased water retention resulting in greater plant available water (Cornelissen et al. 2013; Martinsen et al. 2014; Obia et al. 2016). In clayey soil of Ethiopian highlands, an increase in hydraulic conductivity was observed after application of woody chars (Bayabil et al. 2015). Increased hydraulic conductivity resulted in reduced water retention at low tensions but an overall no effect on plant available water in this clayey soil.

Under field conditions in Zambia in a sandy loam soil, biochar derived from pigeon pea feedstock increased maximum soil water content by up to ~80% under conservation farming similar to the effect of corncob biochar resulting in reduced soil temperature fluctuation by $0.09 \text{ }^\circ\text{C}$ per percent increase in volumetric moisture content (Obia et al. 2018, unpublished data) and therefore lower evaporation. This effect of biochar is similar to the observation by Zhang et al. (2013) where biochar reduced temperature fluctuations by moderating extreme high and low temperatures in the North China Plain. In the North China Plain, reduction in temperature fluctuation was due to reduced thermal conductivity in addition to increased reflectance of near-ultraviolet and blue-light wavelengths and decreased reflectance in infrared wavelength range. In Zambia where soil/biochar mixtures were covered with soil, reduced temperature could be due to increased soil heat capacity caused by greater water contents. Moderation of extreme soil temperature coupled with greater water content can be an important component of climate resilience of agro-ecosystem in a tropical setting and can reduce the negative effect of high temperature and unreliable rainfall on seed germination, root activity, crop growth and eventually yields.

4 Effect of Biochar on Soil Chemical Properties

Given the low inherent fertility of tropical soils associated with low pH, low CEC, low organic carbon and low nutrient availability, biochar is a promising amendment that can ameliorate these soils. However, the effect of biochar depends on feedstock, pyrolysis condition and soil type (Martinsen et al. 2015; Cornelissen et al. 2018). The pH of biochar has been reported to be mostly in the alkaline range but can vary from six to over ten (Atkinson et al. 2010; Martinsen et al. 2015). Such generally high pH of biochar can increase pH of tropical soils as has been found for some acidic soils of Zambia, where pH increased by ≥ 1 unit (Cornelissen et al. 2013; Martinsen et al. 2014). From these same studies, the CEC was also significantly increased by ≥ 2 $\text{cmol}_c \text{ kg}^{-1}$ owing to the low CEC of the soils and high CEC of the biochar derived from corncob and wood. The positive effect of biochar on soil pH may, however, be short term, as reported in a recent study from a highly acidic Indonesian Ultisol by Cornelissen et al. (2018). Elevating the pH in such highly acidic soils will also increase the Ca/Al ratio, limiting the availability of toxic aluminium to plants. Results of the effect of biochars produced from rice (*Oryza sativa*. L.) husk and cacao (*Theobroma cacao*. L.) shell on soil chemical properties and maize (*Zea mays*) yields revealed an initial positive effect of biochar addition, but there was a fading effectiveness after multiple planting seasons. This was believed to be due to leaching of biochar-associated alkalinity and led to the conclusion that biochar should be applied approximately every third season in order to maintain positive effects on yields (Cornelissen et al. 2018).

Biochar contains plant nutrients such as potassium, calcium, phosphorus and some nitrogen (N). However, N in biochar with a high C:N ratio is only to a little extent available to plants, and negative effects of addition of such biochar on crop yields may be observed due to microbial immobilization of N (Gwenzi et al. 2015). Assessing the effect of addition of biochar derived from maize cob (5 Mg ha^{-1}) to sandy or loamy sands (Arenosols) in Zambia, Martinsen et al. (2014) found significantly greater levels of exchangeable potassium in the soil, resulting in significantly higher concentrations of potassium in maize stover. However, the fertilizing effect of biochar is most likely of short duration, since a significant proportion of base cations will be leached when exposed to precipitation and soil water. Recently, Munera-Echeverri et al. (2018) found that the amount of base cations removed during three washings with water and acid prior to determination of CEC was about three (biochar derived from rice husk) to ten times (biochar derived from pigeon pea) greater than the amount of exchangeable cations. A large proportion (14%, 47%, 66% and 71% for biochar derived from pigeon pea, caca shell, corncob and rice husk, respectively) of the cations removed during the initial washings (i.e. not cations associated with negatively charged binding sites) was due to dissolution of salts (Munera-Echeverri et al. 2018). Therefore, direct addition of plant nutrients is one key benefit of application of biochar, though this effect may be short lived. Raising the pH of soil from acidic range to near neutral can increase nutrient availability, especially of phosphorus which is normally fixed to iron oxide in the

acidic weathered soils of tropical areas with $\text{pH} < 5$ and hence not fully available to plants. With enhanced CEC of soil, nutrient retention of base cations can increase, reducing loss of base cations from the root zone to deeper subsoil with percolating water.

With increased nutrient content of the soil and availability of farming systems incorporating biochar, better crop growth can be expected. Well-established crops can tolerate the impact of dry spells, hence improving resilience of the farming system to climate change.

5 Effect of Biochar on Crop Yields

To the farmer, improvement in soil quality due to biochar should translate to an increase in crop yield, as indicated above. The effects of biochar are not positive in all systems, but it may increase yields in low-nutrient, acidic soils in the tropics (Jeffery et al. 2017). In a meta-analysis of a global dataset, Jeffery et al. (2011) showed an overall increase in crop yield of 10% with greatest yield increase in sandy acidic soils (Fig. 2). Acidic soils are very widespread in tropical areas, and hence biochar may have great potentials for increasing productivity of these soils. In an acidic sandy Arenosol in Western Zambia, maize yield increased by 350–450%, whereas in the red sandy clay loam Ultisol of Central Zambia, a non-significant increase in maize yield of 142% and 131% for biochar derived from corncob and wood, respectively, was observed (Cornelissen et al. 2013). From this

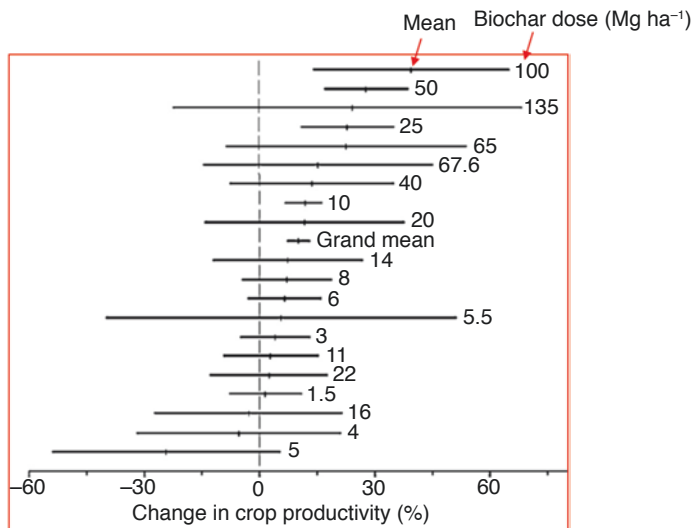


Fig. 2 Result from a meta-analysis of data from various studies showing changes in yield after application of various doses of different biochars (Jeffery et al. 2011)

same study, biochar had no effect on crop yield in “good” soils with loamy texture and near-neutral pH. In a related study by Martinsen et al. (2014), an increase in maize yield of 232% was observed in a fertilized sandy Arenosol with biochar compared to a fertilized control without biochar. The benefit of biochar in increasing yields in very sandy soil has been associated with strong increase in plant available water of the otherwise inherently low plant available water. Therefore, the two main mechanisms for increased yields in tropical soils are pH and plant available water, in addition to CEC particularly of very sandy soils with low CEC.

6 Biochar and Soil Carbon Sequestration

Carbon sequestration as a result of different management practices is due to soil organic carbon sequestered from atmospheric CO₂ through plants, plant residues and other organic solids (Olson et al. 2014). Biochar may improve soil fertility leading to increased biomass production and thus increased carbon sequestration. In addition, depending on the proportion of stable and degradable carbon in biochar (Spokas 2010; Lal 2016), biochar may lock up carbon in the soil for a longer timescale, not comparable to any carbon sequestration approach such as afforestation currently in practice (Lehmann 2007). The carbon content of biochar varies considerably from as low as 17–88% (Atkinson et al. 2010). The low carbon biochar is from non-woody materials such as poultry wastes, whereas high carbon biochars are generally those produced from woody materials. Pyrolysis temperature and retention time during pyrolysis also affect carbon content with higher temperature and longer retention time producing biochars with greater carbon contents. Of the carbon content of biochar, only a small amount of <1% is easily degradable (Luo et al. 2011), leaving large amount of recalcitrant materials, which may be responsible for the long resident time of biochars in soils (potentially hundreds to thousands of years).

Despite low amounts of labile carbon in biochars, it may still affect the decomposition of native soil organic matter similar to what has long been observed upon addition of fresh organic materials (Bingeman et al. 1953). Addition of fresh organic materials to soil has been found to increase the decomposition of native soil organic matter, also called priming effects. Some biochars such as those derived from sewage/paper sludge, *Miscanthus* spp., rye grass (*Lolium perenne*), manure, etc. have been found to increase the decomposition of native soil organic matter (Naisse et al. 2015; Cely et al. 2014; Singh and Cowie 2014; Luo et al. 2011). On the other hand, other biochars such as those produced from wood (mixed), barley (*Hordeum vulgare*) straw, oak (*Quercus*), oil seed etc. have been found to decrease decomposition (Rittl et al. 2015; Cely et al. 2014; Bruun and EL-Zehery et al. 2012; Jones et al. 2011; Zimmerman et al. 2011). A number of reasons seem to explain the differences in the observations including soil texture, pH, soil carbon content, land use, biochar feedstock, pyrolysis temperature and retention time. Greater positive priming effect upon addition of biochar to soil has been found in coarse-textured soils with low

pH. Similarly, greater positive priming by biochar addition has also been found in land uses that reduce soil pH and carbon content, e.g. bare fallow or arable land compared to grasslands. Biochar derived from woody materials as well as high temperature pyrolysis and longer retention time results in lower priming effects or even negative priming (i.e. build-up of non-pyrogenic carbon) possibly due to low amounts of labile carbon it carries. In the long term, biochar could as well store native soil organic matter by sorption and physical protection (Zimmerman et al. 2011).

Application of biochar derived from woody materials pyrolysed at high temperature ≥ 400 °C with longer retention time in the pyrolysis unit of more than 1 hour may stabilize soil organic carbon with stronger effects in fine-textured soil with pH of >4 and greater carbon content of $>3\%$ (Cely et al. 2014; Cross and Sohi 2011; Zimmerman et al. 2011). One reason for this could be the low amount of labile carbon on these types of biochars to stimulate priming of native soil organic carbon. Overall, this may be critical in a tropical setting where increasing soil carbon content is challenging.

In Zambia, application of biochar made from corncob to a coarse-textured soil increased soil carbon content from $\sim 0.7\%$ up to $>3\%$ (depending on biochar dose) with much of the carbon coming from biochar after 2 years (Obia et al. 2016). Studies on effect of biochar on native soil organic carbon in Eastern and Southern Africa are lacking, but biochar's effect may be similar to results from similar soils elsewhere. Increase in soil organic carbon after biochar application would be an ideal outcome given the importance of organic carbon/matter in soil. Soil organic matter is known to increase soil aggregation, nutrient retention (CEC), water retention and overall soil quality improvement. In effect, it can improve the resilience of farming system to disturbances, both man-made, e.g. tillage, and natural ones, e.g. droughts. In addition, build-up of soil organic matter is positive in terms of climate change mitigation (i.e. long-term storage of carbon).

7 Incorporation of Biochar in Climate-Resilient Farming System: Conservation Agriculture

Large-scale implementation of biochar has come under scrutiny in recent years due to potentially large quantity of biochar reaching several tens of tonnes per hectare that are not normally available. This is attributable to shortage of feedstock. The current widespread promotion of conservation agriculture (CA) in Eastern and Southern Africa presents an opportunity where the amount of biochar required to cause significant effects is drastically reduced. The quantity of biochar may be reduced to cover only 10% of the land surface (Cornelissen et al. 2013). This is because CA involves minimum tillage where only a small area of the surface is tilled and biochar is added or concentrated only to the tilled area instead of application over the entire area. In addition to minimum tillage, the two other principles of CA are residue retention and crop diversification or rotation. The above principles

may contribute to the climate resilience of a farming system. The climate resilience may be attributed to the water harvesting capacity of CA minimum tillage where water over a wider area is funnelled to the tilled spots (Cornelis et al. 2013; Obia et al. unpublished data). This then increases water availability for crops in the event of reduced rainfall/dry spell. Minimum tillage also prevents exposure of soil organic matter to decomposition, hence maintaining the functions of organic matter in the soil (Corbeels et al. 2018). However, it is believed that climatic and edaphic conditions, combined with management practices such as seeding system, degree of residue retention, fertilizer addition, weeding and crop rotation, determine whether CA has positive, negative or no effect on yields and soil fertility. Under on-farm conditions in Zambia, CA was found to have negligible effects on soil carbon contents and stocks (Martinsen et al. 2017). Other benefits may include reduced chances of soil degradation due to erosion. Residue retention in CA may further enhance soil water availability due to improved soil water infiltration and reduce water evaporation. Residue cover also moderates soil temperature, which is often high in tropical settings reducing water evaporation from the surface. Such temperature moderation also helps in seed germination and stimulating biological activities. Inclusion of crop diversification such as cover crops may have effects similar to residue retention in addition to other benefits such as pest and disease control. The above formed the basis where CA has been considered as a climate-resilient farming system that increases yields (Thierfelder and Wall 2009; Thierfelder et al. 2018). On the other hand, CA minimum tillage is commonly associated with soil compaction over time and weed management challenges, all of which may reduce crop yields. Inclusion of biochar, given its potential benefits in CA systems, can enhance resilience to climate change and increase yields as has been demonstrated in Zambia (Cornelissen et al. 2013). We therefore suggest that among resource-poor farmers in Eastern and Southern Africa, biochar and CA should be implemented as a single intervention. This may then form a sustainable and profitable low-input agriculture among poor smallholder farmers.

Other solutions to limited amounts of biochar due to feedstock shortage, in addition to CA, have been suggested. These include cultivation of crops that have large quantities of biomass wastes such as pigeon peas to provide feedstock and incorporation of limited amounts of biochar in a formulation such as co-composting.

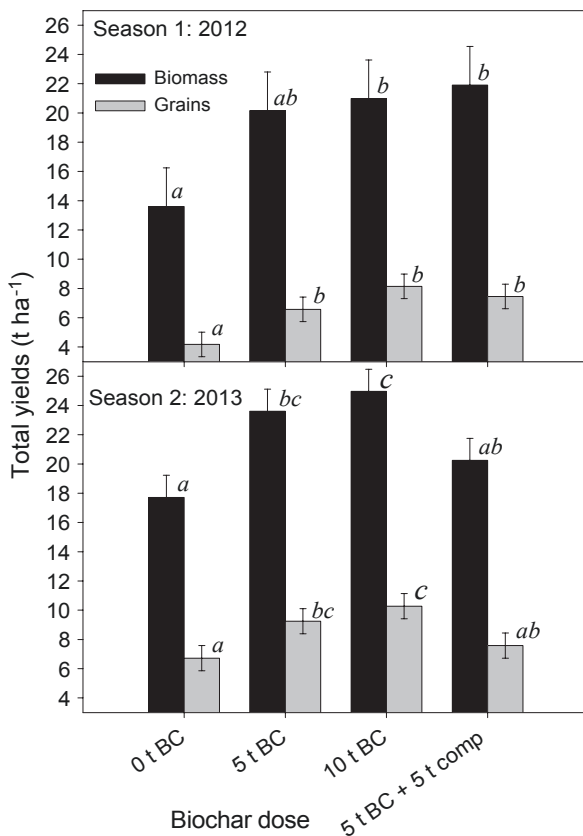
8 Production and Application of Biochar Formulations in Agriculture

There are two reasons why biochar formulations have been considered necessary for field application in agriculture. Firstly, formulations are a way to reduce the amount of biochar in field application while still delivering its benefits in improving soil quality and crop yields. Secondly, the delivery of good biochar properties into the traditional amendment such as manures or removing negative attributes of manures. Several studies have reported two forms of formulations: biochar-manure

mixtures and biochar-manure co-compost (Dias et al. 2010; Kammann et al. 2015; Qayyum et al. 2017; Yuan et al. 2017). Given the easily decomposable nature of manures, its effect is expected to fade within a few seasons unlike biochar. The contribution of manures to the effect of biochar-manure mixture may also fade over a short time. In an experiment on Vertisols in West Timor, Indonesia, the positive effect of 5 Mg ha⁻¹ biochar and 5 Mg ha⁻¹ compost mixture dropped in the second year of the experiment though not significantly (Fig. 3).

A number of attributes of biochar have been identified and can be delivered to manure in co-composting process. In a comparison of biochar, coffee husk and saw dust, Dias et al. (2010) found that biochar promoted humification more than the other bulking materials during composting and further reduced nitrogen losses in mature compost. Increased humification due to biochar may result in better stabilization of native soil organic matter as well as organic matter in manure during co-composting as has been reported by Qayyum et al. (2017). Biochar-manure co-composting has been found to significantly reduced soil CO₂ and N₂O climate gas emissions compared to manure compost (Yuan et al. 2017). In some instances, biochar-manure co-composting has been found to cause yield increases even in soil/

Fig. 3 Maize yields from field plots amended with BC and BC + compost in Vertisols, West Timor. 5 and 10 Mg (t) BC correspond to 2.5% and 5% BC, respectively. Means followed by the same letter are not significantly different. Error bars are the SEs, $n = 6$. (Adapted from Obia et al. 2018)



regions where biochar has been found to have either no or limited effects such as in temperate soil (Kammann et al. 2015; Qayyum et al. 2017). The enhanced benefits of co-composted biochar may be attributed to inherent properties of biochars such as large surface area, porosity, CEC and pH.

9 Conclusions

Building climate-resilient farming systems may remain part of the greater efforts in the coming years to increase agricultural production in the face of climate change. This will require practices that allow sustainable use of resources. Biochar, as one of the possible resources with positive effects on soil quality, can be concentrated into the minimum tillage planting stations of CA. Biochar can then increase the positive attributes of CA in soils such as improvement of soil hydraulic properties (e.g. water infiltration and retention) contributing to increase in the productivity of agricultural lands. In addition, biochar can directly add nutrients to soils and increase the nutrient retention ability of the soil (CEC) and soil pH. Soil water infiltration and retention, nutrient level, CEC and pH are among the soil properties that are generally below optimal range for agricultural production in tropical soils largely due to the advance weathering status. These soil properties can be improved directly or indirectly through application of biochar. Due to long resident time of biochar in soils as demonstrated in Amazonia, some of its effects in soil are expected to last for hundreds to thousands of years alongside the associated carbon sequestration potentials. Therefore, biochar technology and CA can complement each other to increase productivity and should be implemented as a single intervention. In particular, both biochar and CA will improve the resilience of agroecosystem in Eastern and Southern Africa, which is one of the most vulnerable regions to climate change.

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