The Impact of Biochar and Animal Manure on Soil Properties, Yield, and Quality of Crops

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The impact of biochar and animal manure on soil properties, yield and quality of crops

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Abstract

Generally, waste management and nutrient cycling are constrained by inadequate utilization of crop waste products, erratic supply of energy, lack of knowledge of better processing, low value to some waste/ byproducts and disorganized disposal in most of our societies. Biochar and animal manure are becoming popular on environmental issues, sustainable agriculture and food quality concerns globally. Biochar production and application is important in management of crop residues and livestock wastes that conserves environments and cycles nutrients in agriculture. Production and application of animal manures is very important in cycling of nutrients in agriculture and management of livestock wastes.

The effect of biochar on improvement of soil fertility, yield and quality of crops depends on type of feedstock, pyrolysis temperature, soil characteristics, climate and crop type. Application of biochar increases soil pH up to two times in highly weathered acidic soils of tropics while in sand desert soils it decreases soil pH depending on materials used. Biochar may be animal or plant derived.Also, it can be acidic or alkaline depending on a nature of materials which has significant effect on soil reaction and nutrient availability. Application of biochar improves soil texture, structure, bulk density, chemical properties, and flora and fauna in the soil which has positive effect on yields of crops and food quality. The effect of animal manure on soil fertility improvement depends very much on quality of manure, soil properties, climatic conditions and crop type. Animal manure and biochar have been reported to improve soil fertility and crop yield with significant contribution on food quantity and quality.

Key Words

Animal manure, biochar, crop yield, farmyard manure, macronutrients, micronutrients, pyrolysis, residues, soil fertility, waste management

List of Abbreviations

%	percentage
°C	degree centigrade

ADB	animal derived biochar
Al	aluminium
C	carbon
Ca	calcium
CEC	cation exchange capacity
Cu	copper
EC	electrical conductance
g	gram
ha	hectare
K	potassium
kg	kilogram
m	meter
Mg	magnesium
N	nitrogen
Na	sodium
P	phosphorus
PDB	plant derived biochar
ppm	parts per million

S Sulphur

t tones

TARI Tanzania Agriculture Research Institute

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1.0 Introduction

Biochar and farmyard manure use are gaining popularity in the world for sustainable agriculture and environmental issues. Biochar and farmyard manure ensures nutrient cycling in agriculture. Development of biochar from a diversity of feedstock and temperature ranges leads to specific agricultural and environmental application (Fidel et al. 2017). Biochar and farmyard manure conserves environment and agriculture sustainably(Saletnik et al. 2019; Safari et al. 2019; McMichael et al. 2007; Chun-Hui et al. 2018; Nair et al. 2017).

Inadequate utilization of crop waste products, erratic supply of energy, lack of knowledge of better processing, low value to some waste/ byproducts and disorganized disposal constrain waste management and nutrient cycling. On-farm crop residues are inefficiently used because some are left to decompose for addition of soil biomass, some are utilized by livestock in the field, and few crops are processed as primarily and secondary. Byproducts from primary and secondary processing could be used in a number of ways such as for cooking, for soil fertility improvement, and others.Residues from threshing and shelling are usually high in lignified structural components requiring thermo-chemical conversion. Pyrolysis of these residues provides thermal energy for drying, roasting or cooking application using pyrolizer to produce charcoal known as biochar. The biochar is a finegrained product of carbonization that is characterized by a high content of organic carbon and low susceptibility to degradation, which is obtained through pyrolysis of biomass and biodegradable waste (Saletnik et al. 2019). Pyrolysis is a process of the thermal decomposition of biomass occurring in the absence of oxygen (Hass et al. 2012). This process takes place at higher temperatures between 200 and 700°C (Saletnik et al. 2019; Hass et al. 2012).

Biochar is used as energy carrier for cooking, soil amendment and reversing fertility degradation. Further, biochar can be used as an additive to fodder and silage as livestock feed, source of food to fish, immobilization of contaminants from soils, and sewage treatment as a supplementary material in composting and in methane fermentation processes (Pereira et al. 2014; Tang et al. 2013; Malin´ska et al. 2014; Malin´ska and Dach 2015; Qiao et al. 2019; Safari et al.

2019).Furthermore, the biochar has a wide range of applicability in industrial sector (Hoegberg et al. 2010; Ozsoy and van Leeuwen 2010; Tan et al. 2017).

Animal manure ensures proper management of livestock wastes that would otherwise pollute environments. Production and application of farmyard manures is essential in cycling of nutrients in agriculture and management of livestock wastes (Antonious 2018). Biochar production and application is important in management of crop residues and livestock wastes that conserves environments and cycles nutrients in agriculture. Therefore, biochar and animal manure are very important in sustainable environmental conservation and agriculture.

2.0 Biochar and Animal Manure

2.1 Biochar

The term biochar covers carbon (C) products which are obtained from plant biomass, poultry litter and sewage sludge (Hossain et al. 2011; Sing et al. 2010). It is an umbrella term for all pyrolyzed organic materials (Scott et al. 2014).The process of pyrolysis takes place at higher temperatures normally 200 to 700°C in absence of oxygen (Saletnik et al. 2019; Hass et al. 2012).

There are two categories of biochar depending on materials used, these are plant andanimal derived biochar. A plant derived biochar (PDB) is made from plant products; while animal derived biochar (ADB) is made from animal products. These two categories of biochar have different properties in terms of nutrient concentrations and availability. The PDB has higher carbon (C %) content than ADB. However, percentage of ash, nitrogen (N), phosphorus (P), potassium (K), sulphur (S), calcium (Ca), magnesium (Mg), aluminium (Al), sodium (Na) and copper (Cu) are lower in PDB than ADB. Further, electrical conductance (EC), cation exchange capacity an indicator of soluble ions (CEC) and nutrient availability (N, P, K, Mg and Na) are lower in PDB than ADB (Scott et al. 2014; Spokas et al. 2012; Angstand Sohi 2012; Novak et al.2014; Clough et al. 2013; Ippolito et al. 2012). Status of biochar in terms of nutrients contents have different properties basing on whether it is biochar derived from plants and animals are detailed shown in the Table.

Table 1: Nutrient contents of plant derived and animal derived biochar

S/N	Parameter	Plant Derived Biochar (PDB)	Animal Derived Biochar (ADB)
1	Carbon (%)	High	Low
2	Ash (%)	Low	High
3	Nitrogen (%)	Low	High
4	Phosphorus (%)	Low	High
5	Potassium (%)	Low	High
6	Sulphur (%)	Low	High
7	Calcium (%)	Low	High
8	Magnesium (%)	Low	High
9	Aluminium (%)	Low	High
10	Sodium (%)	Low	High
11	Copper (%)	Low	High
12	Cation exchange capacity (CEC)	Low	High
13	Electrical conductivity (EC)	Low	High

Data compiled from Scott et al. 2014.

Therefore, animal derived biochar such as poultry and cow manure have higher nutrient content and better quality than plant derived biochar.

2.2Effects of biochar on soil fertility improvement

Biochar improves physical, chemical and biological properties of soils. Application of biochar is important on soil fertility improvement as shown in Table 2. Quality attributes of biochar and its effect on soil amendment depends on type of feedstocks and pyrolysis conditions (Graef et al. 2018; Brassard et al. 2017). Though, biochar has positive impacts on soil fertility improvement, there are some soil properties that may not change or may change negatively depending on quality characteristics of biochar applied and soil type.

Application of biochar improves soil physical properties such as structure, texture, porosity, and bulk density. Biochar amendment at 9t/ha increased the ability of soil to retain water by 11% in silty loamy soils (Karhu et al. 2011). Further, the biochar application has been reported to improve soil porosity both micro-porous and meso-porous structure, and soil aggregation in tropical soils (Obia et al. 2016). Biochar application in top soils 10 cm depth at 5% ratio with a soil improves soil structure that enhances higher moisture retention capacity in tropical rain-fed conditions (Moiwo et al. 2019).

Biochar contains a number of essential nutrients which may be released directly in a soil to improve plant nutrient availability. These essential nutrients include macronutrients and micronutrients.Macronutrients such as nitrogen (N), phosphorus (P), potassium (K), magnesium (Mg), calcium (Ca) and sulphur (S) are required in large quantity.Micronutrients are required in small quantity by plants (Angst andSohi 2012; Brewer et al. 2011; de la Rosa and Knicker 2011). Application of 20t/ha biochar made from hardwood (*Acer pseudoplatanus*, at 500°C) released 20 - 50 kg K/ha due to high solubility and 2.6 kg P/ha due to slow and gradual release of P in top soil (Angst and Sohi 2012). Also, biochar may change the soil pH which affects availability of plant nutrients (Chan et al. 2007; van Zwieten et al. 2010). Depending on a nature of feedstock used during pyrolysis, biochar can be acidic or alkaline with implication to soil pH either positive or negative. Application of biochar at 20 t/ha increased soil pH from 3.9 to 5.1 in highly weathered tropical soils (Yamato et al. 2006), corn cob biochar at 9t/ha/year increases soil pH and enhance alkaline phosphatase activity 2 to 3 times in sandy loam soils (Gul and Whalen 2016). Addition of biochar in oxisol increases soil pH that enhances availability of calcium (Ca) and magnesium (Mg)(Major et al. 2010).In contrast, application of pine-sawdust biochar at 15, 22, and 45t/h decreased soil pH by 4.3%, 8.9%, and 11.3%, respectively ina sandy desert soil(Laghari et al. 2015). Further, biochar improves nutrient retention of the soil through adsorption, cation exchange capacity, and reducing nutrient losses through leaching and volatilization (Hua et al. 2009; van Zwieten et al. 2010; Ding et al. 2010; Zhang et al. 2010; Martinsen et al. 2014).

Biochar improves biological properties of the soil by enhancing flora and fauna activities that improve nutrient availability and uptake by plant. Application of biochar in a soil provides a habit for microorganisms' soil microbial activities (Palansooriya et al. 2019). Biochar changes microbial metabolism and diversity in the soil (Lehmann et al. 2011, Deenik et al. 2010). Application of biochar enhances activities of mycorrhiza fungi and colonization rate of arbuscular mycorrhizal fungi (Atkinson et al. 2010), this increases plant root growth significantly (Yamato et al. 2006; Abiven et al. 2015). Application of biochar improves microbial activity through changes in soil pH from corncob biochar at 9t/ha/year (Gul and Whalen 2016). Application of grass and wood biochar enhances soil surface area and micro-pore volume that improves microbial diversity. Activated grass biochar in arid sub-soils increases microbial gene abundances which are involved in nutrient cycling (Palansooriya et al. 2019). Therefore, biochar application improves soil biological properties which are important for nutrient cycling and plant growth.

Hence, application of biochar is important in soil characteristics improvement such as physical, chemical as well as biological properties. The soil structure, texture, organic matter, soil chemical reaction from pH, macro-nutrients and micro-nutrients in the soil are affected by biochar application. Also, biochar application affects flora and fauna activities in the soil. This contributes to improvement of fertility status of the soil. Therefore, application of biochar has significant effect on ability of soils to supply nutrients for plant growth.

Table 2: Application of biochar on improvement of soil physical and chemical properties

S/N	Parameter	Control (no biochar application in a soil)	Biochar (2% rate of biochar application in a soil)
1	Sand (%)	32.70	32.70
2	Silt (%)	49.90	50.70
3	Clay (%)	17.40	16.70
4	Textural Class	Silty loam	Silty loam
5	Soil moisture content (% volume)	6.9	39.3
6	Field capacity (% volume)	29.83	35.30
7	Plant available water (% volume)	20.82	25.55
8	pH (0.01 M $CaCl_2$)	5.34	6.58
9	Organic carbon (%)	1.35	2.94
10	Total nitrogen (%)	0.12	0.14

11	Total hydrogen (%)	0.48	0.48
12	Phosphorus (mg/kg)	11.10	84.16
13	Potassium (Cmol/kg)	0.26	1.75
14	Calcium (Cmol/kg)	5.96	8.87
15	Magnesium (Cmol/kg)	0.54	1.07
16	Aluminium (Cmol/kg)	0.03	0.006
17	CEC (Cmol/kg)	7.63	11.92

Data compiled from Pandit et al., 2018.

2.3 Influence of biochar on crop yield and quality

Response of crops in terms of growth and yield may increase or decrease than control or no change from biochar application. The effectiveness of biochar on yield and quality of crops depends on materials used as feedstocks, method of pyrolysis, temperature during pyrolysis, quantity of biochar applied, method of biochar application, type of soil, crop type and climatic conditions (Scott et al. 2014).The quality and effect of biochar on crop growth and yield depends on the feedstock, pyrolysis condition, residence time, and additives added (Shiralian 2016).

Application of biochar increases crop yield and quality. Biochar amendments increases crop yield by 25% in highly weathered soils found in the humid tropics (Jefferyetal.2017). Biochar made from maize cobs increased maize crop yield from 0.96 t/ha in control to 1.43 and 1.52 t/ha in 5 and 10 t biochar/ha, respectively under flat tillage method (Graef et al. 2018). Application of biochar reduces the risk of crop yield during dry season (Shiralian 2016). The combination of biochar and fertilizer micro-dosing increased maize yield from 0.96 t/ha in control to 2.34t/ha in 5 t/ha biochar and 25% fertilizer micro-dose, and 2.37 t/ha in 10 t/ha biochar and 25% fertilizer micro-doseapplications (Graef et al. 2018). However, application of biochar under tied ridges might perform less than flat cultivation as the case of 0.07, 0.47, 0.47, 0.16 and 0.06 t/ha from control, 5 t/ha biochar, 10 t/ha biochar, 5 t/ha biochar and 25% fertilizer micro-dose, and 10 t/ha biochar and 25% fertilizer micro-dose, respectively (Graef et al. 2018).Further, biochar made from weed plants increased maize biomass at different watering rates by 67% with a significant increase to 120% under one third of NPK micro-dose rate in moderately acidic low in put soils (Pandit et al. 2018). Application of biochar as green waste at 450°C pyrolysis in presence of nitrogen fertilizer showed significantly higher yield of radish (*Raphanus sativus*) crop(Chan et al. 2007). Biochar prepared from a nut shell (*Macadamia integrifolia*) withlowamount of volatile organic matter 63g/kg, when supplemented with fertilizer, increased maize yield significantly (Deenik et al. 2010). A fixed ratio 1:20 biochar-soil application increased NERICA-4 upland rice by 480 kg/ha with a potential to reach 695 kg/ha under tropical rain-fed conditions (Moiwo et al. 2019). Biochar increased yield of maize crop by 52% and 101% from application rate of 27 and 67.5 t/ha insalty conditions due to enrichment of soil organic matter, phosphate and water-stable aggregates (Kim et al. 2016; Palansooriya et al. 2019).

There are some cases where biochar application does not increase crop yield. Biochar as hardwood at 500°C pyrolysis did not increase corn silage yield in the first season on calcareous soils (Lentz and Ippolito 2012).The study reported by Hammond et al (2013) in United Kingdom revealed that biochar application has no or has very little effect on crop yield in temperate soils.

There are some cases where biochar is reported to decrease yield than control that is no biochar applications. Biochar as hardwood at 500°C pyrolysis, decreased corn silage yield by 36% in the second season on calcareous soils (Lentz and Ippolito 2012) due to reduced soil carbon mineralization (Zimmerman et al. 2011). Also, biochar derived from nut shell (*Macadamia* *integrifolia*) which have high levels of volatile organic matter about 225g/kg, with or without fertilizer, reduced the growth of maize due to stimulated microbial growth and immobilization of plant available nitrogen(Deenik et al. 2010; Scott et al. 2014).

Apart from quantity of food in terms of yield, biochar has effect on food quality. Quality attributes may include but not limited to protein content, calories, vitamins and minerals. Application of biochar increases uptake of nitrogen and has effects on amino acid variability in crops, hence an important indicator on food quality (Wiedner et al. 2019).

In conclusion, application of biochar has a variety of effects on crop growth and yield, as well as food quality attributes. The effect may be positive, negative or no any change on crop growth and yield. Positive effects of biochar on crop yield are reported in soils with poor fertility status especially in tropical conditions. There are factors that influence response of crop from biochar application. These factors include quality of biochar, method of application, type of soils and climate.

Table 3: Effect of biochar and fertilizer rates on maize yield under flat and tied ridge tillage in rain-fed farming conditions

Treatment application	Maize yield (t/ha) under flat tillage	Maize yield (t/ha) under tied ridge tillage
Control (0 fertilizer + 0 biochar)	0.97	1.27
Biochar at 5t/ha	1.15	1.44
Biochar at 10t/ha	1.60	1.51
Fertilizer micro-dose 25% and Biochar at 5t/ha	1.65	1.48
Fertilizer micro-dose 25% and	1.90	1.64

Biochar at 10t/ha		
Fertilizer 100% dose and Biochar at 5t/ha	1.37	1.91
Fertilizer 100% dose and Biochar at 10t/ha	1.78	1.81

Data compiled from Graef et al., 2018.

2.4 Animal manure

Animal manure are by-products either in solid, fluid or semi-fluid form generated by animals that are grown purposely for production of meat,milk, eggs, hides and/ or skin as well as other agricultural products for humanuse and consumption (Sims and Maguire 2005). These are combination of animalfaeces, urine, and bedding materials for instance straw, sawdust, andrice hulls.There are other materials related with animalproduction, these include waste feed, soil, wash waters, andany chemical or physical improvement used duringhandling and storage of manure. Animal manure is a heterogeneous composited organic material consisting of animal dung, urine and bedding materials in various stages of decomposition that contain both macro-nutrients and micro-nutrients required for plant growth (Saidia and Mrema 2017).

There are a number of animal manures categorized basing on species or types of animals. These animals may be domesticated or not domesticated, for instance chicken, cattle, goats, sheep, pigs, horse, donkey, bat and others. Some common animal manure include: cattle manure, poultry manure, goat manure, sheep manure and bat manure.The quality of manure depends on type of animal, age of animal, quality of animal feed, and method of manure handling and storage conditions (Saidia and Mrema 2017; Sims and Maguire 2005). Poultry manure has more content of nitrogen than cattle manure. The type of animal husbandry or livestock management influences chemical composition in animal manure. For instance, poultry manure was found with potentially dangerous chemical elements required in minute quantity such as arsenic, copper and zinc originating from the chemicals used to take care of diseases in production of commercial chicken (Bolan 2010).

2.5 Effects of animal manure on soil fertility

Animal manuresarea valuable soil amendment that improves soil properties for a long time.Farmyard manures sometimes known as animal manure improves physical, chemical and biological soil properties due to its nutrient contents as shown in Table 4.They are the main sources of plant nutrients which are well known to improve physical and biological properties of the soil through addition of organic matter(Sims and Maguire 2005; Utamy et al. 2018).

Animal manures contains more organic matter above 6% organic carbon, and nutrients such as nitrogen, phosphorus, potassium, calcium, magnesium, sodium, copper, iron, zinc and manganese (Saidia and Mrema 2017). Application of farmyard manure increased organic matter by 29.9% in the soil that improved soil structure, moisture holding, plant nutrient retention capacity, aggregate stability and aeration (Khan etal. 2010).Farmyard manure at 40 t/ha improved soil properties from 1.47 to 1.24 Mg/m^3 bulk density, 0.93 to 1.21 % organic matter, 0.05 to 0.08% total nitrogen, 9.1 to 19.4 ppm phosphorus, and 157.9 to 189.4 ppm potassium (Khan et al. 2010). Application of manure improved soil chemical characteristics, total nitrogen and organic matter (Utamy et al. 2018).The livestock manure, sewage sludge and composted household waste increased soil total nitrogen by 13–131% thaninorganic fertilizerssuch as NPK compound fertilizer (Antonious 2018).

Table 4: Nutrient contents in animal manure or farmyard manure

S/N	Parameter	Farmyard manure	Farmyard manure with activated effective micro-organisms
1	Organic carbon (%)	6.91	12.36
2	Total nitrogen (%)	0.94	1.33
3	Carbon and nitrogen ratio (C/N)	7.5	9.4
4	Phosphorus (%)	0.48	0.37
5	Potassium (%)	0.37	0.78
6	Calcium (%)	1.66	1.19
7	Magnesium (%)	0.33	0.31
8	Zinc (mg/kg)	121.82	56.80

Data compiled from Saidia and Mrema 2017.

2.6 Influence of animal manure on crop yield and quality

Animal manures are valuable sourcesof nutrients essential for crop growth and yield (Shober and Maguire 2018).Farmyard manure contains essential nutrients which consequently improves crop growth, development and yield as shown in Table 5. Application of cattle manure increased rice crop growth and yield significantly under upland rain-fed conditions from 5 to 8 tillers, 0.4 to 1.0 leaf area index, and 1.3 to 3.3 t/ha grain yield (Saidia and Mrema 2017). Farmyard manure at 10t/ha increased rice yield and yield components by 25% grain yield, 12% straw yield, 12% number of tillers, 6% number of filled grains, and 9% seed size than control (Satyanarayana et al. 2002).Depending on environmental conditions, application of manure improves crop growth and yield more than or sometimes better as chemical fertilizer. Manure application at rate of 184 kg nitrogen ha^{-1} $year^{-1}$is recommended asappropriatealternate for inorganic fertilizer application with an equilibrium nitrogen budget for sustainable Napier-grass(*Pennisetum purpureum*Schumach) and ryegrass (*Lolium multiflorum* Lam.) production in hilly region of southern Kyushu Japan (Utamy et al. 2018).Application of horse manure increased total marketable tomato yield by 20% (Antonious 2018). Chicken manure known as chicken litter contain about 3% nitrogen, 3% phosphate (P2O5), and 2% potash (K_2O) which is very important on growth and crop yield (Antonious 2018; Saidia and Mrema 2017).

Application of animal manure improves crop nutritional composition, hence promote crop quality. Vitamin C (Ascorbic acid) was greatest in tomato fruit plants grown in native bare soils amended with chicken manure (Antonious 2018).Animal manures increase concentration of soluble sugars and phenols in fruits compared with none amended soils because ofhighproduction of these water soluble compounds by plants grown in organic fertilizers such as manure. Application of high rates of phosphorus (P) and nitrogen (N) at 140 kg P ha^{-1} and 150 kg N ha^{-1} increased significantly vitamin C content in tomato fruit (Dumas et al. 2003).Application of animal manure increases crude protein concentration of herbages (Utamy et al. 2018). However, the concentration of vitamins, sugars, proteins, and mineral elements vary significantly among crop types, different animal manures and environment.

Table 5: Effect of animal manure on growth and yield of upland rice crop

Treatment	Leaf area index (LAI)	Biomass (g/m^2)	Harvest index (HI)	Rice grain yield (kg/ha)
Control (0 t/ha)	0.36	370	0.43	1350
Farmyard manure at 5 t/ha	0.94	610	0.62	3050

Farmyard manure at 10 t/ha	1.02	620	0.64	3310

Data compiled from Saidia and Mrema 2017.

3.0 Conclusion

Biochar and animal manures production, processing and application are effective and efficient way of waste management and nutrient cycling.Application of biochar and animal manure has a variety of effects on soil fertility, crop growth and yield, as well as food quality attributes. This depends on quality of materials used during production, method of application, soil properties, crop type, and weather conditions. Biochar production and application is important in management of crop residues and livestock wastes that conserves environments and cycles nutrients in agriculture. These enhance crop-livestock-fish integration under farming conditions, hence promoting sustainable agriculture.

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Conflict of Interest
There is no conflict of interest.

Reference

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