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Effect of Some Organic Residues on Yield Productivity: A review

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ABSTRACT

Sustainable management of low fertile arid soils using carbon-rich organic amendments such as biochar and compost is of great concern from both agricultural and environmental points of view. The impact of pyrolysis, composting, and co-composting processes of different feedstocks on carbon loss and emissions, soil properties, and plant growth in arid soils with low organic matter content has not been sufficiently explored yet. the aim of this work was to investigate the effects of the pyrolysis, composting, and co-composting processes on the properties of the produced biochar, compost, and co-composted biochar from rice straw and sugarcane bagasse, and examine the impact of addition of biochar, biochar, compost, compost, co-composted RS biochar, and co-composted biochar on soil properties, carbon emission and growth of plant. Carbon loss was significantly lower during the preparation of the compost and co-compost –biochair than biochair. The C/N ratio of the compost and co-compost –biochair were narrow than the corresponding values of biochairs. All amendments increased significantly soil organic carbon content as compared to the non-amended control. All amendments increased dry weight, total chlorophyll content, root and shoot length, as compared to the control. Moreover, all amendments organic compound showed a positive soil carbon balance. The modified integrated two-way ecological model data also indicated that the co-composted biochar, particularly RSCB is a promising amendment to improve soil quality and plant growth in sandy arid soils.

Keywords: pyrolysis, compost, biochiar, co-compost, soil, plant growth, carbon balance.

1. Introduction

Agrochemicals are widely used around the world to increase crop production and meet the growing global demanded for food; yet these chemicals may deteriorate soil biodiversity and affect negatively sustainable agriculture (Abdelhafez *et al.,* 2021b and Ganguly *et al.,* 2021). Minerals from these agrochemicals i.e., inorganic fertilizer find their way to water bodies via leaching, soil erosion and rinsing out causing crucial environmental risks. Also, now days, fertilizer costs are increasing continuously. Therefore, the circular economy via- recycling agricultural wastes may be suitable alternative to substitute inorganic fertilizers; thus, reduce fertilizers casts and lessen its negative implications and the environment. Organic amendments that are considered safe products can be used to increase crop production while lessen dependence on inorganic fertilizers. Their implications on soil fertility and soil characteristics are more significant on the long term (Elcossy *et al.,* 2020). One of the promising organic amendments that is widely used to enhance soil quality is the biochar. It is termed the black diamond (Abdelhafez *et al.,* 2017) that can effectively increase plant growth and productivity, even under the stressful conditions of salt affected soils (Moradi *et al.,* 2019) through osmotic adjustment of the grown plants. Moreover, biochar increases soil microbial biomass carbon (Zhang *et al.,* 2020) and can sorb toxic elements in soil and water; hence lessen their mobility (Gautam *et al.,* 2021). This carbon rich product persists longer in soil versus other organic amendments and therefore

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its implications may last for longer time periods (Wang *et al.,* 2021). However, massive amounts of C may emit through the pyrolysis process of biochar and these emissions can increase the global warming threats (Abdelhafez *et al.,* 2020). Compost is sometimes preferable than biochar in improving soil fertility and crop performance (Elshony *et al.,* 2019; Manirakiza and Şeker, 2020). Yet, this organic amendment undergoes rapid degradation in soil and reaches its steady state within a period less than one week while emits considerable amounts of C within this short period and this may possess an alarm to the global warming threats. Probably, mixing biochar with compost can be more beneficial to plant growth and soil fertility exceeding those attained for the application of each solely (Debode *et al.,* 2020). This co-composted biochar may also help mitigating the emissions of greenhouse gases

The positive impacts of amending degraded soils with composts, biochars and co-composted biochar to mitigate such soils have been extensively studied yet, little researchers have assessed all pros and cons using environmental analyses models to investigate how far these amendments are beneficial or not to soils and plants versus their negative impacts through C-emissions. The pyramid model was used to evaluate the efficiencies of amending soils with organic amendments. (Bassouny and Abbas 2019). This model weighs the outcomes of organic amendments on plant and soil and also considers C emissions from these products (during processing and after soil application) to calculate the carbon balance and know if C emissions increases when using these amendments or C-sequestration in plants by photosynthesis dominates.

Zucchini (*Cucurbita pepo* L.) is a highly polymorphic vegetable crop (Kathiravan *et al.,* 2006) that can be grown during the summer seasons (Shah *et al.,* 2008). It is one of the most significant crops of the Cucurbitaceae family (Galal, 2016). The total cultivated area in Egypt was estimated by 24923 hectare in 2016, producing about 471,571.000 Ton (mega-grams) according to Ministry of Agriculture and Land Reclamation (2016). Fruits of this crop are suitable as a low-calorie diet (Verdone *et al.,* 2018) beside of their high contents of bioactive components including antioxidants, flavonoids, vitamins and minerals such as K, Mg, P, Ca and Fe (Tamer *et al.,* 2010).

The aims of the study was assessed investigating the impact of amending a light-textured soil of low fertility with either biochar or compost and their combination (co-composted biochar) as possible amendments to increase germination and improve safely plant growth performance and productivity.

2. Agricultural wastes in Egypt

Agricultural wastes are the parts of plants that remain after collecting crops. Their amounts are influenced by a number of factors e.g. types and variety of the grown crops (Karaj *et al.,* 2010). The traditional method that is used to get rid of these wastes, is to burn them directly in open fields; yet this process causes environmental pollution (Nguyen *et al.,* 2019) and increases the global warming threat. Instead, this massive amount of wastes should be put to good use (Qiu *et al.,* 2017). For example, safe recycling of organic biowastes for reclamation and sustainable management of degraded soils is of great interest from the agro-environmental point of view and may help in the achievements of the United Nations-Sustainable Development Goals (UNSDGs) (Shaheen *et al.,* 2022). These wastes can be changed into valuable products to be used for supporting plant growth and productivity while lessening the dependence on inorganic fertilizers (Bass *et al.,* 2016). Unlike, agrochemicals which may deteriorate soil biodiversity and affect negatively the sustainability of agriculture (Abdelhafez *et al.,* 2021a; Ganguly *et al.,* 2021), organic products are safe (Ramakrishnan *et al.,* 2021) and have prolong positive impacts on soil characteristics and fertility (El-Naggar *et al.,* 2019a; El-Naggar *et al.,* 2019b; Farkas *et al.,* 2020; Korai *et al.,* 2021).

Although, inorganic fertilizers are still used extensively in many areas around the world to increase crop production (Tommasi *et al.,* 2020) and meet the growing global demands for food (Stewart *et al.,* 2005). Yet, improper use of these fertilizers negatively affects soil health (Atieno *et al.,* 2020). Minerals from these fertilizers find their way to water bodies via leaching, soil erosion, and rinsing out (Ashitha *et al.,* 2021), causing crucial environmental risks (Rahman and Zhang, 2018). Moreover, fertilizer costs are increasing continuously (Li *et al.,* 2013). Therefore, the circular economy via recycling agricultural wastes in soil may be the safe alternative to substituting inorganic fertilizers (Diacono *et al.,* 2019), while reducing fertilizer costs. A point to note is that Egypt produces between 22 and 26 million tonnes of agricultural waste per year while only 18% of agricultural wastes are used as organic fertilizer (El-Mashad *et al.,* 2003). Rice, sugarcane, corn, cotton, and wheat are the considered the main crops that produce huge amounts of waste.

2.1. Rice straw

Rice straw is a by-product that is removed from the rice grains during harvest. Its ratio accounts for 0.7 - 1.4% of plant biomass depending on the variety and growth. It is a lignocellulose biomass that comprises 12% lignin, 25% hemicellulose and 38% cellulose (Yokoyama and Matsumura, 2008). Mainly, rice cultivation is concentrated within the Delta region (99.5 percent of Egyptian rice production) (Abdelhady *et al.,* 2014) which produces about 20 million tons per year (Afify *et al.,* 2002). Farmers burn the straw in air, resulting in black clouds and its impact are negative on visibility, health and global climate by releasing particulates and other gaseous pollutants (Lemieux *et al.,* 2004 and Hays *et al.,* 2005).

2.2. Sugarcane bagasse

This bagasse is a carbon-rich biomass, like most crop residues. (Mothé and de Miranda, 2009) which is the leftover product from sugarcane after the juice has been extracted (Nakhla and Haggar, 2014). It is a complex lignocellulose substance made up mainly of cellulose, hemicellulose, and lignin, as well as pentons, -cellulose, and inorganic compounds known as ash (Pandey *et al.,* 2000). Egypt's sugarcane industry dates back to 710 AD which exist mainly in the upper Egypt region and this region produces about 16 million tons of sugar cane per year (Nakhla and Haggar, 2014). Bagasse has various benefits over other crop residues such as rice straw and wheat straw, which have 17.5 % and 11.0 % ash content, respectively. Moreover, it yields around 80 t/ha vs. 1, 2, and 20 t/ha for wheat, other grasses, and trees, respectively (Pandey *et al.,* 2000).

3. Uses of crop residues

There are a variety of agricultural amendments that can be used successfully to improve soil characteristics and increase plants grown thereon. Common agriculture practices used today, such as the use of compost, biochar and manure, have been identified to increase soil fertility (Glaser *et al.,* 2002). These amendments could be summarized as follows:

3.1. Biochar

Biochar is one of the promising organic amendments that are widely used to enhance soil health (Allesina *et al.,* 2018) and quality (Alkharabsheh *et al.,* 2021 and Bolan *et al.,* 2021).

It is useful for soil improvement and has been demonstrated to improve crop output. Therefore, it can raise agricultural system productivity through direct and indirect impacts on crop development and soil quality (Diatta *et al.,* 2020).

3.1.1. Characterization of Biochar

Biochar is a carbon-rich product obtained during the thermochemical processing of plant residues-heated at several hundred degrees of Celsius in oxygen-limited environments (Abdelhafez *et al.,* 2021b). The quality of the resultant chars is affected significantly by both the source of feedstock and the reaction conditions (Diatta *et al.,* 2020). This product is gaining popularity due to its potential utility as a soil supplement related to its high surface area (Lehmann *et al.,* 2006) beside of its high porosity that is improved at higher pyrolysis temperatures (Somerville and Jahanshahi, 2015).

The essential features of biochar, such as high pH, porosity, specific surface area, and CEC, are mostly influenced by the feedstock type and production process (Joseph and Taylor, 2014). These characteristics influence the material's interactions with the physical, chemical, and biological characteristics of soil components, as well as its destiny within the ecosystem (Joseph *et al.,* 2013).

Wu *et al.* (2016) found that C, H, O, and N are the most important components in biochar, whereas P, S, Si, Cu, Fe, Zn, and Mn, are present in varying degrees depending on the biochar.

3.1.2. Biochar production and composition

Biochar is produced primarily by pyrolysis at high temperatures (300–650°C) in the absence of oxygen. This method results in formation of a carbon-rich solid product (biochar), a liquid phase (bio-oil) and non-condensable gasses (CO, CO_2, CH_4, and H_2). Slow pyrolysis (heating speeds ranging from 10 to 30 C / min) is considered the main process for biochar development among the various used techniques (Kambo and Dutta, 2015 and Cha *et al.,* 2016). The reaction time, temperature, heating levels and initial moisture content of the biomass are the main parameters affecting the physicochemical properties and the percentage yield of generated biochar (Xiao *et al.,* 2017). During the pyrolysis of organic wastes, biochar also produces organic acids that affect the end product pH; however, because of the presence of alkali and alkaline metals in the feedstock that aren't volatilized during the pyrolysis process, biochar becomes of alkaline pH. (Cheng *et al.,* 2018; Yang *et al.,* 2018). It is worthy to mention that the total N content fell by 58% in swine waste biochar and by 53% in wood chip biochar, whereas the total P content decreased by 17% in swine waste biochar and by 27% in wood chip biochar. The volatilization of NH_4^+ was shown to be the primary cause of nitrogen loss during pyrolysis (Hass *et al.,* 2012).

3.1.3. Biochar effects in agriculture

3.1.3.1. Biochar effects on soil properties and fertility

Biochar technology has received increasing interest because of the possibility for ameliorative soil structure and the availability of plant nutrients (Glaser *et al.,* 2002). This amendment improves soil physical properties such as bulk density, surface area, water holding capacity, and permeability (Abel *et al.,* 2013; Sun and Lu, 2014). Such improvements were not only affected by the rate of biochar, but also by its size as small biochar particles reduced the volume of soil pores with diameters less than 0.5 m while increasing the volume of bigger pores with diameters 0.5–500 m. (Głąb *et al.,* 2016). Moreover, biochar provides a micro-habitat for soil microorganisms due to its high surface area and porosity (Kookana *et al.,* 2011). Although, specific surface area and porosity increase with increasing pyrolysis temperature; however, microspores may be destroyed at higher temperatures (Kookana *et al.,* 2011).

This amendment also decreases soil bulk density (Mukome *et al.,* 2013) and increases aggregation, hydraulic conductivity and gas transportation, which in turn impacts chemical properties and microbial activities in soil (Lehmann *et al.,* 2011). Its effect is more pronounced on the sandy soil via increasing soil water holding capacity (Basso *et al.,* 2013). Furthermore, its affects aggregate stability, water management, porosity and surface area of this poor fertile soil (Sohi *et al.,* 2010). Similar results were also detectable on loamy sand and sandy loam soils (Peake *et al.,* 2014).

Biochar tend to be a stable component in soil that persists for years (Kätterer *et al.,* 2019) or probably decades (Wang *et al.,* 2016 and Lanza *et al.,* 2018), resulting in lower CO_2 losses (between 0.5% and 5.8% of total added C) relative to other plant-based bioenergy by-products (Cayuela *et al.,* 2010). This biochar also lessens the emissions of N_2O yet it may increase the emissions of CH_4 (Taghizadeh-Toosi *et al.,* 2011). Ameloot *et al.,* (2013) stated that adding biochar to the soil has a significant impact on the soil pH via balancing the acidity of the soil. When biochar was crushed to a fineness of 0.18 mm and applied to soil, the pH of the soil increases obviously (Uzoma *et al.,* 2011).

Biochar has positive impacts on decreasing soil EC (Prapagdee and Tawinteung, 2017). In spite of that, this amendment enriches soil with nutrients like K and Mg, hence improves soil fertility (Ameloot *et al.,* 2013 and Mosa *et al.,* 2020). Moreover, it enhances the retention of NO_3^- –N and NH_4^+-N in soil by 33% and 53%, respectively (Gao *et al.,* 2016) and also increases nutrient availability (Agegnehu *et al.,* 2016) via the formation of organic complexes that chelate immobile nutrients, and increase their availability in soil and uptake by plants (Elshony *et al.,* 2019).

Biochar has a positive effect on the CEC of a sandy soil following the addition of biochar at a rate of 15 g kg^{-1} (Namgay *et al.,* 2010)

On the other hand, biochar can sorb toxic elements in soil (Palanivell *et al.,* 2020; Bolan *et al.,* 2021) and water (Shaheen *et al.,* 2019), hence reducing their mobilization and bioavailability (Abdelhafez *et al.,* 2014; Mohamed *et al.,* 2018; Gautam *et al.,* 2021; Sun *et al.,* 2021). It is worthy to mention that, the effect of biochar is dependent on the qualities, the dose of biochar and soil parameters (Głąb *et al.,* 2016). The main advantage of using biochar is attributed to the massive amounts of C that are emitted through the pyrolysis process for production of biochar (Abdelhafez *et al.,* 2021b) and these emissions can increase the global warming threats.

3.1.3.2. Biochar effects on plant growth and crop productivity:

Biochar can help plants growth by enhancing soil physical, chemical and biological characteristics. Biochar can effectively increase nutrient uptake by plants (Lehmann *et al.,* 2003); hence enhance plant growth and productivity (Revell *et al.,* 2012; Vassilev *et al.,* 2013; Raboin *et al.,* 2016), even under the stressful conditions of salt-affected soils (Moradi *et al.,* 2019) through osmotic adjustment of the grown plants (Kanwal *et al.,* 2018) and stimulation of growth hormones (Lehmann *et* *al.,* 2011). Biochar contains significant quantities of plant nutrients that improve plant growth. Biochar produced from tropical plant wastes, for example, it has 0.35-5.1 % potassium, 0.04-4.3% calcium, 0.05-0.70 % magnesium, and 0.03-0.93 % phosphorus. The availability of nutritional elements for plants relies on the rate and degree of breakdown of these compounds in the soil, which are typically found as crystalline compounds in the pores of the biochar (Prakongkep *et al.,* 2015). Moreover, biochar increases soil microbial and enzymes activity (Ali *et al.,* 2020; Zhang *et al.,* 2020 and Pan *et al.,* 2021) and stimulates biological N fixation (Rondon *et al.,* 2007). Because of its alkaline nature, biochar improves plant growth under soil acidic conditions versus the alkaline ones (Jeffery *et al.,* 2011).

Plants may benefit from using biochar as a source of nitrogen. It comprises inorganic N forms such as NH_4^+-N, NO_3-N, and N_2O-N, in addition to organic N forms (e.g., hydrolyzable-N, water-soluble-N, and non-hydrolyzable-N) (Liu *et al.,* 2018). Moreover, its application led to significant reductions in N leaching and improvements in applied N recovery because this amendment decrease N gaseous emissions and erosion losses (Güereña *et al.,* 2013). It also affects N and P cycle (Gul and Whalen, 2016)

Bruun *et al.* (2014) showed that hardwood biochar (slow pyrolysis at 450-480° C) application to a coarse-textured soil with 32 t ha^{-1} led to sustainable development of spring barley

Sigua *et al.* (2016) found that root growth of winter wheat increased when amending soil with 40 t ha^{-1} of pine chip biochar and 44 t ha^{-1} of hardwood biochar (both produced by slow pyrolysis at 350̊ C).

Akhtar *et al.* (2014) stated that improvements in sweet potato yields of 10%, 74%, 89%, 107% and 121% were attained with higher application rates of wheat straw-derived biochar (5, 10, 20, 30, and 40 t ha1). In addition, the addition of a rice husk and cotton seed shell biochar combination affects significantly the fresh weight of tomato fruits when grown under different irrigation regimes.

Kim *et al.* (2016) also found that applying biochar at rates of 27 and 67.5 t ha^{-1} increases maize production by 52 % and by 101 % in saline conditions and such increases were ascribed to the concurrent improvements in SOC, phosphate content, and fraction of water-stable aggregates.

Abujabhah *et al.* (2016a) found that exchangeable Ca, Mg, and Na in black clay loam, red loam, and brown sandy loam soils were significantly increased due to the application of woody biochar, even at a modest rate of biochar application (1.25%), soil Ca availability increased.

3.2. Compost for sustainable agriculture

Composting is a viable and cost-effective method of reusing agricultural biomass wastes (Li *et al.,* 2020). In this process, organic materials such as rice straw, sugarcane, other agricultural by-products, and animal wastes undergo aerobic decomposition by microorganisms to form an easily decomposable useful humic-rich product known as compost (Barik, 2019). Temperature, pH, carbon-to-nitrogen ratio (C/N), and other variables are thought to be the main factors affecting composting process (Nghi *et al.,* 2020). An initial C/N value of 25 is considered sufficient for this process (Hamelers, 2001). If the C/N ratio turns high (>30), nitrogen becomes the limiting factor and the degradation process will slow down (El Haggar, 2005).

3.2.1. Effect of compost on vegetative growth and yield composition.

Compost is an effective management approach for maintaining nitrogen (N) absorption and maize yields, as well as lowering nitrogen loss and improving soil fertility (Zhang *et al.,* 2016b). It helps farmers to deal with the issues of declining soil fertility (Madeleine *et al.,* 2005). This product is characterized by its rapid degradation rate. It requires only 2-3 days in arid soils to reach an almost constant negligible rate (Abdelhafez *et al.,* 2018). During this process, nutrients are released in available forms to satisfy plant needs for proper growth and productivity (Manirakiza and Şeker, 2020). Also, compost application decreases soil pH which increases additionally nutrient availability (Caballero *et al.,* 2009). On the other hand, some of these nutrients may later be immobilized under the alkaline conditions of the arid soils (Arif *et al.,* 2017).

Naguib (2003) revealed that compost additions significantly improved the productivity of the three mint species, with progressive and substantial improvements in all growth and chemical components with increasing the levels of applied compost from 3.5 to 7.5 t/feddan.

Hussein *et al.,* (2006) showed that compost treatments enhanced the growth characteristics of dragonhead plants. These results may be attributed to the role of macro- and micro-nutrients provided by compost as well as the improved soil conditions owing to compost application in stimulating metabolic processes, encouraging growth and increasing the synthesis and accumulation of more metabolites in plant tissues.

Agegnehu *et al.* (2014) reported that compost includes a range of important trace elements as well as substantial levels of vital plant nutrients such as N, P, K, Ca, Mg, and S.

Seran *et al.* (2011) found that compost can partially satisfy nutrients to plants and the combined application between compost and biochar may effectively increase the crop yield while reducing the cost of production in onion farming. Similarly, applying half the recommended N and P rates as inorganic fertilizers plus half the recommended rate in the form of manure and compost resulted in pronounced increases in yield gains, recording around 129 % increase above the control.

Ali (2011) showed that the application of compost at rates of 5 and 7 ton fed^{-1} improved marketable maize yields by 107 and 124 %, respectively above the control treatment.

3.2.2. Effects of Compost on Soil Properties

3.2.2. 1. Soil organic matter

Soil organic matter (SOM) content and its mineralization rate can influence levels of potassium (K), phosphorus (P) and micronutrients in soil (Martin-Rueda *et al.,* 2007) and this will affect directly crop productivity. Maintaining SOM through compost amendment is important not only for sequestration of carbon and lessening greenhouse gas (GHG) mitigation, but also for improving the physical, chemical, and biological properties of soil (Ashagrie *et al.,* 2007). It may modify the pH of the final mix and has the ability to buffer or stabilize soil pH (Hazem, 2001). This amendment has positive impacts on increasing soil water retention (Rawls *et al.,* 2003) and nutrient availability as well. In this context, Hoyle *et al.* (2014) reported that about 15 kg of each of phosphorus and sulphur and about 100 kg of nitrogen becomes available to plants for every ton of carbon in soil organic matter after organic matter degradation.

According to the study of Bouajila and Sanaa (2011), food waste compost application resulted in substantial increases in organic carbon, versus the control. The application of 120 t/ha home waste compost and manure enhanced organic carbon by 1.09-1.74 %.

Roghanian *et al.* (2012) found that the high levels of organic matter in compost raised the organic carbon in soil, and such increases were more noticeable in uncultivated soil versus the cultivated one.

According to Amlinger *et al.* (2007), application of 7–10 Mg compost per hectare can meet the typical SOM need of agriculturally utilized soils. As a result, more than 10 Mg dry matter compost ha^{-1} is required for a long-term increase in SOM.

3.2.2.2. Bulk density

In soils, the density of the organic fraction is much lighter than the mineral fraction. As a result, increasing the organic component lowers the soil overall weight and bulk density (Brown and Cotton, 2011). It also increases the amount of meso- and macrospores in the soil due to enhanced soil aggregation and stability, which is mostly due to soil organisms (Liu *et al.,* 2007). This beneficial impact has been checked in the majority of situations, and it is usually linked to an increase in porosity due to interactions between organic and inorganic components (Amlinger *et al.,* 2007).

Curtis and Claasen (2009)found that the addition of 540 Mg ha^{-1} of compost to soil at 50 cm depth decreased the bulk densities of soils with various parent materials by 19–21% compared to the compacted control.

Aggelides and Londra (2000) also found that incorporating 15 m^{3}ha^{-1} of compost into a clay or a loam soil resulted in a significant drop in bulk density. The largest reduction in bulk density was detected with the application of compost at a rate of 300 m^3 ha^{-1} (16.7%).

3.2.2.3. Soil water content

Compost has a great water-holding capacity and may retain soil moisture needed for plants over time (Cogger, 2005). In this concern, Bouajila and Sanaa (2011) indicated that applying 120 Mg/ha of household waste compost and manure increased water infiltration (549.25 cm) and enhanced water quality (596.46 cm). Also, Aggelides and Londra (2000) found that higher compost rates resulted in greater water retention in clay and loam soils. Compost increased the sized big pores, particularly those that store water at a pressure of approximately 5 Mk-Pa.

3.2.2.4. Compost and greenhouse gas emissions

This organic amendment undergoes rapid degradation in soil and reaches its steady state (a negligible rate) within a period of less than one week, while emits considerable amounts of C within this short period (Abdelhafez *et al.,* 2018). This may be an alarm to the global warming threats. Probably, mixing biochar with compost can be more beneficial to plant growth and soil fertility (Antonangelo *et al.,* 2021 and Kang *et al.,* 2021) than the individual constituents applied solely (Debode *et al.,* 2020).

3.3. Biochar use in composting

Mixing biochar and compost, forming so-called "co-composted biochar" (Kammann *et al.,* 2015), could possibly be more beneficial for soil fertility and plant growth than applying either of them separately (Naeem *et al.,* 2018), especially in soils of low fertility (Wang *et al.,* 2019). The positive impacts were not only noted on increasing nutrient availability (Pandit *et al.,* 2020) and enhancing plant growth (Agegnehu *et al.,* 2017) but also on mitigating greenhouse gas emissions (Agegnehu *et al.,* 2016). Recent improvements in biochar-assisted composting have demonstrated benefits in terms of increasing the physiochemical characteristics of compost while lowering hazardous chemicals and emissions (Godlewska *et al.,* 2017 and Wu *et al.,* 2017).

3.3.1. Effects on compost physiochemical properties

Biochar is characterized by its high-water holding capacity and porosity, large surface area, and dissolved organic carbon sorption. It can also improve the environmental conditions that promote microbial growth via increasing the aeration of the compost mix, not only as a bulking agent but also as a result of microspores within the biochar structure, which enhance micro-aeration (Sanchez-Monedero *et al.,* 2018). Using excess biochar (40% w / w) might theoretically reduce the availability of readily degradable compounds and could result in lower temperatures relative to conditions where no biochar (Tsapekos *et al.,* 2018).

Camps and Tomlinson (2015) showed that the benefits of adding biochar to the composting process may include shorter compost times; reduced rates of greenhouse gase (GHG) emissions (methane, CH_4 and nitrous oxide, N_2O); reduced ammonia (NH_3) losses. It also served as a bulking agent for compost; and reduced odor. For the biochar material itself, undergoing composting helps to charge the biochar with nutrients without breaking down the biochar substance in the process.

The pH value is crucial during composition of organic amendments, because its profile reflects the biochemical changes that occur during the process. The pH of the compost usually drops within a short period after application because of the buildup of organic and inorganic acids caused by the decomposition of organic materials. The subsequent production of ammonia resulted in a pH increase (Casini *et al.,* 2019). On the other hand, using an alkaline biochar will increase the pH value of compost (Godlewska *et al.,* 2017).

Sánchez-Monedero *et al.* (2019) observed that composting with biochar had a lower pH profile during the thermophilic phase and a higher pH profile in the mesophilic and mature phases. The early lower pH in compost with biochar might be attributable to the increases that occurred in acid formation from biochar-induced increased microbial activity; however, the later higher pH was related to the retention of accumulated ammonia via biochar absorption rather than the direct loss by volatilization. During the thermophilic phase, however, biochar-added compost had a higher pH than compost that had not been altered with biochar.

Otterpohl (2012) found that addition of biochar to wheat straw + pig manure compost resulted in a lower pH, which might be ascribed to the formation of organic and inorganic acids from the breakdown of bulk organic matter. Another explanation for the compost's lower pH is that biochar can form microporous areas in which lactic-acid bacteria can inoculate excrement and lower the pH.

Jain *et al.* (2018) reported that the total nitrogen of the final compost product increased by 45 per cent with the addition of 5 per cent (w / w) biochar compared to the control.

Zhang *et al.* (2016a) found that adding biochar to compost from wheat straw at a rate of 10-15% (w / w) could increase electrical conductivity (EC) and water-soluble compost nutrients, including PO_4^{3-}, K^+ and Ca^{2+}.

3.3.2. Composting-biochar effects on plant growth and crop productivity

Crop yields can be improved via using biochar and biochar-compost mixtures in a number of ways, including direct nutrient supply, improved soil pH, nutrient use efficiency, and nutrient uptake for a given fertilizer application rate beside of the significant increases in the CEC and water holding capacity of the soil (Jeffery *et al.,* 2011). Such positive effects were more detectable on sandy substrate rather than on loamy substrate (Glaser and Birk, 2012).

Agegnehu *et al.,* (2015a) also reported that using compost and fertilizer in one application enhanced plant growth, improved soil nutrient status, and recorded higher plant nutritional content. Improved nutrient availability and absorption have been found to be the primary cause of increased plant growth in the biochar + compost treated soil when compared to biochar alone.

3.3.3. The ecological impacts of application of organic amendments

The positive impacts of amending degraded soils with composts, biochars, and co-composted biochars in order to improve their characteristics have been extensively studied (Jiang *et al.,* 2021). Yet, little effort has been put in assessing their benefits to soils and plants versus their potential negative impacts concerning C-emissions (during their production and after soil application). For example, Bassouny and Abbas (2019) presented their pyramid model to estimate the efficiency of these amendments; however, they placed equal weights on components of crop productivity, soil hydro-physical and environmental indicators. This model weighs all outcomes of organic amendments on plant and soil and also considers C emissions from these products (during processing and after soil application).

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