Biochar and Organic Amendments for Sustainable Soil Carbon and Soil Health

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Abstract Organic matter is the life of soil and vital to environmental quality and sustainability. Intensive cultivation solely depending on inorganic fertilizers with lesser quantity or no organic fertilizers resulted in lower carbon content in soils of tropical and subtropical countries. This paper attempted to identify the best soil and crop management practices which ensure slower microbial decomposition of organic materials, cause a net buildup of carbon in soils, and potentially mitigate the negative effect of global warming and climate change. Biochar and other organic materials have been applied to soil as most valuable amendments for increasing carbon sequestration, soil health improvement, and reduction of greenhouse gas emission from soil. Being recalcitrant in nature, biochar is highly efficient in storing carbon in soils. Biochar possesses a larger surface area and therefore is capable of holding and exchanging cations in soils. Quantity and quality of biochar produced from different organic materials are highly variable because of various production temperature and meager oxygen control system. This review contributes to understanding details of production technologies and performance mechanisms of biochar and other organic amendments in soil. Biochar and organic materials improve soil bio-physicochemical properties, serve as a sink of atmospheric CO_2, and ensure ecological integrity and environmental sustainability.

Keywords Compost · Greenhouse gas · Mitigation · Environment · Carbon sequestration

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Abbreviations

BSMRAU	Bangabandhu Sheikh Mujibur Rahman Agricultural University
CEC	Cation-exchange capacity
CFU	Colony forming unit
DMBC	Dairy manure biochar
EC	Electrical conductivity
FRG	Fertilizer recommendation guide
FYM	Farmyard manure
GHG	Greenhouse gas
NETL	US National Energy Technology Laboratory
Pg C	Petagram of carbon
RHBC	Rice husk biochar
SOC	Soil organic carbon
USDE	United States Department of Education
WHC	Water holding capacity

1 Introduction

The agricultural land has been declining every year by 1% due to the new establishment of houses, industries, factories, and markets and road construction in many Asian countries including Bangladesh and India. Worldwide, it is estimated that feeding the world population will need 60% more yield by 2050 (Rosenstock et al. 2016). Such a massive increase in agricultural production needs to be accomplished without jeopardizing soil and environment. Greenhouse gas (GHG) emission like CH_4, CO_2, etc. from different agriculture practices have some notable effects on climate change, but suitable management practices could improve soil fertility and also mitigate the negative impact of climate change through sequestering the huge amount of carbon in the soil (Rahman 2013; Rahman et al. 2016; Varma et al. 2017). Appropriate use of organic materials is essential for organic amendments in the soil to address and minimize such types of challenges. The maximum organic residues remain available in the agricultural fields in stacked forms which are used as fuel by the people for cooking or get discarded in the dumping places. A remarkable nutrient loss like nitrogen, sulfur, etc. occurs as a result of burning the organic residues and may lead to air pollution by emitting different GHG gases (Tipayarom and Oanh 2007; Chen et al. 2008).

A probable novel attempt to outline the limitation of soil fertility is the recycling of different organic residues (Kamara et al. 2014). The quick decomposition of organic materials occurs in soil due to the direct application or in the form of compost. As a result, quick nutrient release and leaching loss occur from the organic sources and also emit carbon dioxide gas into the atmosphere as GHG gases. It is not a sustainable practice to conserve soil fertility because organic residues need to apply every year repeatedly through this process. Biochar can be the substitute of organic materials, and it is produced from any organic biomass. Biochar contains a huge amount of organic carbon because it has been produced by heating organic biomass through pyrolysis method at a high temperature under limited or no oxygen. Biochar can be recycled as organic amendments in the soil (Singh et al. 2010; Lehmann et al. 2011). Biochar is a stable compound, and it can stay in the soil more than hundreds of years based on its source, quality, manufacture methods, and temperature of pyrolysis (Zimmerman 2010). Biochar is the stable carbon-rich product, and the decomposition rate of biochar is very slow due to its resistant aromatic structure which retards the degradation (Baldock and Smernik 2002; Antal and Grønli 2003). Therefore, the effects of biochar on soil property improvement remain a long time than other organic residues, manures, composts, etc. The application of biochar in the soil can improve soil health (physical, chemical, and biological properties), and the duration of this effect would be endless (Amonette and Joseph 2009; Atkinson et al. 2010; Cornelissen et al. 2013; Liu et al. 2012; Meena et al. 2017a).

The agricultural soil can be amended by biochar that is the part of the crop or environmental management (Sparkes and Stoutjesdijk 2011), and it has the potential to become a new technological approach employed in agricultural systems because it has the capacity to increase nutrient availability in various soils. Additionally, biochar is the substitute of organic matter for various soils to improve soil health, quality, and crop productivity. It has also a positive impact on crop productivity when incorporated into acidic soils with low water holding capacity or low organic matter (Biederman and Harpole 2013; Jeffery et al. 2011).

Therefore, biochar is a type of pyrolyzed organic material which can play an important role in sustaining soil health and crop productivity for a long time. For this reason, recently, biochar has been considered as one of the key research materials worldwide for the academician, researchers, policy makers, and farmers.

2 Biochar

2.1 What Is Biochar?

The term “biochar” is comparatively new, but it becomes familiar day by day all around the world. The word “biochar” comes from a combination of “bio-” means “biomass” and “char” means “charcoal” (Schulz and Glaser 2012). Biochar is highly porous fine-grained charcoal, which has been produced under limited oxygen condition using organic biomass that optimizes certain special characteristics like large surface area and porosity and ability to preserve in soils for a long time with very little biological deterioration (Robertson 2014). As a result, it can be differentiated from other charcoals because it can be used as a soil amendment. Due to the huge surface area and porous characteristics of biochar, it is able to hold nutrients and water and also enhance the soil microbial activities for the improvement of soil health as compared to other soil amendments (Lehmann and Rondon 2006; Glaser et al. 2002; Warnock et al. 2007; Dadhich and Meena 2014).

One of the most fertile and productive soils has been found at Prairie of the USA (west of the Mississippi River and east of the Rocky Mountains) because the soil of that area is highly rich in naturally occurring biochar. Biochar has been using historically for soil amendment which dates back at least 2000 years (O'Neill et al. 2009). The unusual fertile soils were created by ancient time in the Amazon Basin known as Terra Preta and Terra Mulata due to extensive use of biochar through indigenous cultures (Lehmann 2007). The soils of this region still remain fertile even with centuries of leaching due to high rainfall in this tropical place. Biochar use in the soil for better and safe agriculture production also has a long history in Australia and some part of Asia particularly Japan, Korea, and China. But recently, keen interest grew in other Asian countries like Bangladesh, India, and Malaysia to use biochar as a soil amendment for sustainable crop productivity and remediation for heavy metals and other toxic organic pollutants.

2.2 Preparation and Characterization

2.2.1 Biochar Preparation and Production

Different types of sun-dried organic materials (rice straw, rice husk, any other crop residues, wood, grass, manure, and sewage sludge) can be used to produce biochar through pyrolysis process at 400–550 °C in the absence of oxygen or limited oxygen using biochar production stove. A modified two chambers containing pyrolysis stove have been developed by the Department of Soil Science of Bangabandhu Sheikh Mujibur Rahman Agricultural University (BSMRAU) to produce small-scale biochar for doing research (Figs. 1 and 2). The organic materials are placed in the outer chamber and put to the opposite direction to maintain limited oxygen, and then heat is gradually increased using the gas flame burner in the bottom and middle of the chamber up to 400–500 °C and held constant for 4–5 h. The produced hot biochar after pyrolysis is allowed to cool at room temperature and then powdered, weighed, and stored for the application in the agricultural field (Fig. 3). Rather than this procedure, there are many methods explained by many other scientists to produce biochar by heating plant biomass in the limited or no oxygen. The relative quality as a soil amendment of different biochar is greatly affected by the sources of organic materials and the conditions of biochar production (McClellan et al. 2007; Chun et al. 2004; Yuan et al. 2011; Ashoka et al. 2017).

Biochar only can produce through pyrolysis of biomass. The production yield of biochar depends on sources and pyrolysis temperature (Table 1). The important organic biomasses for biochar production are animal manures, crop residues, and all forestry wastes. Feedstock selection is the primary criteria for better and economical biochar production. The rice husk, rice straw, cow dung, poultry manure, and sawdust are the best for highest and economic yield and easily available biomass sources for biochar production in Bangladesh. The other researchers have also

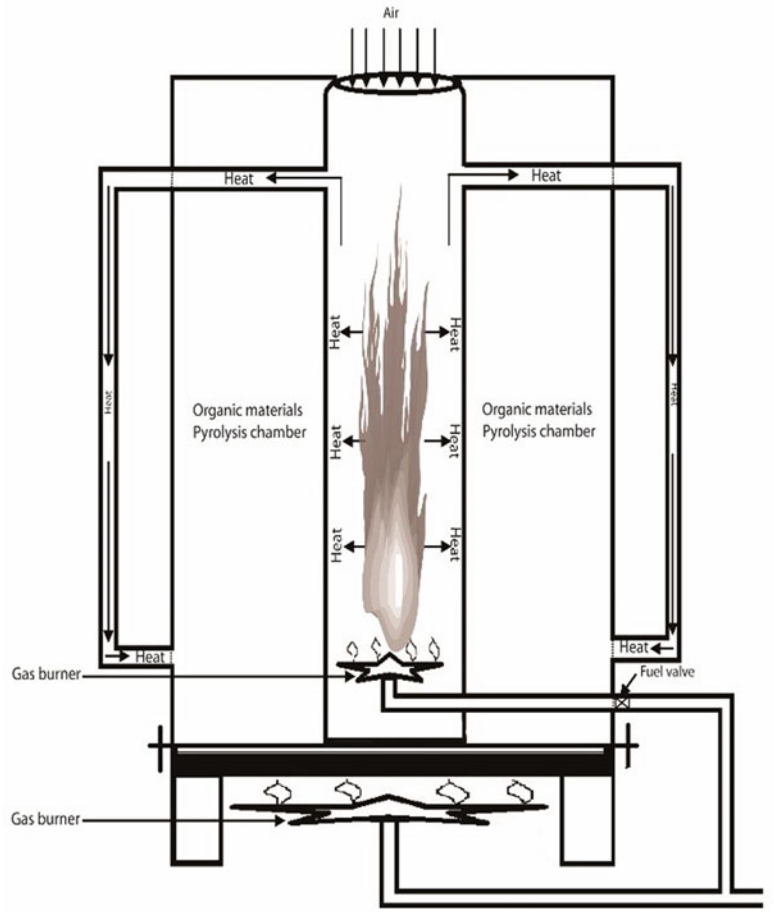

Fig. 1 Modified biochar preparation stove. (Developed by Department of Soil Science, Bangabandhu Sheikh Mujibur Rahman Agricultural University (BSMRAU), Gazipur, Bangladesh)

reported that different types of organic biomass such as plant branches and wastes, wood, magnolia leaves, other crop straw, etc. are good feedstock for biochar production (Table 1) (Wu et al. 2012; Yuan and Xu 2011; Laghari et al. 2016; Zhao et al. 2013; Kinney et al. 2012).

2.2.2 Chemical Characters of Biochar

The chemical properties of biochar derived from different organic materials are presented in Table 2. It has been reviewed and found that most of the biochar showed neutral to slightly alkaline in nature at a temperature range from 450 °C to 500 °C. But the pH of any biochar from any biomass source is independent, while it is dependent on temperature. That means biochar pH is increasing with elevating

Fig. 2 Different biochar production by modified biochar preparation stove at the Department of Soil Science, BSMRAU, Gazipur, Bangladesh

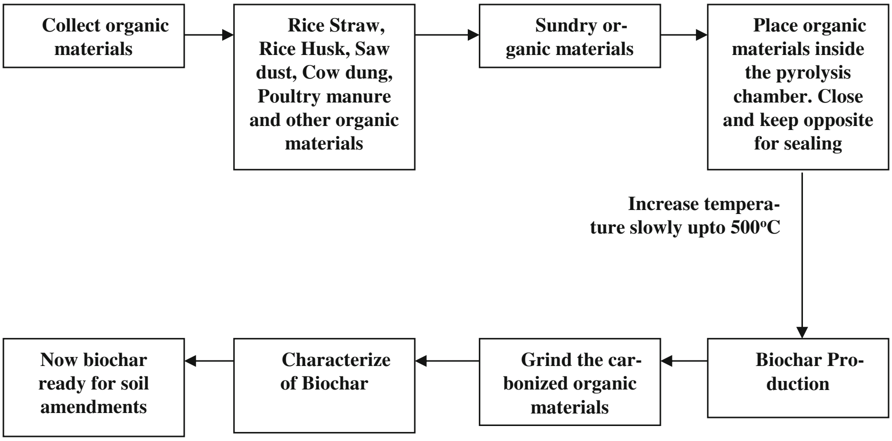

Fig. 3 Flowchart of biochar production

temperature (Table 2). On the other hand, the CEC of biochar is more dependent on the biomass used rather than the temperature for pyrolysis. The process happened due to higher pyrolysis temperature resulting in the loss of some acidic functional groups from the surface of biochar (Zhao et al. 2013).

Table 1 Effect of different biomass on biochar production yield at different pyrolysis temperature

Source of biomass	Pyrolysis temperature (°C)	Biochar production yield (%)	References
RS	450–500	35.6	Rahman (2018, Unpublished)
RH		46.1	
MSD		53.3	
PM		49.1	
CD		48.5	
RS	300	50.1	Wu et al. (2012)
	400	42.8	
	500	39.0	
	600	36.3	
	700	36.5	
CS	350	24.4	Yuan and Xu (2011)
RS		33.3	
SS		32.5	
PS		30.2	
PS	400	55.0	Laghariet al. (2016)
SD	550	28.0	Zhao et al. (2013)
ML	300	61.6	Kinney et al. (2012)
AW	600	25.0	
SGW	400	51.0	

RS rice straw, *RH* rice husk, *MSD* mixed sawdust, *PM* poultry manure, *CD* cow dung, *CS* canola straw, *SS* soybean straw, *PS* pea straw, *SD* sawdust, *ML* magnolia leaves, *AW* apple wood, *SGW* spotted gum wood

Table 2 represents the cation exchange capacity (CEC) values of different biochar. Usually, biochar encompasses high CEC, but pyrolysis temperature slightly influences the CEC of biochar (Song and Guo 2012). The biochar from crop straw demonstrates higher CEC than the biochar derived from manure (Table 2). It can be concluded that during pyrolysis, some nutrients like Ca, Mg, K, Na, and P in the organic residues promote to form O-containing functional groups on the surface of biochar which can support to produce higher CEC of biochar (Agrafioti et al. 2013).

The rice straw-derived biochar contains remarkable amount of N (0.80%), P (0.07%), S (0.005%), Ca (16.80 Cmolkg^{-1}), Mg (4.86 Cmolkg^{-1}), K (8.36 Cmolkg^{-1}), Na (2.10 Cmolkg^{-1}), and organic carbon content (44.5%). The higher pH (7.63) and CEC (32.12 Cmol kg^{-1} biochar) are also contained in rice straw biochar.

2.2.3 Biochar Potential as a Soil Amendment

Biochar can be used as soil amendments especially for acid soil correction because most of the biochar contain high pH and also a higher number of basic cations with

Table 2 Chemical properties of different biochar at different temperatures

Source of biomass	Pyrolysis temperature (°C)	pH	Organic carbon (C) (%)	CEC ($\mathrm{Cmol_+kg^{-1}}$)	Total N (%)	P (%)	References
RS	450–500	8.96	46.45	32.12	0.800	0.070	Rahman (2018, Unpublished)
RH		7.75	44.50	34.67	0.673	0.065	
MSD		7.92	53.10	28.90	0.584	7.310	
PM		7.57	42.70	45.17	0.091	0.311	
CD		8.12	39.80	47.80	0.132	0.143	
RS	300	9.91	72.1	56.9	1.550	0.005	Wu et al. (2012)
	400	9.96	77.2	61.6	0.174	0.006	
	500	10.45	82.8	32.0	1.770	0.003	
	600	10.84	87.1	23.9	1.520	0.002	
	700	10.87	85.2	23.1	1.610	0.018	
CS	350	8.00	61.7	180.0	0.170	0.220	Yuan and Xu (2011)
RS		7.69	42.5	152.0	1.650	0.330	
SS		9.02	54.1	98.0	3.620	0.720	
PS		unavailable	unavailable	unavailable	unavailable	unavailable	
PSD	400	6.35	51.7	27.5	0.930	12.000	Laghari et al. (2016)
	700	9.08	73.6	24.9	0.600	21.000	
PIM	350	9.65	39.1	49.0	0.290	0.230	Zhao et al. (2013)
WS	350	8.69	58.9	87.2	0.004	0.294	
CM	500	10.20	43.7	149.0	0.064	0.100	
SD	500	10.50	75.8	41.7	0.006	unavailable	

Note: *RS* rice straw, *RH* rice husk, *MSD* mixed sawdust, *PM* poultry manure, *CD* cow dung, *CS* canola straw, *SS* soybean straw, *PS* pea straw, *PSD* pine sawdust, *PIM* pig manure, *WS* wheat straw, *CM* cow manure, *SD* sawdust, *CEC* cation-exchange capacity high CEC (Rahman 2018, Unpublished). Biochar has two parts: one is stable and the other one is easily degradable. Thus, biochar can stay a long time varying from hundreds to tens of thousands of years in the soil due to its stable properties (Yuan and Xu 2012) and as a result, enrich carbon permanently in soil and reduce GHG (CO_2) (Lehmann 2007). The aromatic ring structure of biochar might be responsible for the stability in soil. Rapid initial surface oxidation of fresh biochar occurs due to abiotic processes rather than biotic processes (Cheng et al. 2006; Yadav et al. 2018). The mineralization of biochar can be enhanced by this initial oxidation; consequently, negatively charged surface areas increase the cation exchange capacity and the cation retention which helps to improve soil fertility (Glaser et al. 2002; Cheng et al. 2006; Liang et al. 2006). Most of the research indicated that biochar application improved soil fertility and crop productivity in tropical forest soil and acid soils with low active pH. Thus, biochar can be used as a liming material for improving soil health of high aluminum toxic soil and strong acid to increase crop productivity. Therefore, the response of the biochar amendment directly involves the soil health and the crop productivity which remains dependent on the particular characteristics of the soil. As a result, biochar application may or may not bring positive effects on crop production based on the categories of soils. Chemical fertilizer plus biochar using integrated nutrient management has shown better crop yield. This might be due to the increasing soil CEC and microbial activity as a result of carbon enrichment in the soil (Dutta and Raghavan 2014).

2.2.4 The Sorption Capacity of Biochar

The sorption capacity of heavy metal like Ni in the industrial polluted soil is shown in Fig. 4. Application of different rates (1%, 5%, and 10%) of biochar shows a positive effect on the reduction of available Ni than control soil (Fig. 4). The initial amount of available Ni of the contaminated soil of the textile industry was 61.80 ppm (Fig. 4). After the end of the incubation period (90 days), the available Ni content of textile industry soil reduced to 18.20%, 25.10%, and 29.94% at the rate of 1%, 5%, and 10% biochar application, respectively (Fig. 4). Biochar contains some alkaline substances due to high pH; thus, biochar incorporation increases soil pH (Yuan et al. 2011) and accelerates the formation of heavy metal precipitation in the soil. Biochar contains many functional groups on its surface, but dominant are oxygen-containing functional groups (e.g., COOH and OH) (Lee et al. 2013), and these functional groups along with heavy metals make the surface complexes, and hence, the heavy metal adsorption increases on the surface of biochar-incorporated soils. Therefore, abovementioned, both the mechanisms involve to increase heavy metal immobilization in soil, and as a result, bioavailability and activity of heavy metal decrease in biochar-amended the soil.

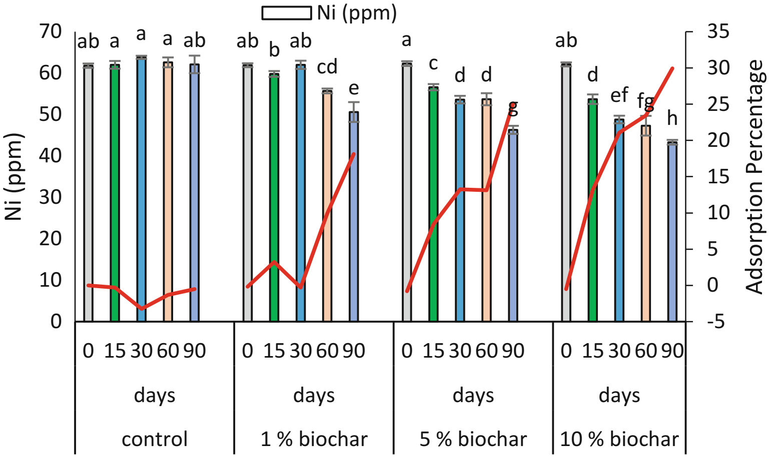

Fig. 4 Nickel (Ni) adsorption on biochar

2.2.5 Remediation of Polluted Soil for Improving Soil Fertility

Several established techniques such as physical ways, electrokinetic remediation, biological remediation, and combined remediation technologies are involved in the restoration of heavy metal pollution in the soil. But recently, biochar is popularly used as adsorbents of heavy metals from soil. Different organic biomass can be used to prepare such carbon-rich materials (biochar) through pyrolysis process at a high temperature in limited or no oxygen, which contains large surface areas with different active functional groups those are renowned as an effective tool to hold contaminants for mitigation of heavy metal contaminants. Comparatively, biochar is the best for the remediation of heavy metal contamination than any other organic absorbents because it contains all categories of adsorptive properties like large surface area, dynamic porous structure, and alkaline in nature and also contains different functional groups especially oxygen-containing functional groups (Ahmad et al. 2014; Meena and Meena 2017). Various mechanisms may play a role in controlling heavy metal removal from aqueous solutions of soil using biochar.

Besides reducing heavy metal from the soil, it is also capable of improving physical, chemical, and biological properties in soils due to its high organic carbon content (Dutta and Raghavan 2014) and high surface area (Fig. 5) (Xu et al. 2013). The maximum sorption capacity demonstrated by the dairy manure biochar (DMBC) and the rice husk biochar (RHBC) based on the findings of Langmuir modeling metals get reduced in the system of multi-metal. On the other hand, higher sorption capacity is observed in the RHBC then DMBC (Xu et al. 2013). Biochar application for soil amendment increases soil health including the soil physical, chemical, and biological properties and enhances crop production through the essential nutrient adsorption and supply to the plant (Houben et al. 2013).

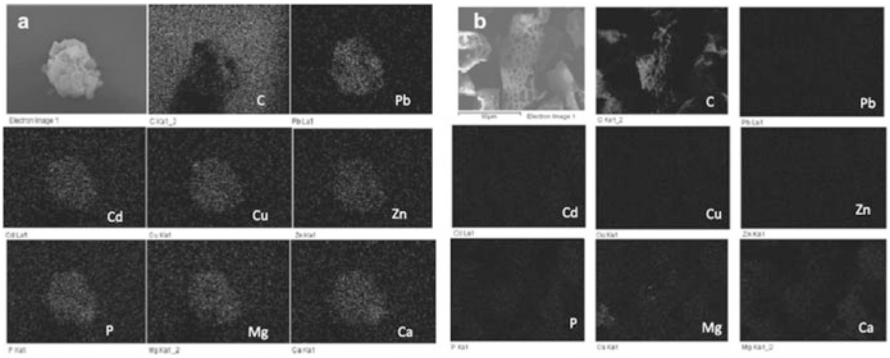

Fig. 5 SEM photographs with elemental dot maps of (**a**) dairy manure biochar (DMBC) and (**b**) rice husk biochar (RHBC) after metal sorption in the multi-metal system. (Scotti et al. 2013)

3 Organic Amendments

Soil organic matter is a key indicator of living force and soil fertility. Both anthropogenic activities and climatic condition (high temperature and humidity) lead to organic matter ruin ultimately accelerate soil degradation. Soil organic amendments provide an unpaid solution for improving degraded land by improving soil physical, chemical, and biological qualities. Any material of organic origin (plant or animal) added to the soil to improve soil properties, designated as an organic amendment. The organic amendments also become a tool for enhancing carbon stocks on low organic matter enrich soil such as degraded tropical soil.

3.1 Sources of Organic Amendments

Organic amendments irrespective of origin or decomposing state add substantial quantities of organic matter in the soil. Organic amendments usually originated from suitable plant species that may be derived directly from the nature (peat soil, peat moss, etc.) or may be obtained as by-products from food processing and agro-based industries (sawdust, oil cake, sugarcane trash, bagasse, rice husk, brans, etc.) or disposal of waste materials (different types of compost, bio-solids, processed sewage sludge, etc.), crop residues, green manuring, etc. Moreover, it is also derived from animal origin (poultry litter, cow dung, farmyard composts) and various worm origins (e.g., vermicomposting). Reclamation organic amendments like biochar, activated charcoal, gypsum, etc. are added in the degraded soil like heavy metal-polluted and salinity-affected soil to convert productive soil. A brief description of the commonly used organic amendments from various sources is given below:

3.1.1 Green Manure

A crop grown for the purpose of being plowed down in soil while green to improve the soil characteristics instead of harvested for animal and human consumption is known as green manure. To sustain the soil health, green manure is a popular practice all over the world. Generally, leguminous plants such as pea (*Pisum sativum*), cowpea (*Vigna unguiculata*), groundnut (*Arachis hypogaea*), black gram (*Vigna mungo*), lentil (*Lens culinaris*), clover (*Trifolium* spp.), soybean (*Glycine max*), mungbean (*Vigna radiata*), dhaincha (*Sesbania aculeata* and *Sesbania rostrata*), sun hemp (*Crotalaria juncea*), etc. are commonly used to prepare the green manures. Green manuring with legume plants is better than any other plants as they provide a substantial amount of nitrogen to the soil through the process of biological nitrogen fixation. Fresh leaves of the forest plants may also be used as the green manure. Farmers collect green leaves and twigs from the forest plants and incorporate into the soil (FRG 2012) to increase the soil organic matter status. This practice is termed as green leaf manure.

3.1.2 Household Waste Compost

Household wastes are organic materials that generally contain kitchen and yard wastes and wastes derived from food and wood materials. Household waste compost is prepared from the degradable waste which is generated in day to day operations at the household level. The major portion of household wastes comes in the form of food products especially the nonconsumable portion of fruits and vegetables. Proper management of household waste is necessary; otherwise, the environment may be polluted. The utilization of household waste compost for crop production will obviously reduce the dependency on synthetic chemical fertilizer application in the agriculture sector which will reduce the production cost of agricultural products as well as ensure the safe environment. Thus, the compost prepared from household waste materials might be an attractive source of soil organic matter.

3.1.3 Compost

Compost is an important type of organic manure which is produced by the decomposition of various plant and animal wastes. Good compost can be prepared from a variety of refuse materials like plant leaves, kitchen waste, banana trashes, pineapple trashes, weeds, water hyacinth, paper mill wastes, sugarcane trashes, straw, sawdust, rice husk, animal slaughter waste, etc. Compost may also be prepared from municipal waste, garbage, and leather industry waste, but it should be free from heavy metals and other toxic trace elements. At least, the harmful materials and pollutants should be below the critical level so that safe crop production can be ensured. The process of the preparation of compost through decomposition of organic materials is called composting. Compost is popularly known as black gold to the gardeners and vegetable growers as it is highly beneficial to the growing plants.

3.1.4 Farmyard Manure (FYM)

Farmyard manure is a kind of organic manure that includes the solid and liquid excreta of livestock, normally mixed with small amount of litter such as straw (mainly rice straw) used for bedding of animals. It is a by-product consisting of animal dung, urine, fodder residues, and animal bedding materials. It is one of the oldest manures used by farmers to grow different crops especially the vegetables due to its easy availability and the presence of most of the nutrients required by the crops. Cattle urine is an important part of farmyard manure as it is rich in nitrogen (FRG 2012), but the major portion of urine is lost due to the soaking by the earthen floor of the animal shed. Therefore, the animal shed should be cemented to overcome the situation. In the case of earthen floor straw, sawdust, dry weeds, rice husk, etc. might be used to reduce the urine from the cattle shed.

3.1.5 Vermicompost

Vermicompost is a kind of compost which is produced by different species of earthworms. Earthworms frequently use different types of decomposable organic wastes as their food of which only a little portion (5–10%) is absorbed by their body, while the major portion of the consumed food is released from the body as excreta in the form of pellets which is treated as vermicompost. The vermicompost contains not only excreta but also earthworm cocoons and plant growth-promoting hormones like auxins and gibberellins, enzymes, vitamins, beneficial microorganisms, etc. Vermicompost provides plant nutrients in a readily available form which is easily uptake by the plants. Moreover, the application of vermicompost in the soil improves soil chemical, physical, and biological properties.

3.1.6 Poultry Manure

Poultry manure is one of the important traditional manures that has long been used in the agricultural field for better crop production in many countries of the world. It is the organic waste derived from the feces, urine, and bedding materials of the poultry birds. To meet the increasing demand of a growing population, the number of poultry bird is increasing every year all over the world leaving huge quantities of poultry litter. It is essential to manage the poultry litter properly as early as possible. Otherwise, it may create severe environmental pollution. Though poultry manure has diverse use like biogas and electricity generation, fish feed, mushroom production, etc. but the use as organic manure in the crop field is the most important.

3.2 Preparation and Characterization

Preparation technique and nutritional composition of organic amendments vary from one to another. This chapter briefly includes the preparation techniques of some important organic amendments and their characteristics in terms of nutritional composition.

3.2.1 Green Manure

It is better to select a quick growing plant to prepare the green manure. Green manure can be prepared in two ways: First, by growing of the green manuring plants in the original land where the green manure will apply. This practice is called in situ green manuring. In this system, the crop especially the legume plant is grown in the field a few weeks before the sowing/transplanting of the main crop. The growing plants should be plowed down just before they flower or at the time of flowering. It will take 1 or 2 weeks to decompose the green manure in soil properly, and after that, the main crop can be grown in the field. Second, the green manure crop is grown in another field where the main crop will not grow. Under this practice, the green manure crop is harvested at maximum vegetative stage (just before flowering or just at the time of first flowering), cut into pieces, and incorporated into the main field just before 1–2 weeks of main crop sowing/planting. Depending on the types of the plant species, 10–15ton fresh biomass could be obtained from a hectare of land which may supply a substantial amount (60–120 kg) of nitrogen to the soil (FRG 2012). Nutrient composition of green manure greatly depends on the plant species used to prepare the manure. The data presented in Table 3 indicated that nitrogen content in *Sesbania* green manure and sun hemp green manure is similar, but P content is higher in *Sesbania*, while K content is higher in sun hemp.

3.2.2 Household Waste Compost

The composting of household waste generated from household level is a simple process. To prepare the household compost at the individual farm level, it is needed to dig an earthen pit in a suitable place nearby the homestead. The size of the individual pit largely depends on the volume of the waste material, but the ideal size might be 2 m × 1 m × 1 m. It is better to make a shed over the pit to protect the waste materials from rainfall and excessive sunlight. The daily collected household wastes like kitchen waste that includes peel of fruits, vegetable and fish wastes, yard sweepings, etc. should be gathered simultaneously and spread over to the pit. When the pit is about 30 cm deep with wastes, approximately 300 g of urea needs to apply over the surface of the waste material to accelerate the microbial decomposition of wastes, and then again, wastes should be placed into the pit, and the practice needs to continue until the pit gets full. Finally, a thin layer of cow dung or urea fertilizers is to be spread over the pit, covered with soils, and kept for about

Table 3 Nutrient composition of commonly used organic manures

Name of the manure	% N	% P	% K	Reference
Vermicompost	0.51–1.61	0.19–1.02	0.15–0.73	Nagavallemma et al. (2004)
Garden compost	0.80	0.35	0.48	Nagavallemma et al. (2004)
Compost (rural)	0.75	0.60	1.00	FRG (2012)
Compost (urban)	1.50	0.60	1.50	FRG (2012)
Green manure (*Sesbania*)	0.70	0.40	0.40	FRG (2012)
Green manure (sun hemp)	0.70	0.12	0.50	FRG (2012)
Farmyard manure	0.53	0.22	0.59	Parihar et al. (2012)
Poultry manure (decomposed)	1.25	0.70	0.95	FRG (2012)

3–4 months. Three to 4 months later, the household waste compost is ready to use in the field. The prepared compost supplies a considerable amount of essential (both macro and micro) nutrients to the plants. However, the nutrient content may vary with the variation of waste materials that are used to prepare the household waste compost. Nutrient content in household waste compost may also be influenced by the compost preparation techniques. However, research findings demonstrated that household waste compost contains 3.32% total N, 0.61% total P, and 1.59% total K (Smith and Jasim 2009).

3.2.3 Compost

The preparation of compost is almost the same as the preparation technique of household waste compost. In the composting process, it is important to maintain a suitable C:N ratio as decomposition of organic material is largely influenced by proper C:N ratio. Microbial activity can be accelerated by maintaining a good C:N ratio of the composting materials. The C:N ratio of 25:1–30:1 is suitable for better composting of the materials. Proper aeration and sufficient moisture are needed for rapid decomposition of the composting materials. The use of cellulolytic microorganisms in the composting piles will fasten the decomposition process. It takes about 3–6 months to prepare the compost. Rapid decomposition is favored by high temperature and high humidity. Addition of nitrogenous and phosphatic fertilizers to the composting materials will also accelerate the rotting of slow decomposing materials. The good-quality compost should have the following characteristics: dark brown to black in color, loose and crumbly in structure, largely insoluble in water but soluble in dilute alkali, pleasant earthy smell that doesn't attract flies and that maintain pH around neutral, and C:N ratio between 10:1 and 15:1. The nutrient composition of compost mainly depends on the nature of the composting materials. Normally, compost prepared from materials collected from urban areas contains higher amounts of nutrients as compared to the compost prepared from the materials collected from rural areas (Table 3). In general, compost contains 0.75–1.5% N, 0.35–0.6% P, and 0.48–1.5% K.

3.2.4 Farmyard Manure (FYM)

Dung obtained from domestic animals like cows, buffaloes, sheep, goats, horse, and other animals along with urine, bedding materials, and fodder residues are collected daily and placed in a pit or trench of desirable size. Depending on the number of animals, the size of the pit might be 6–7 m × 1.5–2 m × 1 m. The pit should be provided with a shed to protect the manure from rainfall and hot sun especially in the summer and rainy season. If the dung is too dry, some water might be added. The collected dung and other materials are added properly over the layer made a day before. The manuring materials should be added to the pit until the height of the added material is approximately 40–50 cm from the ground. Then the upper portion of the stack should be coated with a mixture of mud and cattle dung. Farmyard manure can also be prepared by heap method. In this method, the collected materials from the animal shed are placed uniformly in a high land until the height of the heap reached about 1 m above the ground level. The farmyard manure becomes ready to apply in the field after 3–6 months.

The quality and quantity of farmyard manure depend on the types and the ages of animals, the function of the animals, the types of animal feeds, and the care in handling and preserving the materials used to prepare the manure. Farmyard manure is used to grow different vegetables all over the world as it provides essential nutrients to the growing plants. However, a good source of farmyard manure contains 0.535 N, 0.22% P, and 0.59% K (Table 3).

3.2.5 Vermicompost

Vermicompost can be prepared using any type of biodegradable wastes including vegetable waste, crop residues, weeds, agro-industry waste, dry leaves of crops and trees, sugarcane trash, animal manures, dairy and poultry waste, etc. Though there are more than 2000 earthworm species in the world, *Eisenia fetida*, *Eisenia andrei*, and *Lumbricus rubellus* are considered as the best types of worms for vermicompost preparation. For vermicomposting, it is essential to select a shady place having cool weather and high humidity. After collection of the degradable wastes, a predigestion of the materials for a month by heaping the materials along with cattle dung slurry is recommended as the predigested material is suitable for earthworm’s consumption. Vermicompost can be prepared by different methods, but it is easy to prepare the compost in the containers or tanks of different materials. Earthen bowls can also serve as containers to make the vermicompost. The predigested organic residues along with animal dung are placed in the container, and then suitable species of earthworms is released into the container. The container should be covered with thick cloth or jute bag to maintain a dark environment which is suitable for earthworm’s activity. Based on a suitable condition, it takes 2–3 months for vermicompost preparation. After collection from the container, the compost should be sieved to separate fully composted material. The partially composted material, earthworms and their eggs, or cocoon should be placed in the container again for further compost preparation. Vermicompost contains a considerable amount of plant nutrients. Moreover, it provides soil vitamins, antibiotics, enzymes, and plant growth hormones (Molaei et al. 2017; Molaei et al. 2017a). Vermicompost also enhances nitrogen fixation and phosphorus solubilization as it carries certain beneficial microorganisms. The nutritional composition of vermicompost mainly depends on the type of waste material used to prepare the compost, earthworm species, preparation method, etc. Generally, vermicompost contains 0.51–1.61% N, 0.19–1.02% P, and 0.15–0.73% K (Table 3).

3.2.6 Poultry Manure

The decomposition rate of fresh manure is very high, and nutritional quality deteriorates quickly. Therefore, poultry manure needs to be processed rapidly. Fresh poultry manure should never be used in the standing crop field as it may damage the growing plants. The common practice of poultry manure preparation includes spreading the fresh poultry manure in a dry place for pile composting. But the open stockpile causes nutrient losses and environmental pollution. Therefore, it is suggested to make a shed over the manure pile or cover the stack by a plastic sheet. Due to the lower C:N ratio of fresh poultry manure, it is better to add rice husk or straw to achieve a wider C:N ratio which will ensure quality poultry manure preparation. It may take 8–10 weeks for the composting of the poultry manure by open piling method. The loss of nitrogen can be minimized by composting the fresh poultry manures under anaerobic condition. In this method, fresh poultry manure mixed with rice husk or straw is placed in a pit, sufficient water is added to maintain adequate moisture, and finally, the pit is sealed with mud plaster. Under anaerobic condition, it may take 10–12 weeks for composting of the poultry manure.

Nutritional quality of poultry manure depends on various factors including types of birds, production techniques, quality of feeds, storage and handling methods, climatic condition, age and moisture content of manures, etc. Decomposed poultry manure contains a considerable amount of plant nutrients including 1.25% N, 0.7% P, and 0.95% K (Table 3). In addition to NPK, poultry manure also contains a considerable amount of micronutrients (Amanullah et al. 2010).

3.2.7 Crop Residue

Agricultural field residue includes the materials like stem, leaves, stalk, root, etc. that are left after different management practices and harvesting activities in a field. The residue can be encompassed in soil through plowing directly into the ground or burning. Moreover, crop processing leaves several materials as an unusable product like husks, unfilled grain, seeds, and root that can also be used as soil amendment. Directly incorporation of such fibrous materials can improve soil physical properties because they act as an energy source for soil microorganisms. Crop residues from various sources contain a considerable amount of plant nutrients especially N, P, and K (FRG 2012).

3.2.8 Oil Cake

Oil cakes are milling by-products of oilseed crops (mustard, sesame, linseed, etc.) after the oil has been extracted from an oilseed. Oil cake is a greater source of N and P. Oil cake contains lower C:N ratio, but the higher mineralization rate in soil provides quicker nutrient release. Oil cake normally contains 5.0–6.2% N, 1.4–2.0% P, and 1.20% K (FRG 2012).

3.3 Organic Amendments Influence on Soil Health

Organic matter status of soil greatly influences the soil quality and soil health. But the decline of organic matter status in the soil due to intensive cropping with the utilization of huge quantities of synthetic chemical fertilizers leads to the deterioration of soil fertility, a major concern of sustainable agriculture. Though it is very difficult to recover and maintain the soil organic matter status up to a satisfactory level, research findings indicated that organic amendments from various sources improve the soil physical properties (Leroy et al. 2008), chemical properties (Scotti et al. 2013) including recovery of soil organic C stock (Zhang et al. 2015; Sihag et al. 2015), and biological fertility of soil that ultimately improves the soil health.

3.3.1 Soil Chemical Properties

3.3.1.1 Soil pH

Soil pH is one of the vital chemical properties, which regulates the nutrient availability and crop productivity. The optimum pH range of a productive soil is 6.5–7.5 because such range hastens both macro- and micronutrient availability and ensures higher microbial activity. Incorporation of organic amendment greatly influences the soil reaction (Angelova et al. 2013). Variation of soil pH by addition of organic amendment depends upon the organic residue type, application rate, inherent soil condition, and buffering capacity of a soil. Amended substances initially increase soil pH due to higher decomposition rate; later on, substantial inconsistency is observed either above or below the inherent soil pH (Wong et al. 2000). It is observed that the organic amendments lowered the buffering capacity of soil and activated the disparity of soil pH (Neilsen et al. 1998). Several mechanisms could explain the preliminary rise of soil pH, immediately after organic matter added (Angelova et al. 2013). The regulating mechanisms include organic acid anion oxidation, organic-N ammonification, organic molecule-specific absorption capacity, and anaerobic reduction activity. The organic acid anion oxidation complies with the lessening of H^+ ions or the release of OH-ions during decomposition activity, possibly playing a key role for immediate rise of soil pH (Sparling et al. 1999).

Under anaerobic conditions, reduction of higher valence Mn oxides and/or Fe oxides and hydrous oxides in soils is reduced and raised soil pH. Long-term addition of organic manure or crop residue did not show a larger increase in soil pH (Van Antwerpen and Meyer 1998). Soil pH varied with the type of organic amendment, inherent soil pH, and proton budgeting.

3.3.1.2 Soil C:N Ratio

The soil C:N ratio is one of the important indicators that explain nutrient release dynamics of added soil organic amendments. Heterotrophic microorganisms use organic matter for their body intake and release amine group and different amino acid in a fixed ratio (Datta et al. 2017c). The threshold C:N ratio for higher microbial activity is ~25–30: 1. The addition of higher C:N ratio organic matter in the soil first allows short-term N immobilization in microbial biomass and sudden drop in nutrient availability. Thus, plants suffer nutrient deficiency and impair crop yield. The lower C:N ratio in organic matter demonstrates higher mineralization rate. Several reporters explain that organic waste with below 30:1 C:N ratio indicates gross N mineralization, while above this level favor immobilization (Alexander 1977). The mineralization arises when the organic matter content in soil is more than 2%; below this, immobilization occurs (Sivapalan et al. 1985). The C:N ratio of organic matter varies according to the variety of sources. For example, the composted organic amendment such as C:N ratio of poultry manure is 6.5:1, in cereal residue 82:1, and in sawdust 664:1 (Huang et al. 2004). Moreover, different organic materials having similar C:N ratio demonstrate different mineralization behavior. The variation in decomposition rate of similar C:N ratio substance might be due to its biochemical composition, for example, different lignin, cellulose, and polyphenol content. Thus, in addition to C:N ratio, organic matter quality becomes a key factor for amendment mineralization and nutrient release. Therefore, it is essential to recognize proper quality organic amendment for ensuring sustainable carbon stock and nutrient release.

3.3.1.3 Nutrient Cycling

Sustainable management of organic amendment in soil is essential to comprehend the nutrient release pattern from organic residue. Several factors could enhance nutrient dynamics in organic-amended soil, such as organic residue matrices, residue mineralization mechanisms, sources, climate, soil properties, and management practices. Generally, organic matter contains different nutrient elements, including N, P, and S, in a relatively constant amount. One ton of organic carbon addition through organic amendment has the ability to release 8.3% N, 2.0% P and 1.4% S in soil (Kirkby et al. 2011). The nutrient flux of soil depends on the decomposition rate of the organic matter. This soil organic matter is considered as a source and sink of soil nutrient cycling. Like, cereal crops intake nutrient through uptake mechanism, of which 1/4th N &P, 1/2 of P and 3/4th of K, are accumulated in crop residue. Thus, incorporation of these residues can be an enormous source of nutrient for succeeding crops. Nitrogen cycling is interlinked with the atmosphere, soil solution, organic amendment, plant root system, and microbial activity. Organic material with high C:N ratio encourages immobilization and ingestion of N in a heterotopic organism, while a lower C:N ratio increases the mineralization rate. Submerge condition or anaerobic mineralization of organic amendments will favor the denitrification process. For a precise understanding of N budgeting and N cycling in the soil from the organic amendment, consideration of the gross N transformation is essential. Organic matter-amended 6-year experiment summarizes that farmyard composted soil had a higher nitrification rate than the mineralization rate (approximately 10.2 and 5.7 g N ton^{-1} day^{-1}, respectively); in contrast, opposite trends were seen in liquid cattle-shed waste (approximately 1.6 and 2.9 g N ton^{-1} day^{-1}, respectively). Thus, nitrification rates of dairy wastes are higher than mineralization rate including that repeated application enhances microbial activity and nitrification ability (Habteselassie et al. 2006; Meena et al. 2017b). Organic matter shows a crucial function in heightening the availability of soil phosphorus (Shen et al. 2011). In general, depending on soil type, organic amendment contributes 20–80% of total soil P. Organic amendment is also a good source of sulfur in the soil, although some soil may contain a higher amount of inherent mineral S.

3.3.1.4 Cation Exchange Capacity (CEC)

Soil exhibits CEC mainly due to the negative charge of colloidal substances (clay and humus). It is now a well-established fact that there is a strong positive correlation between organic matter and CEC of soil. The influence of organic amendments on CEC is largely interlinked with the soil texture and pH. A negative surface charge of clay is linked with the isomorphous substitution of silica by aluminum in the clay mineral permanently. In contrast, the decomposition of organic amendment releases different organic acid; the dissociation of those organic acids causes a net negative charge. The negative charge associated with fully decomposed organic matter, i.e., humus, is neutralized by cations in the soil. The CEC interrelated to the organic amendment is termed as pH-associated CEC. Actual CEC of soil is significantly influenced by soil pH. For example, the addition of the same amount of organic matter from a specific source will provide higher CEC in a neutral soil (pH ~7) than a soil with slight acidity. It is observed that the addition of organic amendment in acidic soil ($pH < 5.5$) did not show a significant effect on CEC (Murphy 2015). Higher CEC of a soil signifies the greater amount of organic matter or clay mineral present in the soil indicating its higher fertility. The relationship between the soil organic matter and CEC varies according to the soil textural class. An organic amendment can contribute 4–50 times higher CEC than a given weight of the clay. Depending on the organic residue reserve, the amendment increases CEC, first in the surface soil and subsequently in the subsurface soil. A 20-year long-term experimental result indicated that surface addition of organic residue increased the CEC of soil by 136 % (from 11 to 26 meq/100 g of soil) (Crovetto 1997).

3.3.1.5 Buffering Capacity

Globally, soil acidification is a great concern for sustainable soil management and crop productivity. At low pH, availability of macronutrients gets decreased but tends to increase micronutrient availability including several toxic elements. Buffering capacity of soil can resist the extreme variation of soil pH. At present, it is well established that organic amendment acts as a buffering agent against soil acidification (Helyar et al. 1990). Buffering capacity of organic amendment depends on several factors like source of organic residue, soil texture, clay content, CEC, and soil reaction. For example, compost can be used as a buffering agent in acidic soil, due to its higher CEC and release of nitrogen which helps to neutralize the exchangeable acidity (Latifah et al. 2018; Verma et al. 2015b). The higher buffering capacity might be associated with the higher release of exchangeable NH_4^+ ions and a humic acid fraction. In acidic condition, most of the humic fractions become protonated and provide the basis for decreasing CEC. Moreover, at strongly acidic ($pH < 5$) condition, microbial activity will slow down, thus reducing the decomposition rate of organic amendment and subsequent reduction of buffering capacity. At $pH > 5.5$, the addition of organic matter can show its inherent buffering capacity because of the enormous tendency of releasing H+ ions from humic acid and react with hydroxyl (OH-) for neutralization. Thus, the addition of a judicious amount of organic amendment containing inherent basic cations can actively enhance the buffering capacity of the soil.

3.3.1.6 Electrical Conductivity (EC)

Intensive application of organic amendment enhances the salt concentration and salinization. The organic amendment, more specifically composted manure, enhances soil electrical conductivity of soil and thereby increases salinity and sodicity of amended soil (Angelova et al. 2013). Organic amendment-induced soil salinity might be due to the mineralization process of releasing soluble minerals and solubilization of ions. The EC of the amended soil depends on the raw materials used for composting their biochemical composition and mineralization process (Atiyeh et al. 2002). Several reporters summarize slightly increase of EC due to organic amendment, but the value remains below the threshold level of soil salinity ($4.0\ dSm^{-1}$) (Bonanomi et al. 2014).

3.3.2 Soil Physical Properties

3.3.2.1 Aggregate Stability

Structural stability is a vital property for maintaining soil health. Aggregate stability of soil can improve other physical properties like pore space and thus accelerate gas exchange, water retention capacity, and microbial activity of a soil (Van-Camp et al. 2004). Enrichment of organic matter can ensure higher aggregate stability and lower erodibility of a stress-prone soil. Aggregate stability of soil is influenced by organic amendment in three different ways. Organic materials act as binding agents of clay particles through H-bonding and coordination with polyvalent cation. The functional group of organic matter (i.e., COO) can neutralize the negative charge of the clay surface that reduces the repulsion between clay particles. Moreover, organic matters provide cementation and encapsulation surrounding the clay particles and reduce hydrophobic nature and enhance stability. Fungal hyphen and microscopic plant roots can also hold soil particles together. Amount and type of organic amendment greatly influence the aggregate stability of the soil. The readily decomposable organic amendment has a strong and a transitory effect on the aggregate stability, while more stable lignin and cellulose-containing matter have less but consistent effects. During the decomposition process of organic matter, microorganisms release polysaccharides and raise aggregate stability by enhancing their inter-cohesion. In converse, aggregate hydrophobicity can enhance by adding the more humic compound to the clay minerals (Van-Camp et al. 2004). Mean weight and the diameter of aggregate increased with the addition of more organic carbon in the soil (Haynes 2000). However, to preserve suitable aggregate stability in soil, it is necessary to maintain a minimum of 2% SOC although the threshold level for structural ability is 3–3.5% SOC (Boix-Fayos et al. 2001). Long-term experimentation with organic amendments (crop waste and manure) in rice-wheat cropping pattern showed higher macroaggregates (Das et al. 2014). Source of the organic amendment also plays an important role in enhancing structural stability. Among the plant species, nonleguminous species exhibited greater aggregate stability, because of their higher root mass and higher rhizospheric microbial biomass. Nonleguminous plant compost-treated plot showed higher soil structural stability (28.3%) as compared with leguminous-composted one in 4-year study results (Tejada et al. 2009; Datta et al. 2017b).

3.3.2.2 Bulk Density

The bulk density is the dry weight of soil per unit bulk volume. Soil porosity, cohesiveness, and structural development of soils as well as soil health are strongly coordinated by the bulk density (Heard et al. 1988). Low values of bulk density mean a porous soil and high values a soil with low porosity. Bulk density is an integrated activity of soil solid composition (mineral and organic fraction). There is a strong negative relationship between soil organic amendment and bulk density. Improvement of soil aggregation indicates the presence of higher colloidal substances and lower bulk density. The degrees of decomposition of organic matter predominantly synchronize the bulk density of soil. A partially decomposed organic matter such as fibrous material increases the porosity of soil and decreases its bulk density. Moreover, the type of organic amendment and cropping pattern also considered as influencing factors for bulk density of soil. The application of organic amendment influences the bulk density and macroporosity of sandy loam and clay soil (Rivenshield and Bassuk 2007). In general, soil containing lower density aids easy root penetration and root growth. Lower soil bulk density confirms higher water holding capacity and nutrient use efficiency (Ikpe and Powell 2002). High bulk density accelerates surface runoff and erosion losses of soil and nutrient because of water movement through the soil restricted by compact soil. Thus, organic amendment positively affects the bulk density of all soil types because it clearly increases microporosity.

3.3.2.3 Particle Density

Particle density is used to estimate volume basis, total pore space, soil and water viscosity, soil temperature attributes, and air and water retention in soil (Hillel 1998). Several soil activities including mass flow and preservation of soil air and water, as well as nutrient transportation system within the soil, are largely dependent on the particle density-associated parameters. Organic matter is a part of the soil solid portion and has a noteworthy impact particle density. An increase of soil organic portion in soil signifies its higher particle density. Conversely, the lower ones with similar texture contain higher particle density. The addition of organic amendment decreases the particle density, mostly due to the increasing organic portion in soil, and decreases the ratio of mineral and organic matter in soil solid (Hillel 1998). There is a highly significant correlation between particle density and SOC. Depth effect of SOC on particle density displays inconsistencies. For example, variations in SOC concentration in the 0–10 cm depth explained notably larger variability in particle density (ρ_s) (~ 75% change), while for the 10–20 cm, depth variability in ρ_s was 54% and 45% for the 20–30 cm depth (Blanco-Canqui et al. 2006). Particle density increases with depth because of the simultaneous decreasing trend of organic matter content and increasing metal concentration. Soil organic matter and clay content significantly influence the particle density of a soil (Schjønning et al. 2017; Kumar et al. 2018).

3.3.2.4 Soil Water Holding Capacity

Water holding capacity (WHC) can be described as the ability of a soil to preserve water. Several soil properties like soil porosity, macro- and micropore number, the specific surface areas of soils, surface crust, slaking tendency, and absorption capacity have primarily triggered the WHC of a soil. Organic amendment and its composition significantly affect the major water retention factors, soil structure, and adsorption behavior; thereby organic amendment plays a dominant role in water retention in the soil. Higher organic matter content in soil increases aggregate stability and decreases bulk density and increases porosity and the number of micropore in soil (Haynes and Naidu 1998). Pore space provides key ways for entering soil water and gases within the soil profile. WHC of a soil strongly correlated with the soil structure and bulk density. The effect of the organic amendment on WHC tends to be greater in coarse-textured compared with fine-textured soils because WHC in heavy clay soils gets decreased with increasing SOC content. Thus, there is a strong synergistic relationship among textural components, SOC content, and WHC (Rawls et al. 2003). Plants can uptake readily available water (water held between field capacity FC, at matric suction of -10 kPa), and the unavailable ones were held between permanent wilting point PWP, at matric suction of -1500 kPa. Soil organic carbon can improve available water content in the soil (Haynes and Naidu 1998). An increase of 1% SOM can enhance 1.5% additional moisture by volume at FC (Wolf and Snyder 2003). Again, each gram of SOC can increase 50% water holding capacity of soil (Emerson and McGarry 2003). Organic amendments release humic acid substances, which can enhance water retention, available water content, and aggregate stability (Larney and Angers 2012). The organic amendment covers the soil surface and thus protects the soil from sealing and crusting by raindrop impact, thereby enhancing rainwater infiltration and reducing runoff. The short-term and long-term higher infiltration rate and cumulative infiltration were observed in the decomposed organic residue than stable residue (Mahmood-ul-Hassan et al. 2013).

3.3.2.5 Hydraulic Conductivity

Hydraulic conductivity describes the ease of movement of water through the pore space. The combined activity of hydraulic conductivity and soil porosity regulates soil water movement, soil aeration, and available water for the plant. Organic amendment plays a vital role in improving structural stability, which enhances macroporosity and then encourages hydraulic conductivity or water flow of a soil (Tisdall and Oades 1982). Macropore can regulate the soil water movement, infiltration rate, and good tilth condition of soil (Boyle et al. 1989). Several studies explained that the application of manure could raise soil structure and porosity, thereby improving the saturated hydraulic conductivity (K_{sat}) and infiltration rate (Benbi et al. 1998). It is observed that incorporation of organic amendment increased K_{sat} at all pressure heads at rooting depth (Eusufzai and Fujii 2012; Meena et al. 2015). As compared to control, field-saturated conductivity was increased by 34.4% due to the incorporation of compost while 15.9% for straw and sawdust-amended soils. Thus, organic amendment improves the hydraulic conductivity of soil through increasing the soil porosity.

3.3.3 Soil Microbial Properties

Organic amendments from different sources not only influence the soil physical and chemical properties but also greatly regulate the soil microbial properties. Soil microbes are important drivers of various nutrient cycling, nitrogen fixation, and nitrification process (Lynch and Bragg 1985; Lee and Pankhurst 1992; Tejada et al. 2009). Organic matter decomposition is one of the crucial roles of soil microorganisms. Moreover, microbial communities in the soil have significant control on the dynamics of soil carbon (Grandy et al. 2009) and ultimately influence the global carbon cycle (Doran 2002). Different types of organic amendments potentially increase soil organic matter (SOM) content (Seiter and Horwath 2004), a significant component of soil health. Improvement of SOM content in soil is important because it strongly influences the soil microbial community. The labile fractions of SOM provide the primary carbon substrate for the soil microbial communities, especially for the soil heterotrophic microorganisms. Organic amendments which increase the growth and activity of soil microbial communities indicate a strong relationship between microbial functioning and carbon content in soil (Chakraborty et al. 2011). Research studies demonstrated that organic amendments in soil ensure higher soil quality and higher biological activities including microbial populations, microbial respiration, soil microbial biomass carbon, and nitrogen content as compared to the traditional farming systems (Mäder et al. 2002; Girvan et al. 2004; Baaru et al. 2007).

3.3.3.1 Soil Biomass Carbon

Soil microbes are miracle creature in nature, while microbial biomass carbon is a responsive index of soil fertility and biotic attribute. It plays a crucial role in biogeochemical processes which are influenced by the addition of different organic and inorganic fertilizers in soils (Cerny et al. 2008). Microbial biomass in soil is a labile organic pool which unveils a quick output and acts as a regulatory dynamism of cycles of different macronutrients in crop fields. Microbes constitute about one-quarter of all living biomass on earth. The microbes perform a noble deed in the breakdown of different organic fertilizers, while microbial biomass is used as an early indicator of changing physical and chemical properties of soils because of different soils and crop management practices.

Microbial populations in soils are highly diverse, while the relation between their diversity and function influences soil structural stability and crop productivity. Soil organic matter, nutrient and water contents, physical and chemical properties, and climatic parameters influence microbial biomass in soils (Tomich et al. 2011). Soil microbial communities are influenced by land use changes and management practices. Organic farming with compost amendment has been shown to favor soil biota and provide better results in terms of biomass carbon and nitrogen compared to intensive farming with inorganic fertilizers (Santos et al. 2012; Amaral and Abelho 2016). It is found that the application of different manures and crop residues,

Table 4 Microbial biomass carbon (mg kg^{-1}) and nitrogen (mg kg^{-1}) in soil under different organic residues and chemical fertilizer management practices at different days after transplanting (DAT) of rice (Anik et al. 2017)

	Biomass carbon and nitrogen (mg kg^{-1}) at different DAT				
Treatment	0	30	60	90	120
Biomass carbon					
Rice straw	32.48	47.52	67.53	182.11	304.92
Poultry manure	100.81	114.84	121.25	300.92	431.64
Cow dung	47.30	71.28	91.58	178.34	380.12
Inorganic fertilizer	73.35	140.73	110.88	166.80	328.68
Control	16.99	35.51	49.32	118.32	199.94
Biomass nitrogen					
Rice straw	4.65	6.81	8.41	15.46	18.15
Poultry manure	5.01	13.39	13.81	18.72	31.60
Cow dung	4.70	6.99	11.55	14.37	27.18
Inorganic fertilizer	5.79	11.82	10.93	18.20	20.12
Control	3.25	6.43	6.01	11.52	9.88

adoption of crop rotation, and tillage practices alter soil organic matter dynamics by manipulating the soil environment and microbes hauling out C and N transformations (Anik et al. 2017; Zuber et al. 2018; Yadav et al. 2017a, b; Datta et al. 2014). The application of poultry manure, cow dung, and rice straw along with inorganic fertilizers contributed to higher biomass carbon compared to the sole application of inorganic fertilizers and zero input control (Table 4). Irrespective of organic materials, biomass carbon contents in soils were increased with the advancement of rice-growing periods, while the contribution of organic materials in the enrichment of biomass carbon in soils followed the order poultry manure >cow dung> rice straw (Table 4).

3.3.3.2 Soil Biomass Nitrogen

Like microbial biomass carbon in soils, biomass nitrogen is also a sensitive indicator which maintains ecological stability and strength of the environment. It reveals the soil quality in terms of soil fertility. Biomass nitrogen depends on soil physicochemical properties, microbial diversity, and soil and crop management practices including fertilizer application using organic and inorganic sources and climatic conditions. Undisturbed forest soil generally contains high amount of biomass nitrogen while lower in the grasslands and lowest in the agricultural soils (Miechówka et al. 2011). The typical value of biomass nitrogen in agricultural soils ranges from 10 to 60 g kg^{-1}; however, it may vary from <2 to >30 g kg^{-1} (Anik et al. 2017). The higher the biomass nitrogen, the higher the soil fertility. Different organic and inorganic fertilizers are applied to crop fields which determine the intensity and diversity of microbial populations in soils and thereby depict the amount of biomass nitrogen. Inorganic nitrogen fertilizer application has a significant effect on the transformation of biomass nitrogen (Table 4).

Different organic materials and their quality largely contribute in the biomass nitrogen content in soils. The C:N ratio in soils plays a strategic role in the turn over process of microbial biomass nitrogen. Research findings confirmed that the addition of a readily decomposable organic material with a low C:N ratio did not contribute greatly to the increase in the amount of soil microbial biomass N, while the addition of a material with high carbon with nitrogen ratio (C:N) prompted the immobilization of inorganic nitrogen and amplified the amount of microbial biomass N (Aoyama and Nozawa 1993). Nevertheless, the biomass forms in such a situation do not exist for a longer time period. After a certain period, immobilized N again mineralizes and supplies mineral N to the soil for crops.

3.3.3.3 Soil Microbial Population

Microbial population is considered one of the most important indicators of soil fertility which ultimately ensure the improvement of soil health. Amendment of organic materials to soil stimulates soil microbial populations which enhances the soil biological activities (Brady and Weil 1999). The increased number of microbial population in organic matter applied soils might be due to the supply of sufficient feed for the microorganisms from the organic amendments. It has also been hypothesized that application of organic manure would increase the availability of secondary nutrients as well as micronutrients in the soil, which favors the increase of soil microbial population (Krishnakumar et al. 2005). Investigation results of a long-term experiment indicated higher microbial biomass under organic management practices as compared to the traditional farming systems (Liu et al. 2007; Ram and Meena 2014). Addition of any organic manure either from plant or animal origin ensures the higher input of organic carbon in soil, which enhances the microbial population. Though it is very likely that organic amendments will enhance the microbial population, the number of microorganisms may vary from one source of organic amendments to another.

- *Fungal population*

Among the microbial communities in soil, bacteria and fungi are considered the most important constituents of soil biological characteristics. Fungi play very vital roles in organic matter build up, decomposition, mineralization, and cycling of nutrients especially nitrogen and phosphorus in soil. Fungi greatly enhance crop production through mycorrhizal associations. Fungi are also responsible for C sequestration in soil particularly in forest soils (Clemmensen et al. 2013). Organic carbon status of soil mostly enhances the soil fungal population (Girvan et al. 2004; Marfo et al. 2015; Lojkova et al. 2015). In general, the fungal population is increased in the organic manure-amended soil as compared to the control soil where no organic manure is applied. Research findings indicated a higher number of fungal population in organic manure-amended soil (13×10^4 CFU/g soil) as compared to the control

(4×10^4 CFU/g soil) soil that received no organic manure (Narasimha 2013). The higher fungal population in organic manure applied soil might be due to the favorable soil pH and optimum organic carbon supply by the organic amendments. Different sources of organic amendments greatly influence the fungal population. In a 2-year experiment, it was observed that fungal population in the first year got the significantly highest value of 25.23×10^3 CFU/g soil for vermicompost-amended plots, while the significantly lowest value of 11.37×10^3 CFU/g soil was recorded in control plot (Das and Dkhar 2012). In another experiment, farmyard manure demonstrated significantly higher fungal population among different organic amendments (Swer et al. 2011), and fungal population for different treatments follows the order as farmyard manure > plant compost > integrated compost >vermicompost> control. In most cases, it is evident that organic amendments increase fungal population, but there is also a report regarding no significant variation of the fungal population due to different types of organic amendments. Research findings revealed that the fungal population did not vary significantly due to different organic amendments in the last year of a 2-year experiment (Das and Dkhar 2012; Dhakal et al. 2016).

- *Bacterial population*

The soil is the most important habitat of bacteria. Among all microbial communities in the soil, bacteria are the most populous, even though the weight of fungi may exceed the weight of bacteria. One gram of soil can contain billions of bacteria. Organic matter status of soil is crucial for the multiplication of soil bacteria. Some bacteria may double their numbers within 30 min, especially when the soil contains adequate amounts of organic residues. Most of the soil bacteria are heterotrophic in nature and directly rely on soil organic matter as they receive their food and energy from organic substances. Research findings indicated that organic amendments commonly increase the bacterial population as compared to the no manure amendments but bacterial population may be altered by different sources of organic amendments too. Results of a long-term experiment that was managed for the last 29 years by the Department of Soil Science, BSMRAU, Gazipur, Bangladesh revealed that organic amendments significantly influence the bacterial population. Among the organic amendments, significantly the highest number of bacterial population was enumerated from rice straw-treated plots (22×10^5 CFU/g soil), and the lowest population (6×10^5 CFU/g soil) was observed in control (no organic manures) treatment. The higher microbial population in soil due to the application of organic residues might be due to higher organic carbon build up in soil and creation of suitable soil properties. Among the organic amendments, vermicompost also showed significant influence on soil bacterial population. The highest bacterial population was enumerated in vermicompost-amended plots (55.19×10^5 CFU/g dry soil) followed by the amendment of farmyard manure (54.26×10^5 CFU/g dry soil), whereas the lowest number was recorded in control treatment having a value of 30.89×10^5 CFU/g dry soil (Das and Dkhar 2011).

The rate of organic amendments is also crucial in regulating the bacterial population. Research findings clearly demonstrated that the number of spore-forming bacteria is positively correlated with the dose of applied compost (Zaccardelli et al. 2013). Moreover, some reports illustrated the decline of bacterial population due to organic amendments. Study results clearly illustrated that the addition of wheat straw in soil decreased the bacterial population (Acea and Carballas 1996). This might be due to the slow decomposition nature of the straw which resulted in lower availability of organic carbon for the bacterial community. It is also reported that high doses of organic amendments negatively influence the microbial biomass and enzyme activities (Ouni et al. 2013; Datta et al. 2017a). This negative behavior might be due to the toxic effect of the increased trace elements at a higher dose of organic amendments (Crecchio et al. 2004).

4 Biochar and Organic Amendments for Carbon Sequestration and Climate Change Mitigation

Carbon sequestration is a process of taking away of carbon from the atmosphere in a solid material through biological or physical processes and storing in the natural environment for an unlimited period. Plants naturally perform this function converting atmospheric carbon dioxide (CO_2) into organic carbon through the process of photosynthesis and incorporated into living plant matter (Rice and McVay 2002; Rahman 2010). The continuous falling off of branches and leaves from vegetation increases fresh organic materials to soils and when plants die adds more biomass which decays and becomes soil organic matter (SOM), and thus, carbon is sequestered into the soil. The sequestration of organic carbon is a requisite for soil health improvement, crop yield increment, and higher use efficiencies of plant nutrients (Rahman 2013). Soil organic carbon is a dominant factor which governs soil biological and physicochemical properties and ensures agricultural and environmental sustainability. In the tropical and subtropical climatic regions, high soil and air temperature coupled with high moisture content favors microbial decomposition of different organic fertilizers like compost, manure, crop residues, etc. added to soils, and thereby organic matter content reduces fast. Faster microbial decomposition of leftover crop residues and added organic wastes resulted in lower carbon content in soils (Rahman 2010; Agehara and Warncke 2005). Consequently, the present carbon contents and carbon stocks in soils of many countries in the tropical and subtropical climatic regions are declining at an alarming rate. It is a great challenge and global concern to increase carbon content in soils. Resource conservation strategies and best management practices are essentially required to sequester carbon in soils. The sequestration of organic carbon is the result of the long-term input-output budget, i.e., the balance between input as the addition of organic C using various organic materials and output as losses from the soil as CO_2 emission. Continual soil disturbance through plowing and other soil and crop management practices expedite microbial decomposition of organic matter, although a large amount of C is added to the soil through residues of different crops which ultimately results in either a net stockpiling or a net reduction of soil carbon in soils.

The soil has enormous potential in storing carbon more than three times of the terrestrial vegetation which depends on how we manage our soils. It is reported that the world's agricultural and degraded lands can potentially store carbon 50–66% of the historic carbon loss of 42–78 giga tons (Lal 2004). The organic carbon stocks in the world's soils are 1550 Pg, while inorganic carbons are 950 Pg (Lal 2008). Soil physical properties (texture and structure), climatic factors (rainfall and temperature), and soil and crop management practices manage the rate of soil organic carbon sequestration. Carbon stock and sequestration in soils can be increased through adoption of resource conservation strategies and best management practices like zero tillage, minimum tillage, green manuring, cover crops, balanced and optimum fertilization, manuring, sludge and compost application, and social forestry. Application of different organic amendments including biochar can play a vital role to replenish and conserve carbon in soils and ensure agricultural sustainability. Biochar is a fine-grained, highly carbonaceous material which is persistent in nature and can sequester carbon in the soil for a long time. It has also a significant contribution in developing soil structure encompassing soil particles together, and thus biochar not only sequester its own carbon but also protect inherent and applied carbon using different sources. The mineralization of biochar is much slower than any other organic materials. Research findings demonstrated a carbon mineralization rate of 1.5% in biochar-amended soils, while in the non-amended soil, it was 2.4% (Hernandez-Soriano et al. 2016). The rate of carbon reduction in biochar-mixed soils is restricted compared to cow dung and poultry manure mixed soils (Fig. 6). Biochar is known as an inert matter which contributes to the soil recalcitrant organic carbon pool which is resistant to high temperature and high moisture and to further microbial decomposition. The rates of organic carbon sequestration of different biochar in soils might be about 1 Pg C year^{-1} (Sohi et al. 2010). The half-life of carbonized materials in biochar is about 1400 years (Kuzyakov et al. 2009). However, several estimates confirmed that carbon could remain in soils at least 100 years through the application of biochar in agricultural lands if managed properly (Shackley et al. 2009). The application of rice husk and corn stover biochar significantly improves soil aggregation and structural stability, increases carbon, and improves soil health. A healthy soil containing high organic carbon is capable of exchanging different cations and holding more water in soils and decreasing CO_2 emission (Mohan et al. 2018).

Carbon added to the soil using different organic amendments and crop residues undergoes a series of transformation from labile to recalcitrant forms. The labile C upon decomposition releases CO_2 to the atmosphere which favors the globe to become warm. The labile pool of carbon in soils is vital for maintaining soil fertility, its productive capacity, and ecosystem community, while the recalcitrant carbon pool promises to sequester more carbon and inevitable for maintaining the structural integrity of the soils and long-term sustainability of the environment. The organic material that contains a higher amount of labile carbon sequesters less amount of carbon in soils while releasing more carbon to the atmosphere as shown in Table 5

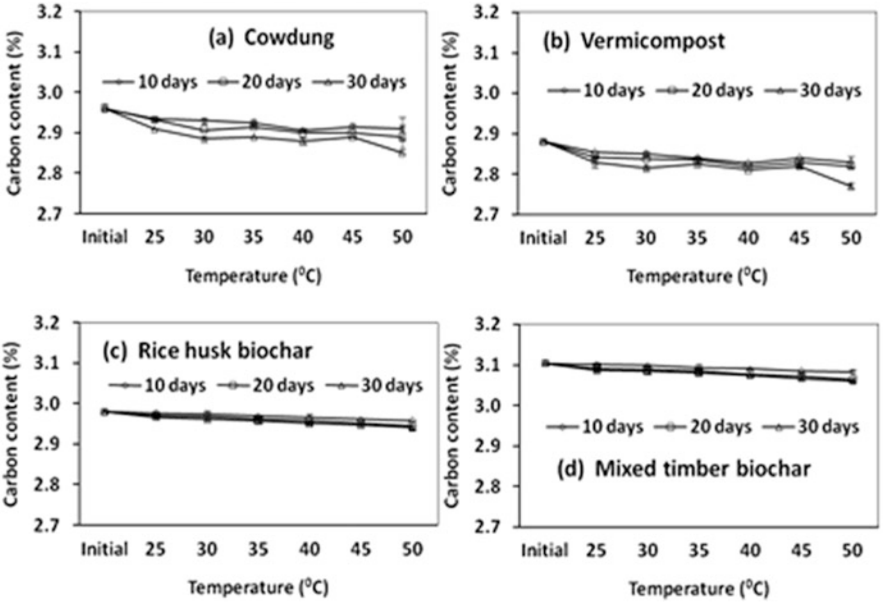

Fig. 6 Reduction in carbon contents of organic materials added soils under different temperature regimes: (**a**) cow dung, (**b**) vermicompost. (Source: Hossain et al. 2017); (**c**) rice husk biochar, and (**d**) mixed timber biochar

Table 5 Effect of organic manures, rice straw, and inorganic fertilizers on carbon sequestration and carbon loss in the soil after harvesting of five rice seasons where C was applied at 2000 kg ha^{-1} in each crop season (0–15 cm soil depth) (extracted from Rahman et al. 2016)

Treatment	Total C input (kg ha^{-1})	Labile C (g kg^{-1})	Carbon sequestration (t ha^{-1})	%C emission loss	%C sequestration	%C unaccounted
Control	–	2.92	−1.36	–	–	–
CD	10,000	5.70	3.03	36	30	34
PM	10,000	4.88	4.90	28	49	23
RS	10,000	6.98	1.04	37	10	53
STB	–	3.78	0.04	–	–	–

Note: *CD* cow dung, *PM* poultry manure, *RS* rice straw, *STB* soil test-based fertilizer, *C* carbon

(Rahman et al. 2016; Meena and Yadav 2014). The data presented in Table 5 revealed that among different organic materials, the highest amount of organic carbon sequestered in poultry manure-treated soil is followed by cow dung, rice straw, and inorganic fertilizer. Manure was found more powerful in building soil carbon than straw, possibly because of the occurrence of more humified and obstinate C forms in manure contrasted with rice straw.

Soil carbon content is influenced by tillage operations, fertility levels, cropping systems, and cropping intensity. More tillage and intensive cultivation with high

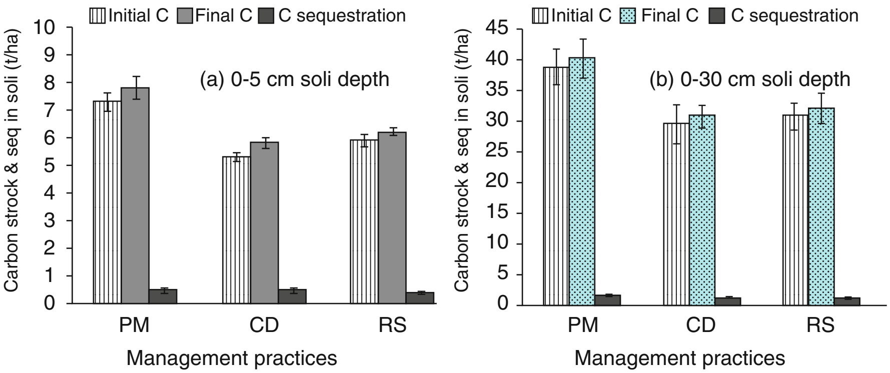

Fig. 7 Carbon stock and sequestration (t ha^{-1}) in soils under different management practices in rice-fallow-rice cropping systems in Bangladesh. (Rahman 2010), *PM* poultry manure, *CD* cow dung, *RS* rice straw

levels of inorganic fertilization enhance the decomposition of inherent as well as added organic materials in soils resulting in lower carbon in soils. The cropping systems and soil and crop management practices that provide higher carbon input might help in sustaining the carbon level and maintaining good soil health. Findings of a research study revealed that minimum tillage in an uninterrupted monoculture of cotton increased soil organic carbon by 24% compared to conventional tillage, while crop rotation increased soil carbon contents by 28% in a cotton corn (*Zeamays* L.) (Wright et al. 2008) rotation compared to continuous cotton. In another experiment, it was found that minimum tillage in rice cultivation contributed to higher carbon accumulation in soils compared to traditional tillage even though total carbon input was low under minimum tillage (Table 6). Figure 7 revealed the carbon stock and sequestration in soils of rice-fallow-rice cropping systems under different organic management practices. It was found that poultry manure contained more stable carbon and contributed to higher carbon stock as well as carbon sequestration contrasted with cow dung and rice straw (Rahman 2010). Management practices that ensure slower microbial decomposition of added residues are likely to increase carbon content in soil and thus enhance carbon store in soils. Therefore, the identification of such soil and crop management practices is the main concern for building carbon in soils and sustaining crop productivity.

The organic matter content in soil is responsible for making the agricultural system sustainable. The soil has an immense capacity to serve as an eventual sink of atmospheric CO_2. The concentration of CO_2 and other GHGs in the atmosphere is high enough to make the globe warmed and climate changed. During the last century, the planet's average surface temperature has increased by 1.1 °C which is caused by the increased emission of CO_2, CH_4, N_2O, and NO into the atmosphere. The sequestration of carbon in soils can possibly alleviate the harmful effect of global warming and climate change on crop cultivation. Different soil and crop management practices and organic materials including biochar increase soil carbon stock, and thus soil health is improved which makes it capable of acting against the negative effects of climate change (Soderstorm et al. 2014). Different management practices like diversified cropping systems, application of wastes/compost, and tillage operation coupled with balanced fertilization using organic and inorganic sources have high potential to increase carbon content in soils. Organic debris and plant residues added to soil convert into more steady humic substances and contribute in the development of various organomineral compounds and microaggregates which safeguard soil carbon from mineralization and thus help to enhance C sequestration (Lal 2016). Carbon sequestration prevents CO_2 emissions produced by human activities and remove it from the atmosphere in different ways and stores it in soils. Carbon sequestration increases with enhancing plant physiology and rate of photosynthesis which ultimately results in higher plant biomass (Lal 2004). It is found that 1 ton of carbon increases in soils can increase yields of maize, wheat, and cowpeas by 10–20, 20–40, and 0.5–1 kg ha^{-1}, respectively, while such augmentation in carbon can possibly relieve 5–15% of the worldwide emission from fossil fuel burning (Lal 2004; Verma et al. 2015).

Capturing CO_2 from large point sources such as fossil fuel power plants and enduringly storing it in different reservoirs away from the atmosphere is a process to lessen global warming (USDE & NETL 2007). It is reported that the use of organic amendments like manures, composts, biochar-compost mixtures, etc. can be the better option for the improvement of soil fertility, restoration of degraded land, and mitigation of emissions of greenhouse gases from agricultural practices and land use changes (Agegnehu et al. 2017). It is understood that the application of organic amendments to agricultural lands ensures a continuous supply of carbon pool which might reduce the emission of greenhouse gases from soil, and thus it helps in the mitigation of global warming and climate change (Rahman et al. 2016; Lehmann and Joseph 2015). Biochar releases less emission compared to fresh organic materials. Carbon dioxide emissions in chicken manure, rice straw, vermicompost, cow dung, and rice husk biochar were 19.69, 18.60, 12.16, 12.01, and 7.96%, respectively (Hossain et al. 2017). It was also reported that biochar produced from poultry manure releases more greenhouse gas compared to biochar from sugarcane straw. However, both can considerably reduce the CO_2eq emission (Novais et al. 2017).

5 Conclusion

Intensive cultivation coupled with high temperature and high moisture content favored faster decomposition of organic matter in soils. The resultant effect of faster mineralization of organic matter is declining soil fertility and increasing greenhouse gas emission. Biochar and other organic amendments potentially can sequester carbon in soil and reduce carbon dioxide emission to the atmosphere. The application of such materials improves soil health through developing soil aggregates, increasing soil nutrient and water contents, exchanging cations, easing hydraulic conductivity, and enhancing microbial activity, biomass carbon, and nitrogen while maintaining soil pH and bulk density to a favorable level for crop production. Resource conservation strategies and continuous supply of organic materials help to increase and maintain carbon content as well as the fertility of soil where biochar appeared as a promising amendment for storing carbon in the soil and mitigating global warming.

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