9

Organic Sources and Tillage Practices for Soil Management

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Contents

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Abstract

Soil is the most valued natural resource, which needs to be used until the existence of the world for our food production. There is a limited option to bring new land under crop cultivation. The finite land resource is decreasing continuously due to a new settlement, industrial, and other development activities. Intensive agriculture ensured food security, which, however, exerts huge pressure on arable land through increased frequency of crop cultivation, repeated tillage, and indiscriminate use of unbalanced agrochemicals. The resultant effects of long-term intensive agriculture are the depletion of organic matter (OM) and degradation of soils, which attributes to lower use efficiencies of agricultural inputs. It is anticipated that 60% more yields of cereals will be needed by 2050 contrasted with the current level. Because of poor soil health, it has become a great challenge to keep increased food production onwards. If the productive capacity of soils could not be maintained, the present civilization must be collapsed. Therefore, the soil needs to be kept alive by adding locally available organic amendments and adopting conservation tillage practices. Soil carbon (C) is the fuel and driving force of ecosystem functions. Application of organic amendments increases soil C, builds soil structure, enriches biological diversity, and contributes to reducing inorganic fertilizers in crop production. Rice straw is the most available residue in many countries of the world, which increases soil aggregate stability, organic C, and cation exchange capacity by 27.8, 45.5, and 27.2%, respectively, compared to sole inorganic fertilizer application. Poultry manure and cow dung were found effective to reduce soil acidity, which depends on the rates and frequency of their application. Conservation tillage like no-till, reduced tillage, and strip-tillage, etc. diminishes mineralization of OM and increases C accumulation in soil. No-till with residue retention has global demand, which is one of the best options of increasing soil C. No-till system alone can save about 70% energy and fuel consumption compared to traditional tillage. Rotation of crops, retention of residues, and adoption of other suitable resource conservation strategies further ensure good soil health and its productive capacity. The combined adoption of organic amendments and conservation tillage can revitalize degraded soils and bring multiple benefits including agricultural sustainability and mitigation of climate change.

Keywords

Crop residues · Intensive agriculture · Organic fertilizer · Soil health · Sustainability

Abbreviations

AEC	Anion exchange capacity
Al	Aluminum
AMF	Arbuscular mycorrhizal fungi
B	Boron
BNF	Biological nitrogen fixation
BSMRAU	Bangabandhu Sheikh Mujibur Rahman Agricultural University
C	Carbon
Ca	Calcium
CA	Conservation agriculture
$CaCO_3$	Calcium carbonate
cc	Cubic centimetre
CD	Cow dung
CEC	Cation exchange capacity
CFU	Colony forming units
CH_4	Methane
Cl	Chlorine
Co	Cobalt
CO_2	Carbon dioxide
CP	Compost
Cu	Copper
FAO	Food and Agriculture Organization
Fe	Iron
FRG	Fertilizer recommendation guide
FYM	Farmyard manure
$g\ cc^{-1}$	Grams per cubic centimetre
$g\ kg^{-1}$	Grams per kilogram
GHG	Greenhouse gas
GM	Green manure
H	Hydrogen
$H_2PO_4^-$	Phosphate
HCO_3^-	Bicarbonate
K	Potassium
$mg\ kg^{-1}$	Milligrams per kilogram
Mg	Magnesium
mm	Millimetre
Mn	Manganese
Mo	Molybdenum

MT	Minimum tillage
N	Nitrogen
N_2O	Nitrous oxide
Na	Sodium
NH_4^+	Ammonium
Ni	Nickel
NO_2^-	Nitrite
NO_3^-	Nitrate
NUE	Nitrogen use efficiency
O	Oxygen
OC	Organic carbon
OH^-	Hydroxide
OM	Organic matter
P	Phosphorus
Pg	Peta gram
PGPF	Plant growth promoting fungi
PGPM	Plant growth promoting microbes
PGPR	Plant growth promoting rhizobacteria
PM	Poultry manure
RHB	Rice husk biochar
RS	Rice straw
RT	Reduced tillage
S	Sulphur
SDGs	Sustainable development goals
Si	Silicon
SO_4^{-2}	Sulphate
SOC	Soil organic carbon
SOM	Soil organic matter
ST	Strip tillage
$t\ ha^{-1}$	Ton per hectare
TT	Traditional tillage
UN	United Nations
Va	Vanadium
VC	Vermicompost
WHC	Water holding capacity
Zn	Zinc

9.1 Introduction

Soil is not only our existence, it is the harbour of entire lives including flora and fauna in the earth. It feeds the global population including all the living beings through producing foods, while the future food production for the ever-burgeoning population depends on soil health (Fan et al. 2011; FAO 2015; Gannett et al. 2019). Kibblewhite et al. (2007) described soil health as an outcome of integrated management of soil and crops, which reveals the ability of soil to restore and replenish fertility and productive capacity on a sustained basis. Nowadays, degradation of soil health is one of the burning issues in agriculture globally. Farmers and commercial entrepreneurs follow traditional tillage (TT) practice and apply an excess amount of inorganic fertilizers. The necessity of organic fertilizers in sustaining soil fertility and crop productivity is ignored in many cases. Sole application of inorganic fertilizers degrades soil health and ultimately soil becomes less productive (Rahman 2014; Drakopoulos et al. 2016). Moreover, our agricultural land is annually decreasing by 1% due to anthropogenic activities like human settlement, industrialization, brickfields, roads construction, etc. (Rahman et al. 2020). World population is increasing in one hand, while the land resource is decreasing in other hand. Of the total global land area, the global agricultural land is 37.431%, and most of the best land is already taken under agriculture practices, therefore, the expansion of new land for agriculture is almost impossible (World Bank 2016). FAO (2009) reported that for an increment of 2.3 billion peoples by 2050, only cereal demand (both for man and animal) will be increased from 2.1 billion tons to 3 billion tons. It will be needed to produce 60% more yields of cereal crops by 2050 then the present yields (FAO 2015; Rosenstock et al. 2016). Climate change increases soil erosion and atmospheric temperature and lowers water tables, which further make difficult to produce more foods and feed the world. In this situation, it is really a great challenge to produce increased foods keeping our soil alive and productive for the future generation. Protection and conservation of soil, land, and water resources and efficient utilization of production inputs should receive high priority to meet our food requirements (Gupta and Sayre 2007).

Factor productivity of different agricultural inputs like land, fertilizers, irrigation water, etc. decreases and ultimately attributed to lower resource use efficiency (Rahman 2013; Alam et al. 2019). The global cereal production vs nitrogen use efficiency (NUE) described by Tilman et al. (2002) is depicted in Fig. 9.1. The cereal production increases almost in a linear fashion from 1960 to 1995 (Fig. 9.1a), while NUE radically decreases from 1960 until 1980 (Fig. 9.1b). After 1980, NUE follows almost stable state, which reveals that the further increment only in nitrogen (N) fertilizer application may not increase cereal production unless attention is paid towards soil health management adopting resource conservation strategies. This has been further endorsed by Alam et al. (2019), where it was reported that rice (*Oryza sativa* L.) yields and carbon (C) sequestration increased due to different management practices. On the other hand, raising N fertilizer application from 100 to 150 kg ha^{-1}, rice yield was not increased, while C sequestration decreased by 25%.

Application of different amendments and adoption of conservation tillage practices may bring a radical change in soil health restoration. Reduced tillage (RT) and addition of different organic amendments like cow dung (CD), poultry manure (PM), rice straw (RS), compost (CP), farmyard manure (FYM), green manure (GM), etc. are practised globally to increase soil microbial abundance and their diversity, improve soil properties, and ensure a healthy soil, which contributes in sustaining crop yield (Beare et al. 1994; Rahman et al. 2016; Wang et al. 2016). It is reported that addition of organic matter (OM) to the soil promotes soil structural

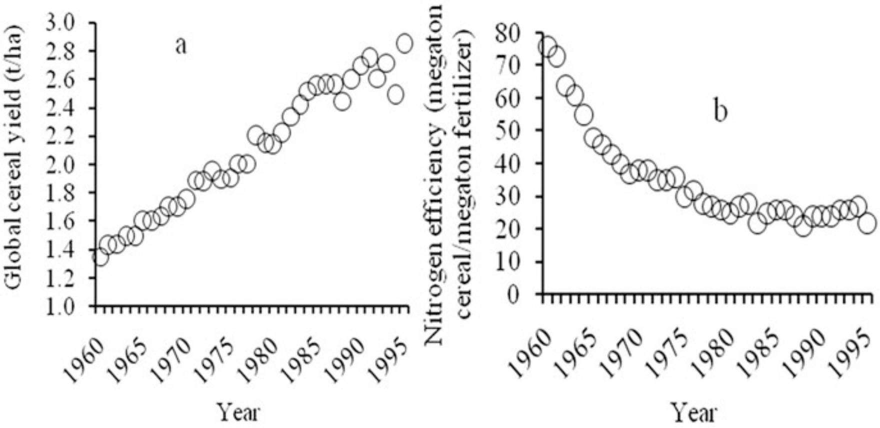

Fig. 9.1 Trends of global cereal production (**a**), and nitrogen use efficiency (**b**). (Adopted, Redrawn from Tilman et al. 2002)

stability, microbial diversity, and nutrient supplying capacity of the soil (Trinsoutrot et al. 2000; Manzoni and Porparato 2009; Roy et al. 2019).

Tillage operation is a turmoil of soil and has long-term effects of conventional or traditional tillage (TT) to soil environment can be compared with the effects of the earthquake, hurricane tornadoes, etc. Long-term practice of conventional tillage substantially degrades soil health, reduces soil nutrients and crop yields, and finally appears as a threat to agricultural and environmental sustainability (Hafeez-ur-Rehman et al. 2015). Conversely, conservation tillage like no-till, reduced tillage (RT), minimum tillage (MT), strip-tillage (ST), etc. decreases OM decomposition and soil gain more C, thus conserving soil fertility and agricultural sustainability (Six et al. 2002).

Carbon contents in soils of the tropical and subtropical regions are inherently low (Mandal et al. 2007). This is because of favourable climatic conditions for the faster microbial decomposition of organic materials. In such a fragile production system application of organic amendments to crop fields makes worthy use of natural resources. Application of organic fertilizers shrinks the requirement of mineral fertilizers and improves nutrient use efficiency in crop production (Rahman 2013; Antonious 2016; Rahman et al. 2020). Resource use efficiency of agricultural inputs must be increased through proper and modern soil and crop management practices. Results from the different investigation revealed that use of C-based amendments in crop fields improves soil aggregates, moisture contents, NUE, and microbiological diversity and their activities, which ultimately influences soil fertility and productivity (Antonious 2016; Roy et al. 2019). Organic amendments slowly release nutrients to soils for crops being grown in several crop seasons. Organic fertilizers contain sugars and amino acids, which enhance the microbiological activity, and thereafter, associated soil fertility.

9.2 Soil Under Intensive Agriculture

Intensive agriculture is an option to get maximum crop yields from a unit area of land using a higher amount of chemical fertilizers and synthetic pesticides creating environmental hazards (Scotti et al. 2015). Such exposures on agricultural land change soil quality in terms of fertility reduction and biodiversity loss in the agroecosystems. It is stated that since the previous 60 years, the worldwide usage of N fertilizers increased by seven-folds, while the usages of phosphorus (P) fertilizers increased by 3.5 folds, which indicates that the traditional or extensive agriculture moving fast towards intensive agriculture (Tilman et al. 2002). Intensive agriculture is a capital- and a labor-intensive system, where the frequency of cultivation is high and the land is subject to deterioration of physicochemical and biological properties (Greenland 1977). About 2–3 crops and even four crops are grown in the same land in a yearly sequence to increase cropping intensity. Four-crops cropping pattern like rice-rice-rice-mustard is practised in Bangladesh to increase crop productivity. Such intensification in agricultural production systems contributed to a large increase in crop yields and ensured food and nutrition security of the global population. However, agricultural intensification caused for severe ecological damages like soil structural degradation, water shortages, fertilizers, and pesticide pollution in the surface and underground water, eutrophication of surface water of lakes, streams, rivers etc., loss of soil microbes, and increasing costs of production (Hunke et al. 2015). Because of the intensive tillage, soils have become physically disturbed. This caused the disintegration of soil aggregates, faster decomposition of soil organic matter (SOM), and finally, soil health and crop quality deteriorated (Paustian et al. 2000; Schiesari et al. 2013). It is reported that the shared effect of intensive agriculture and climate change can severely degrade fertility of soils, and reduce yields of many crops and disrupt the ecosystem functions (Paustian et al. 2000; Rahman et al. 2017). Reduction in crop yields because of soil and land degradation is evinced in Africa, Asia, and Latin America (Kaiser 2004).

9.3 Sustainable Soil Management

Intensive agriculture certainly ensured food security of the global population (Norris and Congreves 2018). A higher amount of fertilizers, more tillage and frequent supply of irrigation water are needed to produce high crop yields under intensive agriculture. Such injudicious agricultural activities seriously degraded soil and environment, thus the ecosystem has lost its capacity to function properly (Norris and Congreves 2018; Meena et al. 2020a). Sustainable management of soils is a great challenge in agriculture of the twenty-first century (Meena and Lal 2018). The key challenge of sustainable agriculture is to conserve soil and land for fostering ecosystem services while ensuring a healthy soil. Agricultural sustainability depends on soil quality, which is defined as the ability of soil to perform its function effectively within ecosystem boundary that maintain plant and animal productivity, protect air and water attributes, care human health, and conserve their habitats

Table 9.1 Rice yield and carbon sequestration as affected by different organic materials (Adapted, Alam et al. 2019)

Treatments	Rice grain (t ha^{-1})	Initial soil C (%)	C at crop harvest (%)	C sequestration (t ha^{-1})
RS	5.66bc	0.77ab	0.85a	1.30ab
VC	5.89ab	0.80a	0.86a	1.02b
RHB	5.24c	0.75ab	0.81ab	1.23ab
CD	5.69abc	0.70c	0.77b	1.45a
PM	6.32a	0.71bc	0.76b	1.13ab
CV (%)	9.02	8.03	6.40	25.87

RS rice straw, *VC* vermicompost, *RHB* rice husk biochar, *CD* cow dung, *PM* poultry manure, *C* carbon, *Seq.* sequestration

(Karlen et al. 1997). Adoption of conservation agriculture (CA) is essential to increase and maintain soil quality. Sustainable agriculture is synonymous with CA, which relies on appropriate management activities of soils and crops. In sustainable or conservation agriculture, there are three pillars viz., no-till/zero till, continuous crop residue retention/cover crops, and legume-based crop rotations. Conservation agriculture greatly depends on soil organic carbon (OC) as OM. Soil OM is one of the vital components that govern soil physical, chemical, and microbiological properties. Lal (2004) reported that the global soil contains 2500 Peta gram (Pg) of C, which is four times higher than that of the biotic pool and three times that of atmospheric C pool. Global soils annually release about 68–80 Pg of C to the atmosphere because of OM decomposition and plant root respiration, which is ten times higher emission compared to fossil fuel burning (Raich et al. 2002; Powlson et al. 2011). Alam et al. (2019) found that C sequestration potential of different organic amendments is highly variable, which depends mainly on its mineralization stage, while such amendments sustain crop yield (Table 9.1). Therefore, if soil and crop management practices can bring a small increment in soil C it would have a hugely positive effect on soil health and environmental sustainability.

Soil OM is a hub for regulating different functions of soil and dealing with CA. Soil health is reliant on the performance of C transformations, nutrient dynamics, soil structural development, and microbial diversity and their abundance, which further largely depends on conservation tillage, and organic amendments (Fig. 9.2). There are several actions and interactions and multiple benefits of adoption of no-till/RT and supply of organic materials to the soil. Such approaches are playing significant roles in developing soil aggregates, conserving nutrients, and increasing microbial diversity for improving soil health, and ultimately driving agriculture towards a sustainable production system (Fig. 9.3).

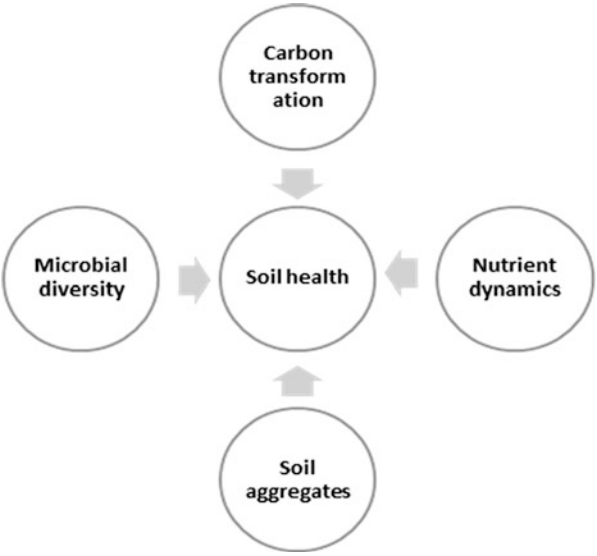

Fig. 9.2 Soil health attributes for better ecosystem performance

9.4 Soil Properties

Soil can be considered fertile when its physical makeup, chemical dynamics, and biological properties are conducive for the healthier growth of plants (Abbott and Murphy 2007). Unbalanced fertilization, intensive tillage operations, repeated crop cultivation, soil erosion, and luxury irrigation in agricultural systems push to worsening of soil health (Wander 2004; Diacono et al. 2012; Liang et al. 2013). Therefore, it is necessary to sustain soil health through best management practices and resource conservation strategies.

9.4.1 Physical Properties

Physical features of soil play a key determinant role for viable soil management and agricultural farming. Physical properties have immense effects on soil chemical reactions and biological functions, and thus nutrient dynamics in soil–plant systems. Soil as a medium of plant growth, its physical properties like soil texture, structure, compaction, density, hydraulic characteristics, etc. ensure the supporting capability of the soil, ease of root penetration, thermal diffusion, airflow, water and nutrient dynamics for better growth, and yields of crops.

9.4.1.1 Soil Texture

It is considered as one of the most prominent physical qualities due to its versatile imperious effects on numerous soil functions. In a brief, soil environment is closely interlinked with soil texture. It refers to the comparative percentage of the distinct

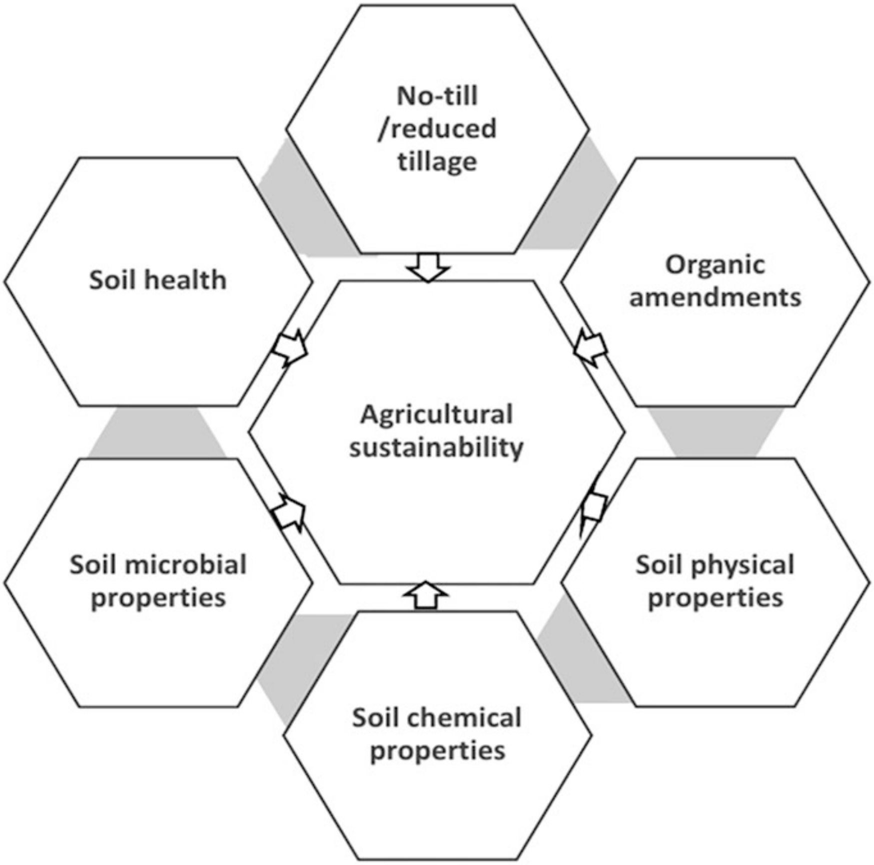

Fig. 9.3 Schematic illustration of roles of tillage and organic amendments on soil properties and agricultural sustainability

size range of soil mineral particles such as sand, silt, and clay. Minerals having 2 mm (millimetre) and/or <2 mm in size is called soil particle. Particle size over 2 mm although may have a slight impact on water retention associated properties but not included in soil texture. Soil texture is a static and inherent soil property derived from the weathered rocks and minerals that cannot be changed easily by adopting different farming practices. Soil texture is considered as the leading factor for proper soil management and determining land use capability.

9.4.1.2 Soil Structure and Aggregates

It is considered as a major functioning aspect that regulates solute, liquid, gaseous and heat flows, root penetration, and nutrient holding capacity of soils. Formation of soil structure is an interactive process of environment, soil–plant management, soil texture, OM, microbial activities, different forms of nutrient reserves, and moisture availability in soils (Kay 1998). A group of soil separates fix together to make a larger structural unit of soil aggregate, which is usually termed as a secondary particle. When such aggregation happened in the natural condition with a relatively stable form is called peds, whereas loose, irregular shaped coherent soil mass formed during tillage operation is called a clod. Thus, soil structure and aggregate are subjected to the spatio-temporal association of soil particles and pore spaces due to natural processes and anthropogenic activities of soil and crop management practices.

Soil aggregate stability states the capacity of aggregates to resists against externally imposed disruptive forces like rain flash, surface runoff, and erosion. It is a strong factor for sustaining soil physical health, which greatly affects various soil properties like improvement of porosity enhances the suitability of gas exchange, water holding capacity (WHC), and microbial activities of soil (Diacono and Mantemurro 2010). Soil with vegetation, higher clay, and OM content provides higher aggregate stability. Conservation agriculture with surface residue retention promotes soil aggregation and sustainable soil health. Disruption of aggregate stability guides to surface sealing and crust formation, which decreases the vertical entry of water through the soil profile and increase erosion risk and soil loss through runoff (Franzluebbers 2002). Higher siltation and low OM accelerate the aggregate breakdown and crusting formation (Ramos et al. 2003).

9.4.1.3 Soil Compaction and Density

Soil structural degradation due to externally or internally applied pressure is termed as soil compaction. Compaction reduces macro-pores and increases dry mass in per unit volume of soil, and thereby increases the soil bulk density. It adversely affects numerous physicochemical properties and microbial functions of soil (Whalley et al. 1995). Compaction is a complex interlinked process of soil, crops, weather, and imposed pressure. Sometimes compaction creates an impermeable layer that restricts water movement and nutrient cycling in the soil system. Some key indicators, e.g. soil pores (macro and micro), sizes of pores, bulk density, consistency and penetration capability of roots quantify the soil compaction (Hiel et al. 2016). The degree of compaction depends on the types and nature of clay, exchangeable cations, water content, and applied energy and soil management.

Bulk density is an important property for computing weight of soil considering the depth of interest. The bulk density is always lower than the particle density. In an ideal porosity (50% volume), bulk density of soil ranges from 1.30 to 1.35 g cc^{-1} (grams per cubic centimetre). In the case of coarse-textured soil, it varies from 1.40 to 1.75 g cc^{-1}, while in fine-textured one ranges from 1.10 to 1.40 g cc^{-1} (Phogat et al. 2015). Soil bulk density varied according to the soil texture, structure, moisture, OM content, and management practices. The lower bulk density indicates the higher OM and clay content of the soil. Different management practices like irrigation management, C sequestration, and nutrient dynamics depends upon the bulk density of soil.

9.4.1.4 Soil Hydraulic Properties

The soil permeability is a measure of the capacity or ease of soil to allow fluids to pass through it. Soil permeability is a very important feature to determine the movement and retention of water, nutrients, and air in the soil. It is affected by particle size, water content, void ratio, degree of saturation entrapped air, organic amendments, and tillage practices. Application of organic amendments makes soil porous and permeable, while intensive and more tillage make soil compacted and impermeable.

Soil water-holding capacity (WHC) depends on soil and crop management practices. Maximum WHC of soil is reached in field capacity when the soil contains more OM. Many soil physical characteristics like porosity, pore numbers, resistance potential, the specific surface areas, crust formation, shrinkage, and swelling ability are closely linked with the WHC of a soil. Climatic factors (rainfall and temperature), OM, texture, and structure play a major role in WHC of soil. Infiltration and evaporation are the most dominant processes that regulate WHC of soils.

Infiltration refers to the process of the downward entrance of water into the soil through the topsoil. It is the first phase that allows the transmission of water into different horizons through the soil profile. It permits the soil to provisionally stock water and keeps available for the usage of plants and microorganisms. An ample amount of water must pass through the soil profile for growth and development of plants is necessary. Gravity and soil water tension or soil matric potential control flow of soil water, which is guided by soil types and crop cultivation practices. When the amount of rainwater is more than the infiltration rate, water accumulates on soil and runoff begins.

Hydraulic conductivity accredits the easiness of water movement via the pore space. It is a computable measurement of the ability of saturated soil to transfer water. Water transmits ability through soil is controlled by the soil pores and their size and geometry (Connolly 1998). Saturated soil hydraulic conductivity is influenced by texture, clay, OM, soil aggregation, bioturbation, shrinkage, swelling and aggregate stability (Lim et al. 2016).

9.4.2 Biological Properties

Soil biology comprises the functions of flora (bacteria, archaea, and fungi) and fauna (protozoa, mites, nematodes, and earthworms). The relationship between these organisms and soil characteristics is incredibly vital on the way to maintain soil health for better agricultural production. It is well known that micro-organisms mineralize different organic materials, thus nutrients become available for crops and microbial immobilization. The nutrients immobilized by organisms restrict the nutrient loss and upon the death of microbes and subsequent mineralization, nutrients are added to the soil. Activities of soil organisms are largely responsible for improving physical and chemical properties, e.g. aeration, pH, SOM, and nutrient dynamics. Similarly, the activity of earthworm increases the infiltration rate, while the microbial activity decreases the content of SOM due to mineralization. Soil biological property can change the whole soil environment by increasing or decreasing the concentrations of nutrients through the decomposition of OM.

9.4.2.1 Nutrient Cycling

Soil microorganisms exert significant influence in controlling the quantities of different nutrients and elements in the soil like C, N, sulphur (S), and P. The mineralization of bio-degradable substances is carried out by the soil microbes that release available inorganic forms of plant nutrients including nitrate (NO_3^-), ammonium (NH_4^+), sulphate (SO_4^{-2}), etc. (Rani et al. 2019; Meena et al. 2018; Kumar et al. 2020). Assimilation of these inorganic nutrients by soil organisms and transformation into organic compounds is termed as immobilization. Microbes are the keys for the remobilization of these nutrients. Nutrient cycling is done as a result of activities of different soil organisms like bacteria (*Bacillus, Pseudomonas, Cellulomonas, Vibrio,* and *Achromobacter)*, fungi *(Aspergillus, Penicillium,* and *Trichoderma).* Protozoa, nematodes, earthworms, mites, soil insects, etc. Nitrification is a process of converting the NH_4^+ form of N to nitrite (NO_2^-) and then to NO_3^-, which is mediated by *Nitrosomonas* and *Nitrobacter*, respectively.

9.4.2.2 Biological Nitrogen Fixation

The atmosphere contains about 78% N_2 (volume basis), which is practically unavailable for the plant uptake. But some microorganisms (especially, bacteria and cyanobacteria) can capture and convert the atmospheric dinitrogen (N_2) as plant-available forms, the process is termed as biological nitrogen fixation (BNF) (Jangir et al. 2016). The BNF is accomplished by free-living bacteria (*Azotobacter, Beijerinckia, Clostridium,* etc.) or by symbiotic bacteria (*Rhizobium, Bradyrhizobium,* etc. with leguminous plants, and Azospirillum species with non-legume plants). Blue-green algae (*Anabaena, Nostoc, Cylindrospermum, Scytonema, Calothrix, Anabaenopsis, Mastigocladus, Fishcherella, Tolypothrix, Aulosira, Stigonema,* etc.) also fix the atmospheric N_2.

9.4.2.3 Plant Growth Promotion

Use of inorganic fertilizers and pesticides in agriculture has increased dramatically to produce more food for the growing population. Increased use of agrochemicals results reduced biodiversity, ill soil health, and degraded environment (Hole et al. 2005; Aktar et al. 2009). Plant growth-promoting microbes (PGPM) comprise rhizobacteria (PGPR) and fungi (PGPF) that might play vital roles to ensure agricultural and environmental sustainability. The PGPM regulates the plant growth promotion through several processes including BNF, solubilization of inorganic fixed phosphorus, production of siderophore, phytohormone and antibiotic, biocontrol of the disease-causing pathogens, nutrient uptake, etc. The important PGPR includes *Rhizobium, Pseudomonas*, *Azospirillum*, *Azotobacter*, *Erwinia, Enterobacter*, *Flavobacterium, Klebsiella*, *Alcaligenes*, *Bacillus*, *Arthrobacter*, *Burkholderia,* and *Serratia*. The species of *Aspergillus*, *Phoma*, *Fusarium*, *Trichoderma*, *Penicillium*, and arbuscular mycorrhizal fungi (AMF) are the most important PGPF.

9.4.2.4 Bioremediation

Industrial effluent discharge is an immoral anthropogenic activity that degrades soil health, air, and water quality. With the rapid urbanization and industrialization, there has been a considerable increase in the discharge of different types of wastewater to the environment. A good number of technologies have been established to handle the waste materials derived from various sources. The technological processes mainly include physical remediation, chemical remediation, phytoremediation, and microbial remediation. Many of the toxic elements embedded in waste materials could be degraded through bacterial and fungal metabolisms. The genera of *Bacillus, Streptomyces, Pseudomonas, Thiobacillus, Achromobacter, Acinetobacter, Nitrobacter, Alcaligenes, Flavobacterium,* and *Micrococcus* are important bacterial community participating in the bioremediation process of waste materials. Among the fungi, *Fusarium, Penicillium*, *Mucor, Pleurotus*, *Aspergillus*, *Trichoderma,* white rot mushrooms, AMF are recognized as efficient agents for bioremediation.

9.4.3 Chemical Properties

Soil is an environmental hub, where inherent compounds or elements and added inputs like fertilizers, pesticides undergo through a series of chemical transformation. Thus, nutrients are released to soil solution as available forms, which plants can absorb. Soil chemistry plays a pivotal role in nutrient dynamics in soil and crop productivity. All of the concepts of the soil ecology are largely controlled by its chemistry. The chemical phenomenon of soils includes nutrient elements and their compounds, OM, colloidal properties, soil reactions (pH), cation exchange capacity (CEC), buffering activity, etc.

9.4.3.1 Nutrient Elements

Solid fraction of soil is constituted by mineral and OM, which have a significant role on the source and availability of nutrient elements. Both primary and secondary minerals of the soil are the reservoir of nutrient elements. Feldspar, micas, illite are the main source of potassium (K) in soil. They also release a significant amount of calcium (Ca), magnesium (Mg), sodium (Na), iron (Fe), silicon (Si), copper (Cu), manganese (Mn), and several micronutrients. Amphiboles and pyroxene are the vital sinks of Mg, Fe, Ca, Si, and several other micronutrients. Phosphorus is released in soil from mineral apatite. Nitrogen comes in soil from organic sources such as protein, peptides, and amino acid. Nutrient elements are release in soil solution from the minerals through physical, chemical, and biological weathering process. All higher plants require 17 essential nutrient elements for completion of their life spans and metabolism (Havlin et al. 2005). Among which nine included as macronutrients (C, hydrogen (H), oxygen (O), N, P, K, Ca, Mg, and S) and rest eight comprised as micronutrients (chlorine (Cl), Fe, boron (B), zinc (Zn), Cu, molybdenum (Mo), and nickel (Ni). Additional four elements (Si, Na, cobalt (Co), and vanadium (Va), whose specific functions are not confirmed yet but their presence provide better yields in some plants. The structural elements C, H, O come from atmosphere and soil water, while all other elements derive from the soil as mineral nutrients (Parikh and James 2012).

9.4.3.2 Soil Organic Matter

Soil organic fractions consist of various stages of decomposed plant or animal tissue, microbial cells and tissues. Soil OM regulates the functions and quality of the soil. Soil OM governs all of its properties, and thus supports soil functions (Brady and Weil 1999). It provides numerous beneficial functions in the soil ecosystem. It improves soil aggregates, conserves water, increases biodiversity, reduces soil compaction, increases infiltration rate, buffering capacity, and nutrient dynamics. Soil organic matter improves soil fertility by providing exchangeable sites and acts as a major source of plant nutrients especially N, P, and S (Jangir et al. 2019). Soil OM is a major source and sink of OC and essence of soils. Fertility status of soil largely depends on OM content, while it acts as a revolving nutrient fund. Through the biochemical transformation and successive decomposition of OM, different nutrients are released to soil and finally the most reactive and stable product humus is derived. Humus is a colloidal particle, which plays an enormous role in the CEC and soil fertility. Peat is developed from un-decomposed plant tissue, while highly decomposed OM is known as muck. Soil OM contents in most of the topsoils range from 1 to 5%, which, however, decreases because of intensive agriculture with higher inorganic fertilizers and smaller amount or no organic fertilizer (Rahman et al. 2016; FRG 2018).

9.4.3.3 Soil Colloidal Properties

The most active part of the soil is its colloids, which takes part as a determinant of numerous physicochemical features. Soil consists of two types of colloids viz., inorganic (clay) and organic (humus). Predominantly most colloidal particles are negatively charged and these are active sites for chemical reactions and CEC of soil. The clay fractions of soil contain both non-colloidal and colloidal particles. Generally, clay minerals are hydrous aluminosilicates along with a noticeable amount of Fe, Ca, Mg, and Na. Clay colloid has higher water absorption and nutrient holding capacity, while humus has higher nutrient adsorptive capacity than clay colloids. Soil inherits clay colloid, while humus contents depend on soil and crop management activities. Conservation tillage coupled with residue retention and organic fertilizer addition increases humus colloid in soils.

9.4.3.4 Cation and Anion Exchange Capacity

The CEC of a soil is the measure of readily interchangeable cations that neutralize anions in the soil. It is the sum of total cations in the soil adsorption site. Soil colloidal particles clay and humus are negatively charged, which are developed during the soil formation process. They can attract or hold positively charged particles or cations. Replacement of one cation by another cation is termed as cation exchange, which makes soils capable of holding nutrients and preventing loss. The more CEC of a soil indicates the higher fertility level. Exchangeable cations in the soil maintain equilibrium between the exchange sites and soil solution (Osman

2013). The CEC varies with the type and size of ion, valance, concentration, and degree of hydration. The cation exchange in the exchange sites of a soil maintains the following order: Al^{3+} (aluminium) > H^+ > Ca^{2+} > Mg^{2+} > NH_4^+ > K^+ > Na^+. The texture, OM, clay type, and pH of soils affect the CEC. Clay soil has higher CEC than the sandy soil and 2:1 type clay mineral has higher CEC than that of 1:1 type clay mineral.

Like cation exchange, soil also shows anion exchange capacity (AEC). Replacement of adsorbed anions such as SO_4^{-2}, NO_3^-, Cl^-, HCO_3^- (bicarbonate), and $H_2PO_4^-$ (phosphate) by suitable anion is termed as anion exchange. The AEC in the exchangeable site maintains the relative order: OH^- (hydroxide) > $H_2PO_4^-$ > SO_4^{-2} > NO_3^- > Cl^- > HCO_3^-. Soil colloidal site is the place, where the anion exchange happened. Measurement of AEC is very important for proper management of problem soils such as acidic, saline and or alkaline soil.

9.4.3.5 Soil pH

Soil reaction or pH is termed as a master variable of chemistry due to its manifold impacts on soil properties (Hillel and Hatfield 2005). Acidity and alkalinity of soil are defined based on H^+ concentration in soil solution. Soil nutrient release, nutrient uptake, ionic toxicity, and microbial mobility are remarkably inclined to soil pH (Heggelund et al. 2014). The pH of agricultural soil ranges 6.0–7.5, which indicates that slightly acidic, neutral and slightly alkaline conditions are good for optimal nutrient availability, and thereby crop productivity. The solubility of macronutrients (N, P, K, Ca, Mg, S) plus Mo is restricted at low pH. In contrast, micronutrient availability (Cl, Fe, Zn, Cu) minus Mo is higher in low pH. Soil pH either lower (<5.5) or higher (>8.5) poses a great threat to global crop productivity due to providing a nutrient imbalance and ionic toxic atmosphere for the plant. Soil parent materials, weathering reaction, rainfall, irrigation water quality, OM, vegetation, and fertilization are considered as the major sources of variation of soil pH (Heggenstaller 2012).

9.4.3.6 Buffering Capacity

Acidification and alkalization pose a great threat to sustainable soil management and agricultural productivity. The extreme variation in soil pH can be minimized by increasing the buffering capacity of soils. The capacity of soil to neutralize pH change is termed as the buffering capacity of the soil. Organic matter and clay contents are the major agents responsible for such safeguarding capacity (Magdoff et al. 1987). Protonation and de-protonation of buffering agents reduce the pH change. Dissolution of aluminosilicate at low pH is considered as acid buffer mechanism, while at high pH calcium carbonate ($CaCO_3$) dissolution activates the buffering capacity of soils. Exchangeable sites of minerals and OM take part in buffering activity, as they are the source and sink of H^+ and OH^- ions. Organic matter displays buffering activity by releasing weak carboxylic and phenolic group, while such buffering depends on soil C contents and tillage practices (Weaver et al. 2004).

9.5 Effects of Amendments on Soil Properties

Organic amendments are a good source of nutrients, which further can improve soil aggregates, enhance nutrient dynamics, harbour microbial diversity and their activity (Antonious 2016). Organic amendments contain a significant amount of C, N, P, and K (Table 9.2). Application of such amendments to crop fields ensures the best use of available natural resources, which slowly release different nutrients to the soil and thus improve soil environment and reduce the requirement of inorganic fertilizers for crop production (Wilhelm et al. 2007).

Retention of crop residues in fields is an important resource conservation strategy, which enhances the physicochemical as well as biological parameters of soil health improvement. In several Asian countries, more especially in the south Asian region, crop residues are utilizing for different purposes such as fuel for cooking, animal fodder, and housing for the animal, fencing, etc. In the intensive production system, farmers remove crop residues from the harvested fields so that the fields become clear and suitable for the growing of next crop. Even the farmers burn the crop residues. However, the crop residue is a large source of OM that replenishes OC and nutrients in soils. Retention of crop residues in crop fields of Asia, Latin America, and Africa revealed that it improves soil quality, increases SOM and C stock, soil moisture content, improves nutrient transformation and decreased soil erosion (Turmel et al. 2015).

Soil is overwhelmingly the greatest natural resource, which is degraded as a result of various anthropogenic and natural activities all over the world. Depletion of soil fertility is considered as one of the vital factors that restrict increased crop production to feed the increasing population. Greater dependency on chemical fertilizers and

Table 9.2 Organic carbon, nitrogen, phosphorus, and potassium contents of different organic amendments

Amendment/manure	OC (%)	N (%)	P (%)	K (%)	References
Rice straw	–	0.5–0.8	0.07–0.12	1.16–1.66	Dobermann and Fairhurst (2002)
	36.2	–	–	–	Alam et al. (2019)
Cow dung (decomposed)	–	1.00	0.30	0.46	FRG (2018)
	13.8	–	–	–	Alam et al. (2019)
Poultry manure (decomposed)	–	1.25	0.70	0.95	FRG (2018)
	8.4	–	–	–	Alam et al. (2019)
Farmyard manure	–	1.60	0.83	1.70	FRG (2018)
Compost (rural)	–	0.75	0.60	1.00	FRG (2018)
Compost (urban)	–	1.5	0.60	1.50	FRG (2018)
Vermicompost	–	1.1	0.11	0.42	Akter et al. (2017)
	12.2	–	–	–	Alam et al. (2019)
Trichocompost	–	2.42	1.26	1.42	Akter et al. (2017)
Household waste compost	–	3.32	0.61	1.59	Smith and Jasim (2009)

imbalanced nutrient management practices without replenishment of OM for intensive crop cultivation, use of high biomass producing crops (e.g. maize), utilization of high yielding crop varieties, removal of crop residues from crop fields, use of less or no organic fertilizers, lack of crop rotation, etc. have created remarkable influences on soil nutrient removal and thus led to the deterioration of soil health and fertility and impaired the productivity of soils (Rahman 2013; Kumar et al. 2017; Sharma et al. 2019). As soil fertility is considered as an essential element for better crop cultivation, therefore, the improvement of fertility status is a must for crop productivity sustainably. Crop residues, CD, PM, farmyard manure, compost, and other manures available in the farm household could be considered as a good source of manure that can be applied to soils (Channabasavanna 2003) for achieving good soil properties to facilitate profitable crop production (Somani and Totawat 1996). Therefore, it is necessary to ensure the application of organic manures in combination with inorganic fertilizers in agriculture for sustainable soil health as well as better crop production. The effects of different organic amendments on soil properties are provided in Table 9.3.

9.5.1 Rice Straw

In a sustainable agricultural system, recycling of nutrients is the key to nutrient management (King 1990). Among different types of organic materials, the availability of rice straw is considerably high in almost all agricultural farms that can be added into the soil as a source of organic manure. It has been reported that rice straw contains different nutrients such as N (0.5–0.8%), P_2O_5 (0.16–0.27%), K_2O (1.4–2.0%), S (0.05–0.1%), and Si (4–7%) (Dobermann and Fairhurst 2002). Being good source plant nutrients, rice straw addition in the soil increases the yield as compared to the burning or removal of straw (around 0.4 t ha^{-1} per season), and the yield increases gradually due to the builds up of soil fertility with time (Ponnamperuma 1984).

It is noteworthy that considerable amount of nutrients up taken by the rice plant remains in vegetative plant parts (N 40%, P 30–35%, K 80–85%, and S 40–50%) at the maturity stage of the crop (Dobermann and Fairhurst 2002). Rice straw is also considered a significant source of micronutrients like Zn and Si. In many countries of the world, it is very common to remove the straw from the harvested field, which consequences the depletion of nutrients especially K and Si from the soil. Straw is removed from the field for different purposes such as cooking, animal fodder, animal bedding, the raw material for industry (for instance, paper making), etc. It is an efficient way to return most of the plant nutrients into the soil through the incorporation of straw and stubbles, which will ensure the conservation of soil nutrient reserves in the long term. Application of synthetic chemical fertilizers along with straw incorporation, the status of soil nutrients particularly N, K, P, and Si are maintained and may even be improved. So, it is revealed that RS is the best alternative to increase OM contents and decrease the bulk density of soil as well as to

Table 9.3 Effect of organic amendments on soil properties

Amendments	Soil properties	References
Rice straw	It decreases soil bulk density by 0.12 g cc^{-1}, and increases total porosity by 4%	Wen-Wei et al. (2011); Gui-mei et al. (2015)
	Rice straw incorporation in soil increases OM content by 1.18 g kg^{-1}, while N, P and K by 25.7, 25.7, and 3.7 mg kg^{-1}, respectively	
Cow dung	Application of 10 t ha^{-1} cow dung significantly increased OM, N, P, Ca, and Mg in soil as compared to the application of NPK fertilizers	Ewulo et al. (2007)
	Soil pH increased by 6.12, 8.16, and 10.20% with the addition of CD at the rate of 5, 7.5, and 10 t ha^{-1}, respectively, as compared to the control treatment	Zaman et al. (2017a)
Poultry manure	It increases the availability of Fe, Cu, Mn, Zn, and B in soils	Ghosh et al. (2004)
	Soil OM, total N, available P, and moisture content were increased but bulk density was decreased with the application of increasing rate of PM	Ewulo et al. (2008)
	After five rice growing season, soil pH increased by 15.34% because of application of PM at the rate of 2 t C ha^{-1} $season^{-1}$ compared to the control treatment	Rahman et al. (2016)
	Soil pH increased by 8.16, 12.26, and 18.36% with the addition of CD at the rate of 5, 7.5, and 10 t ha^{-1}, respectively, as compared to the control treatment	Zaman et al. (2017b)
	Poultry manure contributed to increase macroaggregates in soil by 4–6% as compared to inorganic fertilizer treatment	Hoover et al. (2019)
Farmyard manure	Application of FYM + NPK for three consecutive years increased soil OC by 41% compared to the initial value of 4.4 g kg^{-1}	Hati et al. (2006)
	Integrated use of FYM + NPK significantly decreased soil bulk density (9.3%), soil penetration resistance (42.6%), while increased hydraulic conductivity (95.8%), water-stable aggregates (13.8%), and OC (45.2%) compared to the control	Bandyopadhyay et al. (2010)
Compost	Continuous addition of compost for 5 years increased soil C and N by 2.02 and 0.24 t ha^{-1}, respectively	Whalen et al. (2008)
	The highest bacterial population was enumerated in vermicompost amended soil (55.19×10^5 CFU g^{-1} dry soil) followed by farmyard manure (54.26×10^5 CFU g^{-1} dry soil), whereas the lowest number was recorded in the control treatment (30.89×10^5 CFU g^{-1} dry soil)	Das and Dkhar (2011)

CFU Colony forming unit

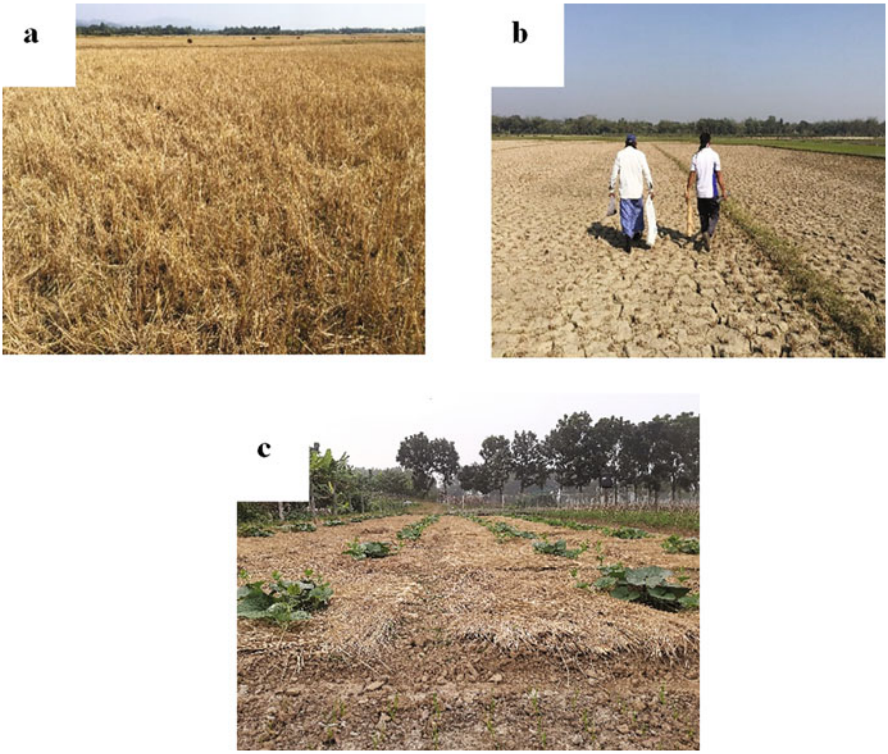

Fig. 9.4 Rice straw retention (**a**), removal (**b**), and mulch (**c**) in crop fields of Bangladesh (Photo courtesy (**a** & **b**): Dr. Alam, BARI, Bangladesh, and (**c**) Prof. Rahman, BSMRAU, Bangladesh)

sustain soil fertility (Table 9.3). Figure 9.4 shows RS retention (Fig. 9.4a), removal (Fig. 9.4b), and mulch (Fig. 9.4c) in different locations of Bangladesh.

Rice straw is considered as a vital source that improves the fertility status of soil by increasing organic matter content and improving soil moisture condition (Ruensuk et al. 2008). Moreover, incorporation of rice straw consequences better soil nutrient status increases soil biological activities, as well as soil fertility. It has been demonstrated that RS incorporation in soil could effectively improve the soil fertility and increase the OM content by 1.18 g kg^{-1} and N, P, and K by 25.7, 25.7, and 3.7 mg kg^{-1}, respectively (Gui-mei et al. 2015). Rice straw addition could also improve the physical properties of the soil. Rice straw significantly improved soil physical properties by reducing the soil bulk density by 0.12 g cc^{-1}, increasing total porosity and ventilation porosity by 4 and 6.8%, respectively (Wen-Wei et al. 2011).

Binte (2020) reported from a 5 years long field experiment that rice straw addition increases the porosity and decreases the bulk density of soil (Fig. 9.5). A long-term ongoing study using rice straw and other organic materials, which commenced in 1988 at BSMRAU research field of Bangladesh reveals that soil physicochemical properties greatly improves due to the addition of organic materials as compared to

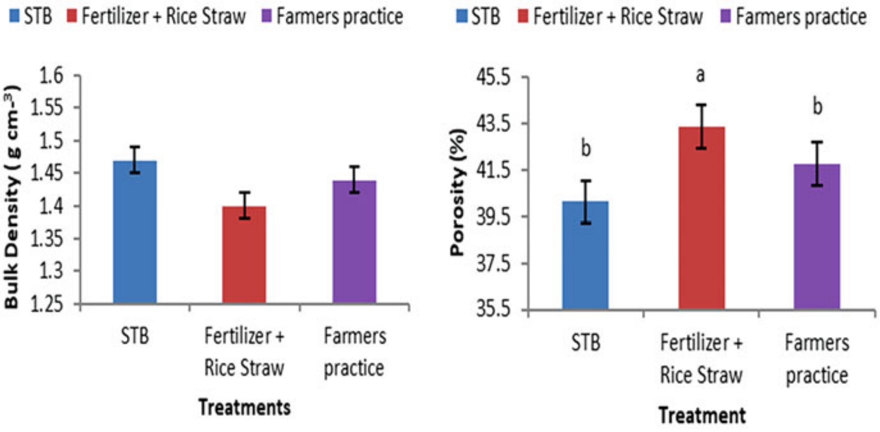

Fig. 9.5 Effects of rice straw on bulk density and porosity of soil (Adapted, Binte 2020)

Table 9.4 Effect of seasonal application of NPK and different organic fertilizers on soil (0–15 cm) chemical properties after 30 years (1988–2017) of cultivation (Unpublished data)

Treatments	Bd (g cc^{-1})	AS (%)	OC (%)	pH	CEC (cmol kg^{-1})	P (mg kg^{-1})
NPK	1.43	43.2	0.77	5.5	99.9	10.1
CD	1.38	55.9	1.14	5.8	119.8	17.5
CP	1.37	56.1	1.15	5.7	132.1	16.8
GM	1.39	53.8	1.08	5.7	135.0	17.2
RS	1.41	55.2	1.12	5.7	127.0	17.6
Control	1.45	42.1	0.84	5.5	94.6	7.7
LSD	0.03	3.75	0.24	0.3	13.96	2.84
CV (%)	1.2	4.0	12.7	2.9	6.5	10.7

CD cow dung, *CP* compost, *GM* green manure, *RS* rice straw, *Bd* bulk density, *AS* aggregates stability of 0.25 mm sized soils, *CEC* cation exchange capacity, *cmol kg^{-1}* centimole per kilogram, *mg kg^{-1}* milligrams per kilogram, different letters indicate significant differences among the values within a column

the sole inorganic fertilizer (NPK) and the control treatments in rice-wheat cropping pattern (Table 9.4). Data presented in Table 9.4 reveals that RS increases soil aggregate stability, OC, CEC, and P by 27.8, 45.5, 27.2, and 74.7%, respectively, compared to only inorganic fertilizer treatment.

Soil microbes play a crucial role in maintaining the soil fertility through participating in various soil processes including nutrient cycling, N fixation, and nitrification process. Better soil microbial diversity is considered as an indicator of healthy soil (Watts et al. 2010; Tautges et al. 2016). It has been demonstrated that addition of RS in the soil increases the number of microbes especially bacteria, actinomycetes, and bacteria/fungi more than two-fold, while the fungal population decreased approximately by 50% (Zhang et al. 2018). Moreover, RS addition had positive effects on soil OC, dehydrogenase activity, microbial biomass C as well as diversity (Goyal et al. 2009; Zhang et al. 2018). Straw is rich in readily available C (Zhang et al. 2018) which might be utilized by the microbes as an energy source. Therefore, straw incorporation enhances the microbial population in the soil.

9.5.2 Cow Dung

The application of organic manures including different animal manures in the soil is the prime need for maintaining soil fertility status for sustainable agriculture. Cow dung is an important resource that has tremendous beneficial effects for improving the soil properties. Cow dung is a traditional source of crop nutrients all over the world more specifically in the Asian and African countries, which not only increase the crop production but also ensure better soil quality. It is a mixture of faeces and urine of herbivorous bovine animals, which consist of lignin, cellulose, and hemicelluloses as major components. It contains most of the plant nutrients, for example, N, P, S, Fe, Mg, Cu, Co, and Mn (Gupta et al. 2016). It has been demonstrated that the CD derived from indigenous Indian cow contains a higher amount of P, Ca, Zn, and Cu compared to the cross-breed cow manure (Randhawa and Kullar 2011).

Experimental results indicated that application of CD in combination with NPK fertilizer improved soil organic matter, available phosphorus, exchangeable cations, CEC and base saturation (Stanley 2010). Application of CD increases soil pH, OM, N, P, Ca, and Mg contents in soil (Table 9.3). Results also show that the application of CD increases porosity, moisture content, and decreases the bulk density, temperature, and dispersion ratio of soil compared to no manure application (Adekiya et al. 2016). Hydraulic conductivity and aggregate stability could also be increased significantly with the application of CD in soil (Nweke and Nsoanya 2015). It has been reported that CD increases soil aggregate stability, OC, CEC, and P by 29.4, 48.1, 20.0, and 74.0%, respectively, compared to only inorganic fertilizer treatment (Table 9.4). Addition of CD considerably improved soil respiration indicating higher microbial activity (Adebola et al. 2017; Meena et al. 2020c). Cow dung addition also increased the microbial biomass C. This suggests that OC derived from CD were utilized by the soil microorganisms and thus promotes the microbial growth.

Cow dung harbours a greater extent of microbial diversity including different species of bacteria and fungi. Experimental results demonstrated broad ranges of microorganisms in CD such as *Bacillus*, *Acinetobacter*, *Serratia, Pseudomonas*, and *Alcaligenes* spp., which are very effective to improve the polluted soils through the degradation of pollutants (Adebusoye et al. 2007; Umanu et al. 2013). Furthermore, bacterial isolates such as *Bacillus*, *Pseudomonas*, *Citrobacter*, *Vibrio*, *Micrococcus*, *Flavobacterium,* etc., and fungal isolates such as *Aspergillus*, *Fusarium*, *Rhizopus*, *Penicillium*, *Mucor,* etc. isolated from CD dramatically improved the petroleum polluted mangrove soil (Orji et al. 2012). Hence, the CD might play a vital role in the improvement of polluted soils. It implies that CD is a valuable natural resource that can significantly improve soil properties. A significant portion of the produced dung is not added to the soil due to use in other purposes like burning for cooking purpose. However, the scenario might be changed through increasing awareness of the rural farmers regarding the importance of soil health as well as providing alternate fuel source to the rural women.

9.5.3 Poultry Manure

Poultry manure is also a vital organic fertilizer that has been using traditionally in crop field for maintaining soil fertility and better crop production all over the world. This manure is originated mainly from the faeces along with urine and bedding material of the poultry birds (Rahman et al. 2020). Globally, the poultry sector is growing rapidly to fulfil the increasing requirement of the growing population. Therefore, a huge quantity of poultry litter is generated every year from a large number of poultry birds. Poultry litter may cause health and environmental hazards due to the lacking of proper management techniques. Utilization of the poultry litter as organic manure in agriculture is profitable as well as environmentally friendly.

Poultry manure is a good source of OM that contains a substantial amount of primary essential nutrients like 1.25% N, 0.7% P, and 0.95% K (FRG 2018), and other essential plant nutrients that are highly available for plant utilization in comparison with other organic fertilizers (Garg and Bahla 2008; Mohamed et al. 2010). Information provided in Table 9.3 revealed that PM could increase the availability of micronutrients Fe, Cu, Mn, Zn, and B, and soil pH (Ghosh et al. 2004; Rahman et al. 2016), and soil macroaggregates by 4–6% as compared to inorganic fertilizer treatment (Hoover et al. 2019). Availability of nutrients in the soil is largely dependent on soil pH. It has been demonstrated that pH value varying from 5.5 to 7.0 is comparatively satisfactory for the availability of most of the plant nutrients (Brady and Weil 2014). Long-term application of inorganic fertilizers decreases the pH value in comparison with the combined application of organic manures and inorganic fertilizers (Ge et al. 2018). On the contrary, PM has a liming effect as it increases the soil pH (Mullens et al. 2002; Rahman et al. 2016), which might be due to the presence of a significant amount of liming materials like $CaCO_3$ in poultry feed. Therefore, in acid soil, PM is a good source of organic manure for the correction of soil acidity as well as to improve the fertility status of the soil.

Poultry manure contributes a significant amount of OC in the soil, thus improve the soil properties through the improvement of soil structure, aggregate stability, WHC, soil aeration, buffering against sudden change of the soil pH, CEC as well as soil microbial activities (Bauer and Black 1992). Organic matter that derived from various sources of organic materials is a rich pool of supplying essential plant nutrients to the soil (FAO 2005). Nutrient availability in soil is basically reliant on its better physicochemical and biological properties. Application of PM enhances chemical properties of soil, for example, it increases OC, N, K, P, Mg, and Ca contents in soil (Agbede et al. 2008; Soremi et al. 2017). Similarly, physical properties of soil were improved with the addition of PM in the soil, for instance, it reduces bulk density, increases porosity & moisture status of soil, decreases soil temperature (Ewulo et al. 2008; Agbede et al. 2008), increases infiltration rate at clay loam soil, while decreases the infiltration rate at sandy clay loam textured soil (Adeyemo et al. 2019). Poultry manure not only improves the physicochemical properties but also contributes to soil biological characteristics. Research findings documented that application of PM as organic waste increases microbial biomass, enzyme activities, and microbial quotients in soil (Kaur et al. 2005; Tejada et al. 2006). Poultry manure increases the bacterial population in the soil, which may enhance the fertility status of soil (Maguire et al. 2006). Bacterial diversity based on species richness and evenness was considerably better in soils that received PM in comparison with the sole application of inorganic fertilizers (Jangid et al. 2008). Therefore, the addition of PM in the soil as an organic fertilizer has great potentialities to enhance the fertility status of soil through the improvement of soil biological as well as physical and chemical properties.

9.5.4 Farmyard Manure

It is one of the important as well as older organic manures applied by the farmers traditionally to the agricultural fields to grow crops especially the horticultural crops due to its higher availability and nutrient supply ability to the crops. Farmyard manure comprises the solid and liquid animal excreta (animal dung and urine), the residual part of the animal fodder and the used bedding material of the animals (Rahman et al. 2020). As organic manure, FYM has the great potentialities to provide all essential primary and secondary plant nutrients, i.e., N, K, P, Mg, Ca, and S as well as some essential micronutrients like Mn, Cu, Fe, and Zn (Meena et al. 2018). Amendment of FYM in the soil increases its nutrient status (N, P, K) (Meena et al. 2018), and therefore, fertility status of the soil improves. The SOC indicates the soil quality, which is directly associated with cycling plant nutrients and improvement of soil properties. Addition of FYM along with a recommended dose of synthetic NPK fertilizers (NPK + FYM) for three successive years improved the soil OC content from the original value of 4.4 g kg^{-1} to 6.2 g kg^{-1} (Hati et al. 2006). Soil OC content directly administers the structural stability of the soil. Soil amendments with FYM manure ensure the improvement of OM, pH, and hydraulic conductivity that provides a better soil environment (Table 9.3).

Sole amendment of FYM in soil or amended with synthetic fertilizers ensure a higher percentage of water-stable aggregates enhanced saturated hydraulic conductivity, improved soil porosity, decreased soil bulk density and soil penetration resistance (Hati et al. 2006; Bandyopadhyay et al. 2010; Meena et al. 2018). Increased porosity of the surface layer of the soil provides better aeration and thereby promotes healthier root growth in soil. Addition of FYM also favour the physical properties of problem soils, for instance, bulk density, porosity, void ratio, water permeability, and hydraulic conductivity of a saline-sodic soil was considerably improved when farmyard manure at a rate of 10 t ha^{-1} was added in conjunction with chemical amendments (Hussain et al. 2001). Soil amendment with FYM improves the soil biological properties as FYM provide a higher amount of OC, which favour increased microbial activity. Experimental results reveal that application of FYM significantly increases microbial biomass, dehydrogenase activity, earthworm community composition, and earthworm cast production in the soil as compared to the soil that received no FYM (Zaller and Kopke 2004).

9.5.5 Compost

Compost is ecologically sound organic manure that improves soil quality as well as reduces the environmental hazards arising from different waste materials generated in both rural and urban areas. Compost is prepared through the decomposition of different organic residues including household waste materials, any plant residues, animal waste, wood waste, industrial waste, municipal waste, etc. Waste materials should be selected carefully for the preparation of compost so that toxic elements remain below the allowable limits. Application of compost in soil favourably enhances the physicochemical as well as biological properties of soil (Table 9.3). Compost application significantly increases the amount of soil OC (Whalen et al. 2008), which directly enhances the soil properties. Organic matter ensures better soil structure through its binding effect as well as enhanced root development and biological activity (Farrell and Jones 2009; Gao et al. 2010). Compost derived from various sources improves soil water retention ability, thus increasing the availability of water to the plants (Farrell and Jones 2009). Results obtained from a field experiment demonstrated 58–86% increase of available soil water content due to the application of cattle manure compost (Celik et al. 2004), which might be due to the improvement of macro and microporosity of the soil. Therefore, the application of organic manure, especially the composted manure in arid and semi-arid areas could be vital to conserve water over the crop growing season. Moreover, compost application could improve the drainage capacity, aeration, and aggregate stability of soil (Avnimelech et al. 1990; Duong et al. 2012). Compost application significantly alters the bulk density of soil. Soil bulk density decreases gradually by the application of an increasing amount of compost (Brown and Cotton 2011). Lower soil bulk density might be due to the increased pore space, which indicates the improvement in soil tilth.

Compost not only provide a considerable amount of plant nutrients but also decreases the leaching loss of nutrients (Hepperly et al. 2009), reduces erosion, and evaporation. Soil amendments of compost appreciably increase the nutrient status of soil, even after several years of application (Butler et al. 2008). Compost increases soil pH, aggregate stability, OC, and P by 13, 29.9, 49.4, 32.2, and 66.5%, respectively, and decreases soil bulk density by 13.4% compared to sole fertilizer treatment (Table 9.5). Effects of compost on soil pH rely on the raw material from, which the manure has been prepared. Application of chicken litter compost results in an increase of soil pH (Hubbard et al. 2008), which might be due to the basic cations associated with the poultry feed. Decrease of soil pH was also reported with the addition of compost prepared from rice straw and waste materials derived from various agro-industries, which might be as a result of the release of different organic

Table 9.5 Tillage operations and their effects on soil properties and crop yields

Tillage	Effects on soil properties and crop yields	References
No-till	In a study of maize (*Zea mays*) and maize with soybean (*Glycine max*) in the USA it was found that no-till system reduces N_2O emission by 40, and 57% compared to moldboard and chisel plough, respectively	Omonode et al. (2011)
	About 70% of energy and fuel can be saved in the no-till system compared to TT	Friedrich and Kassam (2012)
	A 41-year study in France indicated that no-till system did not increase soil C stock	Dimassi et al. (2014)
	No-till with residue holding increased N_2O emission by 82.1% from paddy fields in China	Zhao et al. (2016)
	In a four-year study in Bangladesh, it was found that total C stock in soil increased by 28 and 27% in no-till under wheat (*Triticum aestivum*)-dhaincha (*Sesbania grandiflora*)-rice and wheat-mungbean (*Vigna radiata*)-rice, respectively	Alam et al. (2017)
Reduced tillage	In Australia, wheat yields were found 7.9 and 8.0 t ha^{-1} under RT and TT, respectively	Akbarnia et al. (2010)
	Reduced wheat yield by 67% compared to TT in Germany	Zikeli and Gruber (2017)
Strip tillage	Soil saturated hydraulic conductivity was found 23–138% higher in strip tillage compared to TT	Jabro et al. (2011)
	After 6 years of strip tillage, bacteria and fungi in soil increased by 27 and 37%, respectively compared to TT	Leskovar et al. (2016)
Ridge tillage	A 29-year study unveiled that ridge tillage contributed to higher soil C in the crests and lower in the inter-rows compared to no-till	Shi et al. (2012)
Traditional tillage	From a total of 78 studies comprising no-till and TT across the world, 40 studies showed lower C stock in TT	Govaerts et al. (2009)
	A 10-year study in Inner Mongolia indicated that soil OC, total N and Olsen P decreased by 19, 27 and 21%, respectively in TT compared to no-till with straw cover	He et al. (2009)

acids and release of H^+ during nitrification process (Bolan and Hedley 2003; Rashad et al. 2011). Cation exchange capacity is closely related to the nutrient retention capacity of the soil, and thus play a vital role in the evaluation of soil fertility. The higher CEC prevents the leaching loss of cations into the groundwater. It has been reported that compost application increases the CEC of soil (Agegnehu et al. 2014), which might be attributed as good quality composts provide stabilized organic matter in the soil, which includes various functional groups.

Soil organisms perform a considerable role in preserving soil fertility by regulating the physicochemical properties of soil. Soil microbes like fungi, bacteria, algae, and actinomycetes demonstrate significant contribution in OM decomposition, nutrient cycling and important chemical transformations in soil (Murphy et al. 2007). Biological functioning of soil largely depends on available C content in the soil. The activities of the microbes in soil increase due to the application of composted material. Microbial activity was more than two times higher in compost applied soils as compared to the un-amended soils (Brown and Cotton 2011). Compost amendment results in higher earthworm and microbial biomass, increased mycorrhizal root colonization and higher microbial diversity in soil (Paul 2003). Long-term compost amendment improves soil biological characteristics such as several microbes, biomass C and nitrogen, soil respiration, and enzymatic activities (Chang et al. 2014). Thus, compost amendment in the soil might play an important role in improving soil fertility as well as soil health.

9.6 Tillage Practices and Soil Properties

Soil tillage is widely used traditional cultivation practice employed before sowing seeds or planting saplings. It is done to make the soil suitable for seed germination, crop production and used to mix crop residues and fertilizers in soils, and control weeds in crop fields. However, tillage impacts the soil quality through physical disruption, which brings changes in soil C and water contents, soil structure, diversity of the microbial population, and nutrient dynamics (Wang et al. 2016; He et al. 2019; Meena et al. 2020b). Traditional tillage greatly disturbs soils through more and deep ploughing, which caused for deterioration in soil quality through nutrient depletion and erosion, increasing cost of production and energy use, and contributing to greenhouse gases (GHGs) emissions (Hobbs 2007). On the other hand, conservation tillage viz. no-till, reduced tillage (RT), etc. develops soil structure, improves soil health, and sustains its quality. No-till and reduced tillage reduces GHGs emissions and C footprint of a crop and mitigates the negative effects of climate change (Van den Putte et al. 2010; He et al. 2019). Effects of different types of tillage practices on soil properties and crop yields are shown in Table 9.5.

9.6.1 No-Till/Zero Tillage

No-till or direct seeding is an approach of cultivating crops or grassland without ploughing down the soil using tillage equipment. In the no-till system of crop cultivation, seeds are sown directly into the soil, where the residue is spread over the land surface that has not been tilled (MDA 2011). The previous year's crops or residues are cut down and spread on the topsoil before sowing seeds. After spreading of crop residues on the soil surface, a no-till planter is used that slightly punctures the soil to sow seeds. The no-till cultivation system is commonly used in a big commercial farm using larger implements. Small scale farmers usually go for the no-till system by hand. Under the no-till farming system, incorporation of crop residues into the soil by tools/machinery is avoided but distributed evenly on the soil of the crop field (Kakraliya et al. 2018; Meena et al. 2018). No-till is one of the forms of CA that encompasses least soil distraction, residue mulch, and crop rotation (Campbell-Nelson 2019). Such farming is a win-win technology that reduces labour, irrigation, fuel, and machinery costs, while reduces soil erosion, increases soil C sequestration, reduces GHGs emission, improves soil health, and finally attributed to

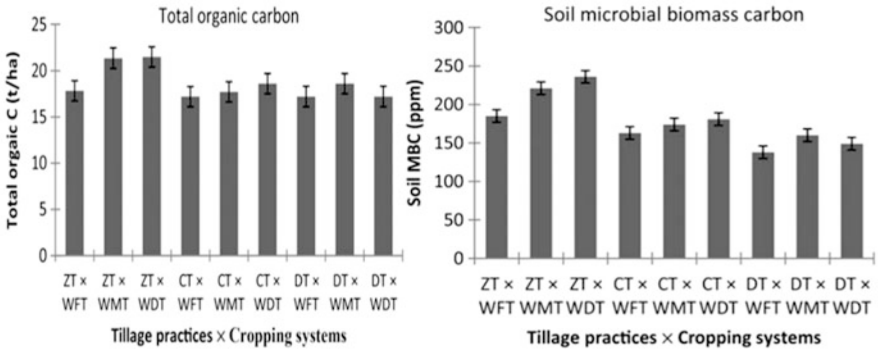

Fig. 9.6 Tillage and cropping patterns on total soil organic carbon (SOC) and microbial biomass C after 4 years of cropping (*ZT* zero tillage, *CT* conventional tillage, *DT* deep tillage, *WFT* wheat-fallow-T. aman, *WMT* wheat-mungbean-T. aman, *WDT* wheat-dhaincha-T. aman) (Adapted, Alam et al. 2017)

higher crop yields (Derpsch et al. 2010). A longer time is obligatory to get the positive results of no-till on yields of crops in wetter condition, however, in moisture limiting drier areas its effect is quick and obvious (Kimble et al. 2007).

A viable and sustainable cropping system comprises no-till, MT, crop rotation, and residue retention. Such a system increases microbial biomass, their abundance and activities in soils compared with traditional agricultural practices. After 4-years of cropping with tillage and crop rotation, Alam et al. (2017) identified a higher amount of OC and biomass C in zero tillage (Fig. 9.6). Contradiction also exists that no-till system may or may not increase C stock in soil, but it is confirmed that it reduces fuel and energy costs (Table 9.5). Adoption of no-till coupled with residue retention and cover crops makes situations promising for the progress of ecological stability and agricultural sustainability. It is stated that practising no-till or reduced tillage devoid of crop residue retention and cover crops long time may result in degraded soil with ill health that pushes the agricultural production and environment towards vulnerable conditions (Govaerts et al. 2007).

No-till alone increased soil aggregates, bulk density, C, and other nutrients in soils than that of TT, while no-till coupled with cover crops and residue retention provides further benefits to soil health management (Valpassos et al. 2001; Mitchell et al. 2017). Valpassos et al. (2001) conveyed that 8 years old no-till with continuous crop rotation with bean, corn, soybean, and dark-oat increased soil OM, biomass C, pH, and P content compared to 10-years old conventional cultivation with crop residue application and crop rotation in Brazil (Table 9.6).

It is evinced that adoption of only one novel technology would not enough to sustain the long-term agricultural production. Location-specific a set of synergistic viable technologies should be selected and recommended for better soil management and higher crop productivity. Adoption of no-till cropping system may offer a huge economic, environmental, and social benefit. Therefore, no-till technology along with other suitable technologies is gaining popularity across the globe. The area

Table 9.6 Physical, chemical, and microbial properties of soil under different management options

Soil management	Soil properties under different management				
	Bulk density (g cc^{-1})	Organic matter (g kg^{-1})	pH	Phosphorus (mg kg^{-1})	Biomass C (mg kg^{-1})
No-tillage	1.32b	42.52a	5.31	35.26a	469.14a
Cerrado	1.18d	30.57b	3.98	6.86c	347.91ab
Conventional	1.26c	24.15c	5.13	16.18a	315.47ab
Pasture	1.60a	22.86c	5.07	10.16b	213.03b

Bd bulk density, *OM* organic matter, *P* phosphorus (Adapted, Valpassos et al. 2001)

under the no-till method is increasing globally with the advancement of time. Derpsch et al. (2010) reported that the no-till farming area was 45, 75, and 111 million ha in 1999, 2003, and 2009, respectively, with a corresponding growth rate of six million ha year^{-1}. The maximum adoption rates of no-till technology have been observed in different South American countries, where some countries have been using the technology on roughly 70% of the total agricultural land (Derpsch et al. 2010). It has been reported that about 62–92% of farmers in Australia practiced no-till farming on 73–96% of their crop fields (Kirkegaard et al. 2014). Such encouraging spreading of the promising no-till practice in agriculture indicates the great compliance of the systems to all climatic and edaphic conditions of the world.

No-till practice emits generally less carbon dioxide (CO_2) due to less disturbance in soil and slower mineralization of OM and fertilizers. Jia et al. (2016) conducted a study in China using maize-corn rotation and found that overall CO_2 emissions under no-till were about 7.8% lower compared to moldboard plough. Regarding N_2O emission, such a statement is not straightforward, where denitrification is more pronounced in the no-till system compared to the tilled system. However, N_2O emission from croplands depends on different cropping systems, soil types, soil and crop management practices. Rochette (2008) stated that average nitrous oxide (N_2O) emissions from a no-till system of well-drained soil were 0.06 kg N ha^{-1} lower than that of tilled soil, while in medium and poorly drained soils were 0.12 and 2.00 kg N ha^{-1} higher, respectively. In a long-term study of maize and maize with soybean in the USA established that no-till system reduces N_2O emission by 40, and 57% compared to moldboard and chisel plough, respectively (Omonode et al. 2011). Likewise, no-till with residue holding increased N_2O emission by 82.1% from paddy fields in China, while no-till with residue removal decreased methane (CH_4) emission by 30% than that of traditional tillage practice (Zhao et al. 2016). Tillage in some cases is also found unresponsive to release N_2O from crop fields (Elmi et al. 2003).

The no-till practice may increase soil C sequestration through reducing CO_2 emission, reduce synthetic nitrogen fertilizer application, irrigation water, and fossil fuel for crop production. Therefore, the cost of crop production under no-till reduces, and so farmers will be economically benefitted. The no-till practice saves time, improves soil health, which leads to additional economic and environmental benefits. Continuous adoption of no-till farming for several years makes the soil capable to hold more water than conventionally ploughed croplands mostly in drought-prone areas. No-till implementation decreases soil loss because of wind and rain actions. Once more, it improves soil aggregation and increases C sequestration thus lessen the effects of warming of our planet (Grandy et al. 2006).

The main constraints to adopting no-till practice are unavailability of know-how including equipment and machines, traditional mindset of farmers, inadequate government policy, and unavailability of suitable weedicides for weed management (Gattinger et al. 2011; Jat et al. 2014; Farooq and Siddique 2014). *The weed management* under the no-till system is a concern and challenge. A longer time is needed to get the stabilized action of no-till on crop harvest and health improvement of the submerged soil, which is another drawback for the adoption of this technology. However, all these barriers can be removed locally mainly creating awareness among stakeholders and changing government policy. It is positive that many international and national organizations including Food and Agriculture Organization (FAO), International Fund for Agricultural Development, World Bank, European Union, French Agricultural Research Centre for International Development, Consultative Group on International Agricultural Research, Government and Non-Government Organizations are working and advocating in favour of no-till CA.

9.6.2 Minimum/Reduced Tillage

It is a resource conservation strategy in agriculture, where at least 30% of the field surface is covered by crop residues after planting. Reduced tillage (RT) contributes to reducing erosion of soil by water and wind (Laryea et al. 1991). In this crop cultivation practice, the soil is conserved allowing minimum disturbance and keeping residues spread on the ground instead of removing or incorporating into the soil. Reduced tillage is synonymous with minimum-till, strip-till, zone-till, ridge-till, no-till or permanent-bed systems (Campbell-Nelson 2019). Reduced tillage can be implemented on farms swapping from moldboard ploughs, disk-harrows, and rototillers to using less impactful tools like chisel ploughs, s-tine cultivators, and spaders. Practicing RT several years may progress towards zero tillage. Reduced tillage is a suitable tool in the conventional farming system that prevents soil degradation, improves soil structures, increases ecosystem services, and decreases production costs (Derpsch et al. 2010). It has a huge prospect to increase and sustain crop yields, improve soil fertility and increase C stock in soils (Zikeli et al. 2013). Researchers also reported reduced yields of several crops under RT compared to TT (Tables 9.5 and 9.7). Reduced tillage improves biodiversity and ecosystems and thus it has immense environmental benefits. It improves soil bio-physicochemical characteristics, restores soil health, and resolves the problems associated with excess tillage and finally mitigates negative effects of climate change.

Reduced tillage was found effective in preventing faster mineralization of SOM, which contributed to more C accumulation in soil and lower the rates of CO_2 and other GHGs emissions (Hafeez-ur-Rehman et al. 2015; Rahman et al. 2017). A study

Table 9.7 Results of reduced (RT) and traditional tillage (TT) practices on CO_2 emission, soil properties and rice yield

Treatment	Tillage practices on CO_2 emission, soil bulk density and rice yield			
	CO_2 emission (kg ha^{-1} day^{-1})	C accumulation (kg ha^{-1})	Bulk density (g cc^{-1})	Grain yield (t ha^{-1})
RT	33.92b	3813a	1.35a	5.83
TT	64.77a	1980b	1.31b	6.05
S.E. (±)	0.95	320	0.014	0.19

(Adapted, Rahman et al. 2017)

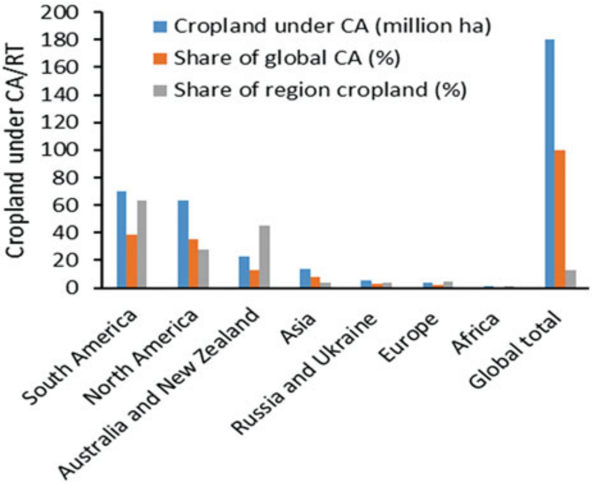

Fig. 9.7 Estimated use of conservation agriculture (CA) and by implication reduced tillage across the region during 2015–16 (Modified, Kassam et al. 2019)

of RT (2 times ploughing) and traditional tillage (TT) (4 times ploughing by a country plough), which was conducted in Bangladesh by Rahman et al. (2017) in four consecutive rice seasons revealed that RT contributed to less CO_2 emission, higher C accumulation, higher soil bulk density, and less rice yield compared to TT (Table 9.7). Reduced tillage is important from the perspective of environmentally safe gourd because crop residues help to prevent soil erosion caused by water and air and thus conserves fertile agricultural soils. Reduced tillage reduces field preparation time by 66% and reduces energy use when compared with conventional tillage (Jarvis and Woolford 2017). Thus, it provides benefits through energy-saving and soil conservation, which may attract farmers' interest in implementing RT.

The RT is getting popularity around the globe because of higher factor productivity of production inputs, increased outputs, lower production costs, better profitability, greater resilience to stresses, minimum land degradation, soil health improvement, climate change adaptation and mitigation. It is reported that over 180 million ha of croplands are under CA and RT across the globe (Fig. 9.7). It is evinced from Fig. 9.7 that America and Australia are the pioneers in adopting CA and RT, while shares of Asia, Africa, and Europe are minimal. In the Indo-Gangetic

Plains, the area under CA is about five million ha, which is insignificant about world coverage (Hafeez-ur-Rehman et al. 2015).

The main barrier of adoption of RT in crop cultivation is the mindset of farmers, where they believe that more tillage, i.e. *traditional tillage provides more crop yields. Moreover, RT increases the abundance of diseases, pest and weed infestations in crops* (Carr et al. 2012; Lehnhoff et al. 2017). Hofmeijer et al. (2019) *reported that RT increases weed infestation by 15–18%. Suitable seeding and planting equipment are lacking in the South Asian countries, which also acts as barriers of RT adoption. Farmers' motivation through training, education, social campaign,* etc. *are suggested to change their mindset in adopting RT. Establishment of industries for manufacturing of seeding and planting equipment and better solution of pest control measures may help in the adoption of RT.* The greater weed pressure especially perennial weeds under RT demands effective know-how to get rid of weeds. Selective biodegradable herbicides and organisms are recommended for a wider practice of RT in crop production. Technical and financial supports from governments, donor agencies, and international organizations are needed especially in Asia and Africa for the adoption of RT.

9.6.3 Strip Tillage

Strip tillage is one of the types of soil conservation approaches combined with zero-tillage and full-width tillage. It maintains lesser till than the full-width tillage and performs parallel to the row direction. One-fourth of the plough layer is generally being disturbed by this tillage practice. In strip-tillage soil is loosened in the tilled strips leaving the remaining area undisturbed. In this technique, narrow space cultivated and seeds are sown and fertilization is done simultaneously. In strip-tillage technique, 25–30% surface area is tilled in strip maintaining strip wide range 10–30 cm and leaving the undisturbed area between the strips varies 40–100 cm based on plant type (Al-kaisi and Yin 2005; ASAE 2013). This tillage technique is suitable for row-crops such as corn, and sunflower. By lowering the equipment and number of tillage frequency, it can conserve the soil. Strip tillage may conserve a relatively higher amount of crop residue within the strip that helps to reduce soil erosion loss (Licht and Al-Kaisi 2005). This tillage technique increases OM and nutrients in the soil and effectively control soil erosion. The soil in the strip-tillage is comparatively warmer and softer as well as less compacted than that of no-till (Cruse 2002).

Strips tilling conserve the soil water by increasing the infiltration rate of dryland agricultural soil. Organic residue in the undisturbed strip spaces reduces evaporation rate and rain flash impact. Compared to conventional tillage, strip tillage activity reduces the surface runoff approximately by 81% (Bosch et al. 2005). Strip tillage has been associated with partial soil coverage by different residual mulch, and thus preserves soil moisture. With an increase of strip width soil moisture content decreases and temperature of surface soil (5 cm depth) increases by 1–1.4 °C (Celik et al. 2013). The insulating capacity of organic residue of the strip space has significant effects on soil temperature and reduces soil dryness in spring. Strip tillage shows comparatively higher thermal conductivity due to lowering soil alteration and creating less air pocket (Licht and Al-Kaisi 2005).

Cultivation practices may considerably affect the soil structure, consistency, clod, plough pan formation, aeration, bulk density, resistance, and ground coverage (Simmons 1992). Compared to no-till and MT, strip-tillage gives lower root penetration resistant (Trevini et al. 2013). Strip tillage provides more lager size clods than that of MT due to the slow pass of strip-tiller. Strip tillage results in comparatively lower bulk density at different depth of soils due to higher OM accumulation. Moreover, compared to TT, strip-tillage provides less soil compaction by lesser frequency of traffic pass probably facilitate higher porosity, higher aggregation and WHC, and lower bulk density (Licht and Al-Kaisi 2005; Jabro et al. 2009).

Soil aggregation and its stability are affected by strip tillage. Juskulska (2019) reported that five-year intensive strip-tillage showed 57.5 and 26.7% more water-stable aggregates compared to conventional plough and plough-less cultivation, respectively. Lesser excavation, limited agricultural machinery use and greater protection of plant of residue technique of strip tillage help to augment soil aggregation (Laufer et al. 2016). Jabro et al. (2009) conveyed the message that strip-tillage ensures 23–138% higher saturated hydraulic conductivity than conventional one at 0–15 cm soil depth (Table 9.5). Strip tillage produces a greater volume of macrospore with more vertical pore connectivity, resulting in lesser bulk density and soil compaction and higher porosity indicate more saturated hydraulic conductivity (Lipiec et al. 2005; Jabro et al. 2009).

According to Juskulska (2019) five-year strip-tillage empirical data also ascribed that compared to conventional plough, strip-till technology increased OC, P, K, Mg in soils by 6.2, 11.7, 4.6, and 4.9%, respectively. Strip tillage helps to accumulate more OM in the surface soil (Awale et al. 2013). Mineralization of OM is affected by different tillage practices. Strip tillage is considered as eco-friendly soil management practice as it reduces CO_2 emission from soil (Reicosky 1998). Strip tillage reduces 19–41% CO_2 emission from agricultural soil to the atmosphere compared to moldboard tillage (Al-kaisi and Yin 2005).

Biological activity of soil is also greatly affected by the strip-tillage due to higher OM accumulation (Table 9.5). Data from a 6-year study elucidates that strip-tillage significantly increases the bacteria, fungi, and nematode population by 49, 37, and 275%, respectively, in a watermelon field (Leskovar et al. 2016). Lower alteration of topsoil helps to accelerate the microbial population microbial abundance in soil under strip tillage compared to conventional and plough-less cultivation. The long-term strip-till vegetable field also in strip-tillage (Sengupta and Dick 2015). Juskulska (2019) reported an increased number of nematode and earthworm than that of conventional moldboard plough cultivation (Overstreet et al. 2010).

9.6.4 Ridge Tillage

Ridge tillage was introduced in the early 1980s and widely accepted throughout the world with several modifications. The ridge tillage technique is a transitional development of moldboard plough tillage (MP) and no-tillage. Ridge tillage is characterized by permanent row-inter-row alignment, in which ridge is built above the planted row by cultivation (Gregorich et al. 2001). Ridge is raised above the mean land surface level and the technique has included three distinct zonal cultivation systems such as ridge centres, ridge shoulders, and inter-rows. Ridge inter-rows are maintained in the same locations every year.

Numerous empirical data summarizes that compared to no-till and MP, ridge tillage provides more soil fertility, water retention, and pest management control option (Jiang and De-Ti 2009), reduces soil erosion, decreases GHGs (Patino-Zuniga et al. 2009), increases SOC and temperature (Shao et al. 2009; He et al. 2010). Conversely, ridge tillage enhances higher P loss and soil bulk density in the surface soil compared to MP (Pikul Jr et al. 2001). Shi et al. (2012) found that Ridge tillage stimulates higher accumulation of soil C in ridges than that of furrows (Table 9.5). Soil pH is also affected by the ridge tillage practice, where continuous ridge tillage increases the soil acidity (Mloza-Banda et al. 2014).

9.6.5 Traditional/Conventional Tillage

Tillage is the mechanical manipulation or alteration of soils to make it suitable for growing crops. Tillage affects all types of soil characteristics, e.g. hydrology, nutrient dynamics, soil density, porosity, aggregation, infiltration, temperature, GHGs emissions, and OM contents (Busari et al. 2015). Traditional tillage is also known as conventional or intensive tillage practice, which involves multiple operations and leaves $<15\%$ crop residue cover. It is a form of crop cultivation technique, where farmers loosen the soil by turning it over either manually with spade/hoes or repeatedly with animal-driven ploughs or mechanical power-driven different types of discs. The modern intensive agriculture is accompanied by primary and secondary tillage with heavy machinery like tractors, rotavators, power tillers, etc. (Fig. 9.8). Such tillage practice shows considerable effects in altering the soil ecology, changing the habitats and functions of soil microorganisms, and nutrient transformation and dynamics in soil-plant systems (Schimel and Schaeffer 2012).

Traditional tillage enhances microbial decomposition of OM and shows significant negative effects on C accumulation in soils compared to RT (Alam et al. 2017; Rahman et al. 2017). It breaks down soil aggregates, enhances nutrient transformation, and increases CO_2 and N_2O emission from soils, and thus contributes to global warming through increasing temperature (Rahman et al. 2017; He et al. 2019). Li et al. (2007) reported that TT alone and with residue removal caused for the destruction of soil structure, degradation of soil health, and ecological disruption. As soil becomes more disturbed by frequent and deep ploughing, TT encourages soil erosion, which has the potential to pollute the environment. In an ongoing study

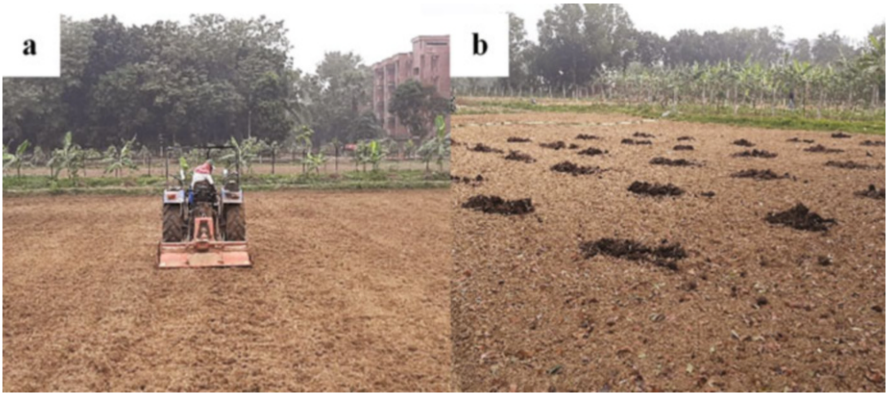

Fig. 9.8 Intensive cultivation system through traditional tillage practices in a rice field at BSMRAU research field of Bangladesh: (**a**) Secondary ploughing by rotavator, (**b**) Application of cow dung

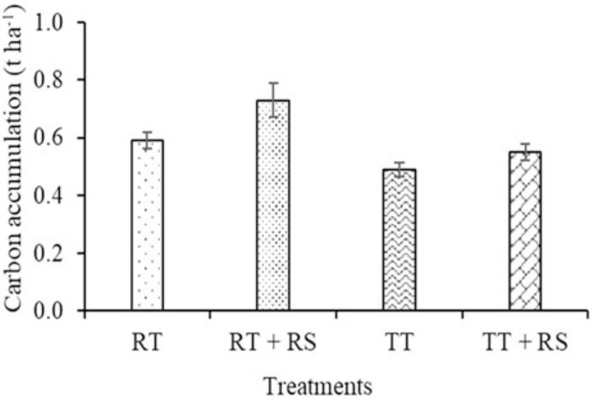

Fig. 9.9 Effects of reduced (RT) and traditional tillage (TT) on soil C accumulation with and without rice straw (RS) application in the paddy field of Bangladesh (Unpublished data)

commenced in 2017 at Bangabandhu Sheikh Mujibur Rahman Agricultural University (BSMRAU) of Bangladesh comprising RT and TT with and without RS application found higher C accumulation in RT compared to TT in paddy field (Fig. 9.9). During the study period, a total of 6 t C ha^{-1} was applied using RS considering a C rate of 2 t ha^{-1} in a crop season. After 3 years it was found that without RS addition, RT contributed 20.42% higher C in soil, while with RS it increased 32.73% more C compared to TT. The inefficiency of TT in terms of C and other nutrient enrichment and biomass C was also attributed as presented in Tables 9.5 and 9.6. Data presented in Table 9.6 revealed that OM and biomass C in soils under TT reduced by 43, and 33%, respectively, compared to no-till.

Soil acts as a habitat of soil microorganisms and also many other animals more specifically earthworms. Tillage practices homogenize soils and exert impacts on soil biota. Through mechanical breaking down and mixing of soil, tillage practice disturbs the unique habitat of soil organisms. Many species of microorganisms are reported to be disappeared because of mechanical turmoil of soil by TT and few species becomes dominant (Sengupta and Dick 2015). It is reported that TT can also decrease earthworm populations by 2–9 times as well as their diversity in soils (Chan 2001). Soil organisms are known as soil engine, which drives the soil functions, i.e. ecosystem services.

9.7 Conclusions

It is a never-ending challenge to sustain soil health maintaining fertility and productive capacity, especially in intensive agriculture. Rational use of organic amendments and tillage practices might recover degraded and exhausted soils through increasing soil aggregates, acting as a sink of C and nutrients and harbouring soil microbes. Crop production for the days ahead needs to be increased many folds like double, triple, quadruple, and so on using the land area today we have subject to a substantial reduction in future. There are no alternatives but to improve and maintain soil health through the collective use of organic and inorganic fertilizers, adopting a need-based tillage system and other soil and crop management practices until the existence of the world.

9.8 Future Perspectives

Vienna Soil Deceleration ‘Soil matters for humans and ecosystems’ emphasized on sustainable soil management. The sensible use of organic amendments and conservation tillage practices must ensure a healthy soil and has huge potential towards achieving UN Sustainable Development Goals (SDGs). Retention of crop residues in the fields needs to be practiced to promote long-term soil health. Replenishment of OM and nutrients to crop fields using available resources increase C sequestration in soil. Combined application of fertilizers using organic and inorganic sources ensures a continuous and steady supply of nutrients to plants and reduce environmental pollution. No-till along with cover crops and crop rotation is found to be the most effective in conserving soil C and the environment. Conservation tillage like no-till, reduced tillage, and strip-tillage, etc. cause minimum damage to the environment, therefore, are recommended for farmers’ practice across the world wherever possible. Soil and crop management practices that are conducive for C sequestration might contribute to reduce CO_2 emission from soil to the atmosphere. Wider adoption of such technologies will certainly secure soil health, mitigate global warming, and climate change.

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