Chapter 7
Soil Organic Matter and Its Impact on Soil Properties and Nutrient Status

Owais Bashir, Tahir Ali, Zahoor Ahmad Baba, G. H. Rather, S. A. Bangroo, Sofi Danish Mukhtar, Nasir Naik, Rehana Mohiuddin, Varsha Bharati, and Rouf Ahmad Bhat

7.1 Introduction

Soil organic matter plays a dynamic role in the improvement and maintenance of physical, chemical, and biological properties of soil. Agriculture is most concerned about these relationships, including the critical limits of soil organic matter with the key soil properties. There has been direct and indirect impact of soil organic matter on the soil properties, including its physical, chemical, and biological properties (Bezuglova et al. 2019; Sachkova et al. 2019; Orlova et al. 2019; Garratt et al. 2018; Zhang et al. 2017; Bhat et al. 2017b). In the physical properties, the soil organic matter affect soil structure, water retention, available water capacity, thermal conductivity, erodibility, infiltration, soil aggregate formation, soil color, soil

O. Bashir (✉) · T. Ali · Z. A. Baba · S. A. Bangroo · N. Naik
Division of Soil Science and Agricultural Chemistry, Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, Srinagar, Jammu and Kashmir, India

G. H. Rather
Division of Fruit Science, Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, Srinagar, Jammu and Kashmir, India

S. D. Mukhtar
Department of Chemistry, Jamia Millia Islamia, New Delhi, India

R. Mohiuddin
Division of Agronomy, Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, Srinagar, Jammu and Kashmir, India

V. Bharati
Division of Plant Pathology, Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, Srinagar, Jammu and Kashmir, India

R. A. Bhat
Division of Environmental Science, Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, Srinagar, Jammu and Kashmir, India

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compaction, soil aeration, saturated and unsaturated hydraulic conductivity (Beck-Broichsitter et al. 2018; Ajayi and Horn 2017; Blanchet et al. 2016; Angin et al. 2013). In the chemical properties, the SOM effect pH, buffering capacity, CEC, base saturation, zeta potential, exchangeable cations, soil fertility, and nutrient release (Garratt et al. 2018; Kwiatkowska-Malina 2018; Sulman et al. 2018). The biological properties include soil microbial population, soil microbial biomass carbon, nitrogen transformation, mycorrhizal population, root length and root growth, dehydrogenase, phosphatase, and urease (Fedoseeva et al. 2019; Orlova et al. 2019; Tikhova et al. 2019; Kallenbach et al. 2019; Wurzburger and Clemmensen 2018; Hazard and Johnson 2018; Parker et al. 2018).

Soil organic matter is a complex system of substance ranging from metabolic products of microbes, products of secondary synthesis components of organic residues undergoing decomposition, and humic substance. Soil organic matter is the plant and animal residues, microbial biomass, partly decomposed biomass fragments, stabilized organic matter, and soluble organic fraction (Zuber et al. 2015; Balesdent et al. 2000; Qadri and Bhat 2020). The soil organic matter generally describes the non-living product of plant and animal origin, but in broader term, it includes the total soil biomass, including the meso and macrofauna (Jiang et al. 2018; Laossi et al. 2008) and the biomass decomposition product. The soil organic matter is the heterogeneous product resulting from the chemical and microbial transformation of organic debris (Sidhu et al. 2016; Streubel et al. 2011; Liang et al. 2006; Mikutta et al. 2006; Dervash et al. 2020; Mushtaq et al. 2018). The soil organic matter has two important constituents: the non-living part, including the decomposed and un-decomposed products, and the living fraction of soil organic matter which is composed mainly of bacteria (10^9 organisms per gram of soil), fungi (10^7 organisms per gram of soil), actinomycetes (10^8 organisms per gram of soil), protozoa (10^6 organisms per gram of soil), algae (10^3 organisms per gram of soil), and nematodes (50 organisms per gram of soil). In the soil organic matter, these microbial populations play an important role in fermentation, mineralization, and humification process (Yuan et al. 2018; Gougoulias et al. 2014; Ahmad et al. 2007; Tiquia 2005; Alfreider et al. 2002; Zaman et al. 1999; Khanday et al. 2016; Singh et al. 2018a, b). The major constituents of the organic inputs are polysaccharides (hemicelluloses, cellulose) and lignin (Hsu et al. 2018; Liu 2014; Torres 2014; Zhu 2010; Kiem and Kögel-Knabner 2003), the others being biopolymers, such as (polyester, protein, tannins, suberin, cutin, and chlorophyll pigments) (Rui et al. 2016; Liu 2010; Bhat et al. 2017a, b). Soil organic matter serves as a substrate for microbial activity, nutrient source, soil conditioner, and major factor for sustaining agricultural productivity (Oldfield et al. 2018; Singh et al. 2020).

Soil organic matter decomposition is directly related to emission of atmospheric carbon, leading to global climate change. Environmental variables (soil moisture and soil temperature), microbial activity, soil chemical properties, and soil organic matter inputs (e.g., root exudates, plant litter, dead fine roots) usually impact decomposition dynamics (Dar et al. 2013, 2016; Genardzielinski et al. 2018; Yang et al. 2018; Dar and Bhat 2020). Apart from the organic inputs, the most influential are microbial activity and soil climate. In the soils, organic matter influences its output through priming effect (Fig. 7.1). The priming effect is small period transition in soil organic carbon turnover caused by the external organic matter input. A positive priming effect accelerates the decomposition rate, while as negative priming effect retards decomposition. The decline in the soil organic matter has a deleterious effect on the soil properties (Matos et al. 2019; Johnson et al. 2017; Huo et al. 2017; Kumar et al. 2016; Pausch et al. 2013; Zimmerman et al. 2011). As predicted in (European Environment Agency 2010) EU Soil Thematic Strategy, a decline of SOM contents is considered among eight main threats for soils. About 108–188 Pg C have been lost since the mid-nineteenth century, mostly from terrestrial ecosystem. However, several mitigating practices in agriculture, such as use of crop residues and residue incorporation into soil, maintain and build up soil organic matter. The mineralization and decomposition of soil organic matter is prejudiced by the land management, especially agricultural lands. Soils easily and quickly lose organic matter when natural soils are converted into agricultural soils. About 20–25% of the soil organic carbon is lost into atmosphere during its conversion and the possible reason is the destruction of soil aggregates. The sustainability in agriculture can be achieved now by the supply of exogenous organic matter. The organic matter having rich carbon pool and poor nitrogen content (e.g., straw, brown coal, wood and tree coniferous) act as substrate for microorganisms and relatively stable energy source (Singh et al. 2018a, b; Wei et al. 2017; Gogoi et al. 2017; Xiang et al. 2015) The current paper reviews the importance of soil organic matter in the

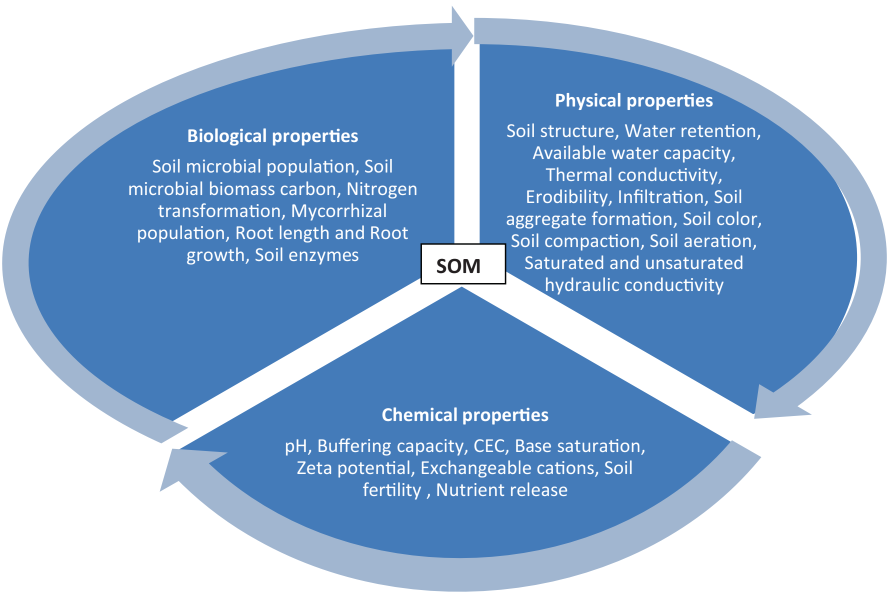

Fig. 7.1 Impact of soil organic matter on soil's physical, chemical, and biological properties

Table 7.1 Various fractions of the soil organic matter and their relative proportion

Fractions	Source	Composition	Amount (%)	Available form
Living organic matter	Plant biomass	Plant litter and roots	1	Active pool, labile soil carbon, decomposable plant materials (low C:N ratio), resistant plant material (high C:N ratio, high lignin)
	Microbial biomass	Bacteria	1–5	
		Fungi		
Non-living organic matter	Particulate organic matter	Litter	5–20	Labile soil carbon, active pool, decomposable plant materials (low C:N ratio, low lignin), resistant plant material (high C:N ratio, high lignin
		Macro-organic material		
		Light fraction		
	Dissolved organic matter		0.1	
	Humus	Non humic	65–80	Slow soil carbon
		Humic		
	Inert organic matter	Charcoal and biochar	1–5	Passive soil carbon, inert organic material

enhancement and amelioration of physical, chemical, biological, and fertility aspects of the soil (Table 7.1).

7.2 Effect of Soil Organic Matter on Soil Physical Properties

7.2.1 Soil Structure and Aggregate Stability

Soil structure stability indicates the resistance of soil to structural arrangement of particles and to different stresses (compaction/trampling, cultivation, and irrigation). Soil structure is the most important property influencing biological, chemical, and physical processes within soil, such as determining water and nutrient movement, air accessibility, seedling emergence, root penetration, resistance to erosion, and soil drainage (Sandin et al. 2017; Toosi et al. 2017; Jozefaciuk et al. 2015; Mehmood et al. 2019). The soil structure is a property which can be greatly influenced and manipulated by organic agriculture management practice. The organic matter has been associated with improved soil structure through the production of organic acids, biodiversity improvement, chelates, and increased earthworm population (Pylak et al. 2019; Bongiornoa et al. 2019; Moos et al. 2016; Kravchenko et al. 2015; Peng et al. 2015; Regelink et al. 2015). The amount of water stable aggregate is connected to macro-aggregate stability and positively related with labile organic carbon. A minimum of 2% soil organic carbon is necessary to maintain soil structure stability (Liu et al. 2013; Celik et al. 2010; Huang et al. 2010). The concept of soil aggregation and soil structure involving different binding agents have been revealed by the work of many researchers. Fine network of roots and hyphae in soil with high soil organic matter held together large aggregates (200 micron), while as aggregates above this size are held by organic cementing agents. Water stable aggregates of 2–20 micron are bound by living and dead bacterial cells. The idea of aggregate hierarchy reveals that organic matter controls aggregate stability and destruction of large aggregates creating smaller and more stable aggregates (Keller and Håkansson 2010; Moni et al. 2010; Kaiser and Guggenberger 2003; Christensen 2001; Oades 1984). Particulate organic matter acts as a substrate for microbial activity, enhancing the production of microbial bonding material. Fresh and active part of soil organic matter (mono, polysaccharides, exudates, fungal hyphae, and roots) are largely responsible for soil aggregation (De Curtis et al. 2019; Frąc et al. 2018; Plaza-Bonilla et al. 2013; Miao et al. 2009). There has been seen a positive relationship between organic farming systems using FYM, compost, vermicompost, sewage, and sludge with the aggregate stability.

7.2.2 Soil Compaction

Bulk density is an indicator of soil compaction and affects infiltration, soil porosity, plant nutrient availability, available water capacity, and soil microbial activity (Karlen et al. 2019; Nunes et al. 2019; Laiho et al. 2004; Aşkın and Özdemir 2003). The soil compaction is regarded as the most serious problem caused by conventional agriculture and the most difficult type to determine, as it shows no evident marks on the surface (Meurer et al. 2018; Masto et al. 2007; Håkansson and Lipiec 2000). The effects of soil compaction on soil properties are very complex and the state of soil compactness is evident soil attribute and determined mostly by the bulk density and soil strength (Singh et al. 2014; Hati et al. 2007). The bulk density and soil strength gives the direct comparable value of soil compactness. Soil organic matter retains soil water, thus helping the soil to overcome the problem of soil compaction. The adequate amount of organic matter in the soil stabilizes soil structure and makes it more resistant to soil degradation and also decreases the bulk density and increases soil strength (Das et al. 2018; Gharahi-Gheni et al. 2012; Heuscher et al. 2005; Calhoun et al. 2001; Han et al. 2012). The various mechanisms by which the organic matter influences the soil compaction are as follows: (a) binding of mineral particles to soil; (b) aggregate wet ability reduction; and (c) influencing the strength of soil aggregates, which is a measure of inter-particle bond. There has been a varying result between the soil organic matter and soil compactness and different researchers have reported different behavior for the different types of organic matter (Pravin et al. 2013). These differences seem to be due to different types of organic manure, C/N ratio of manure, and degree of resistance to degradation. Soil compactness is more influenced by readily oxidizable soil organic matter than the total organic matter. The organic farming system increases the organic matter in the soil and thus improves the bulk density of soil. Furthermore, using high quantity of organic manure or wastes decreases the bulk density of the soil due to a dilution effect caused by the incorporation of the added organic material with the denser mineral fraction of the soil (Almajmaie et al. 2017; Boizard et al. 2017; Guimarães et al. 2017). The plant residues are the common source of organic matter, but the farmers also use animal manures to reduce the soil compaction in the different organic farming systems (Avnimelech et al. 2001; Curtis and Post 1964; Huntington et al. 1989; Bhat et al. 2018a, b). The elasticity of the manure reduces the transmission of stress toward subsoil thus acting as a buffer to subsoil compaction. Incorporation of 50–100 t/ha of cattle manure in the silty clay loam top soils significantly reduces the effects of load 1–2 passes of 48.5 kW tractor (Mosaddeghi et al. 2000). Green or brown manure may not be an efficient source of nutrient for high-yielding environment, but acts as a beneficial practice in improving soil physical properties in compacted soils. Reddy (1991) observed a decrease in bulk density and soil strength of 0.02 Mg/m^3 and 11.8 kpa in the sandy loam soil due to the incorporation of 10 t/ha of green leaf manure. Incorporation of various organic matters in subsoils may prove a better alternative for stable retention in tackling soil compaction.

7.2.3 Soil Porosity

The architecture of soil refers to arrangement of soil particles and soil pores. The soil organic matter directly influences plant nutrition, penetration, and seedbed preparation, ease of cultivation, improved bulk density, greater aggregate stability, increased water holding capacity, and enhanced porosity (Xu et al. 2016; Ibrahim et al. 2013; Jack et al. 2011; Jarvis et al. 2007; Malkawi et al. 1999; Haynes and Naidu 1998). The organic carbon is mostly located in these pores between mineral grains as discrete particles or adsorbed on these particles. The soil porosity can influence the organic material stability through its effect on aggregate stability, isolation, and entrapment of decomposers and water and oxygen availability (Li et al. 2014; Masri and Ryan 2006). The changes in the pore size distribution are accompanied by the higher rates of organic matter mineralization at equivalent values of air-filled porosity. Rose (1991) studied that FYM not only changes aggregate stability but also affects the inter- and intramicro porosity. By the application of FYM and compost, both the micro porosity and macro porosity has increased (Pagliai and Vittori Antisari 1993). The increase in micro porosity occurs as a result of increase in elongated macropores of the newly formed aggregates. The effect of organic farming system can indirectly enhance soil porosity through the influence of soil fauna whose burrowing and feeding activity modify porosity (Park and Smucker 2005; McCallum et al. 2004). The various organic farming systems can also enhance the soil porosity by reducing soil crusting, clay dispersion, tillage, and compaction (Fig. 7.2).

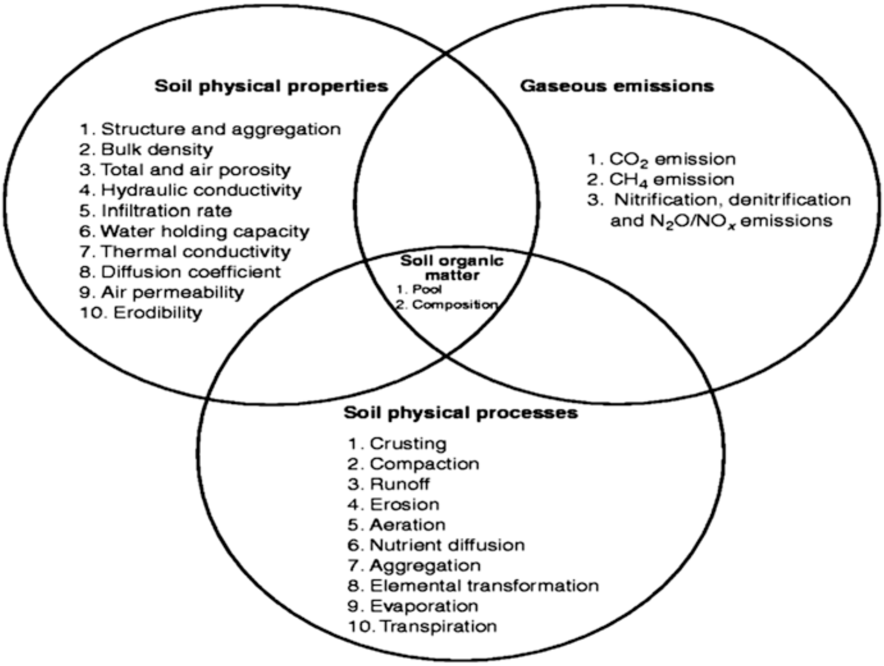

Fig. 7.2 Effect of soil organic matter on the soil's physical properties and processes

7.2.4 Soil Color

A strong relationship exists between soil color and many other important soil properties, including soil fertility mineral composition, soil organic matter soil drainage class, soil moisture, and land suitability (Ben-Dor et al. 2008; Barron and Torrent 1986; Alexander 1971; Brown and O'Neal 1923). The soil color is used to characterize, classify, and differentiate soils. The most convenient way to determine soil color is by the Munsell color chart. The soil color determines the pedogenic process in soil and the most important soil pigmenting agents are organic matter, iron, and manganese (Erskine 2013; He et al. 2003; Ketterings and Bigham 2000). The application of soil organic matter darkens the soil. The concept of Russian chernozem and Mollisol shaving the high organic matter are mostly defined by relative thick, dark surface horizons. The dark brown soils having high amount of soil organic matter are generally considered as an ideal soil. Within similar soil textural class and landscape, the soil color and soil organic matter has a good linear correlation (Ertlen et al. 2015; Kirillova et al. 2015; Kweon et al. 2013; Li et al. 2012; Ertlen et al. 2010; Gao and Xia 2009). The dark color soil having high amount of the organic matter applied by various organic farming systems holds a large amount of water, absorbs more radiation, and affects heat transfer (Sánchez-Marañón et al. 2011; Ketterings and Bigham 2000). The relationship between burned soil color, soil fertility, and fire severity found that color and chroma decreased with increasing heat severity due to decrease of soil organic matter and the soils appeared red, while the light heated soils appeared black due to incomplete burning of soil organic matter (Valeeva et al. 2016).

7.2.5 Water-Holding Capacity

An important soil physical characteristic is the capacity of the soil to supply and store water and air for plant growth. Soil's water holding capacity is the ability of the soil to store water. The soil organic matter increases the water holding capacity of the soil. The effect of organic matter on the water holding capacity is generally assumed to be positive (Ankenbauer and Loheide 2017; Basche et al. 2016; Jordán et al. 2010; Franzluebbers 2002; Bauer 1974; Jamison and Kroth 1958). An increase of 50% water content with per gram addition of organic carbon at −10 kpa suction (Emerson and McGarry 2003; Haynes and Naidu 1998).

The soil organic matter can enhance the hydraulic conductivity by improving the aggregate stability and porosity of the soil (Yang et al. 2014; Xu 2014). The organic manures reduce the compactness of soil, therefore improving water penetration. The effect of organic matter was more pronounced in the coarse-textured soil, followed by medium textured soil, and then the fine soils (Haynes and Naidu 1998). Several researchers have reported that, with an increase of soil organic matter, there is an increase of water holding capacity at both field capacity and wilting point (Sohail-Ur-Raza et al. 2015; Wang et al. 2015; Evrendilek et al. 2004; Matsi et al. 2003). The water holding capacity of soils is mainly dependent on the number of pores and specific surface area of soil. Both these pores and the specific surface area are increased by the application of organic matter. The increased water holding capacity is basically the result of an increase in the number of smaller pores at lower tension (Gülser et al. 2015; Hati et al. 2007; Khaleel et al. 1981). At higher tensions, all the pore space in the soil is filled by air and the water is retained mainly due to specific surface area and the thickness of water film on these surfaces.

7.2.6 Soil Thermal Properties

Soil thermal properties are considered a function of soil organic matter and soil carbon pool. Soil organic matter alters the thermal properties of soil because of its black dark nature. The albedo of soil gets reduced by the potential increase of dark color and more heat gets absorbed. The soils with least organic matter have albedo value of 0.6, while soils with 5% organic matter have albedo value of 0.08. At least, a soil organic matter of 2.5–3.0% is considered significant (Bi et al. 2018; Di Sipio and Bertermann 2018; Cai et al. 2017; Hortensia et al. 2018; Dębska et al. 2016).

Table 7.2 Thermal characteristics of the various soil constituents

Soil constituents	Density	Specific heat capacity	Volumetric heat capacity	Thermal conductivity
	kg/m^3	kJ/kg/°C	kJ/m^3/°C	W/m/°C
Quartz	2.7 × 103	0.8	2 × 103	8.8
Clay minerals	2.7 × 103	0.8	2 × 103	2.9
Water	1.0 × 103	4.2	4.2 × 103	0.6
Air 20 °C	1.2	1	1.2	0.025

The soil organic matter also affects the actual thermal properties of soil, including both its storage and flow of heat (Table 7.2).

The soils with good amount of organic matter have ample germination and higher crop growth because of the favorable temperature. The soil organic matter has substantially different physical characters in view of other soil constituents and with the increase in the soil organic matter the potential change in the soil thermal properties occurs (Bi et al. 2018; Wardani and Purqon 2016; Mondal et al. 2015; Usowicz et al. 2013; Tarnawski et al. 2009). Soil organic matter has the direct effect on the bulk density, which later affects heat conductivity and capacity of the soil. Mostly increase in the soil organic matter decreases the thermal conductivity and the wet soils have higher heat capacity and require lot of heat to raise its temperature. The wet soils are considered to have higher thermal conductivity than the organic and other soils.

7.2.7 Soil Infiltration and Percolation

The soil organic matter influences the infiltration or the admittance of water into a soil, and percolation, or the descendent movement of water, in a soil. The rate of infiltration depends on soil structure, developed soil horizon, soil slope, soil texture, depth of water table, chemical content of water, rate of water applied, and the amount of organic matter. Initially, in any soil, the infiltration rate is higher and then decreases with time (Basche and DeLonge 2019; Korucu et al. 2018; Loecke et al. 2017; Haghnazari et al. 2015). The important characteristic of soil affecting the soil infiltration is porosity of soil. The organic matter has a direct impact on the soil porosity and as the soil organic matter increases the porosity of the soil is also enhanced. The rate of infiltration reduces with time due to deflocculation and breakdown of the peds. The soil organic matter enhances soil aggregate stability and thus allows the greater rate of infiltration. Initial infiltration is higher, but the later infiltration is sometimes superior if there are no macropores on the surface and the soils have good aggregate stability and no surface crusting (Zeng et al. 2019; Acharya et al. 2018; Chavarria et al. 2018; Rodrigo-Comino et al. 2018; Diadin et al. 2018;

Balázs et al. 2018). In the tropics and semi tropics, the infiltration rate is more dependent on hydrous oxides and clay minerals because of having mineral origin of aggregates. In the humid and temperate zones, the infiltration depends on the soil organic matter because the stability of aggregates largely depends on the soil organic matter. The rate of infiltration varies from 0.1 to 5 inches per hour and the general infiltration rate varies from 0.3 to 1.0 inch per hour. The large amount of crop residues, mulches, and soil surfactants can regulate good infiltration rate by breaking droplet size of the rain water.

Percolation or downward movement of water is reliable on uninterrupted pore space in soil. For every doubling of pore size diameter, the rate of percolation in the soil increases by four times. The other factors affecting percolation rate are soil texture, soil structure, soil compaction, and amount of organic matter present. The soil temperature, soil moisture, and depth of soil horizons also affect the percolation rate (Issaka et al. 2018; Bullard et al. 2018; Jakab et al. 2017; Di Prima et al. 2017). The percolation of soil is restricted by the insufficient pans, clay pan, fragipans, plow pans, hard pans, and the presence of higher water table (Gómez et al. 2017; López-Vicente et al. 2016). In general, the percolation rate is considered higher in sandy soils, but the light soils having well stable soil aggregates, good soil structure, and high amount of organic matter have higher percolation rates than the fine sands. Mulches, crop residues, compost, FYM, and other organic soil amendments increase the soil macropores, thus increasing the percolation rate in the soil (Hlavčová et al. 2019; Gómez et al. 2018; Ben-Salem et al. 2018; Lucas-Borja et al. 2018; Fortugno et al. 2017).

7.3 Soil Chemical Properties

7.3.1 Buffering Capacity and Soil pH

Buffering capacity of soil is an important aspect as it assures the stability of soil pH. The buffering capacity of soil is the resistance to change in pH when an acid or base is added. At the pH value between 5 and 7.5, soil organic matter and clay acts as a sink for H and OH and the buffering capacity is governed by exchangeable reaction (Yuan et al. 2011; Nelson and Su 2010; Zhang et al. 2008; Herre et al. 2007). The presence of various functional groups (amine carboxylic, alchoal, phenolic, and amide) in soil organic matter allows it to act as a buffer over a wide range of soil pH (Sohi et al. 2010; Larney et al. 2008). The organic rich surface soils have higher buffering capacity than the mineral soils. James and Riha (1986) reported the buffering capacity of 18–36 $Cmol_c$/kg in the forest soils and 1.5–3.5 $Cmol_c$/kg in the mineral soils. Bloom (1999) studied that soil organic matter has a buffering capacity of 200 $Cmol_c$/kg, while buffering capacity of soil organic carbon was reported 300 times in comparison to kaolonite. Cayley et al. (2002) recorded a good relationship between the buffering capacity and soil organic matter and the importance of soil organic matter to maintain soil pH despite certain acidifying factors. A strong correlation existed between initial soil pH value and the buffering capacity of subsurface horizon, and the highly acidic soils were better buffered than less acidic soils (Curtin and Trolove 2013; Lieb et al. 2011; Bowman et al. 2008; De Vries et al. 1989; Bhat et al. 2018a, b). The soils are poorly buffered between 4.5 and 6.5 and well buffered below 4 and above 7. A number of researchers have studied the relationship between soil organic matter and soil pH. The decomposition of young shoots of trees in Ultisols and Oxisols increased soil pH and decrease in exchangeable aluminum content and the acid neutralization was due to aluminum and proton complexation by the organic anions (Wong et al. 2000; Tian et al. 1992; Hue 1992; Vallis and Jones 1973). The under saturation of aluminum adsorption would result in 3 mol of protons consumed for each mol of aluminum dissolved. The aluminum dissolution by the organic anions would result in proton consumption and the pH increase. The pH increase is not the primary cause for the decrease of soluble and exchangeable aluminum, but also due to adsorption of these substances on soil organic matter (Luo et al. 2015) The soil organic matter and the exchangeable aluminum has a negative correlation at greater depths and the effect of soil organic matter was greater at lower pH values. The relationship of soil organic matter and pH was studied when different type of plant material was incubated in top soil and there occurred increase in pH_{kcl} in a few days and the magnitude of which depends on type of soil organic matter and rate of application. The organic anions (malate, citrate, oxalate) balance the plant derived cations and the oxidation of anions consumes H^+ ion and the release of OH^- ion (Najafi and Jalali 2016). When the decomposed organic matter is added to the soil there is rise in pH due to complexation of proton by organic anion. If the undecomposed organic matter is added, the rise in soil pH is due to decarboxylation of organic anions during microbial decomposition. The decomposition of organic matter will transfer organic nitrogen to ammonia and releases OH^- and results in increase in soil pH (Zhang et al. 2013; Qin et al. 2013; Galloway et al. 2008; Ju et al. 2004). The specific adsorption of soil organic matter onto the aluminum and iron hydroxides results in release of OH^- ion. The long-term effect of organic matter increases soil pH as there occurs accumulation of humic material which complexes with aluminum compounds and decreases their solubility and protects soil from toxicity.

7.3.2 Cation Exchange Capacity

Cation exchange capacity of soil is the measure of exchangeable cations that soil can hold and represents negative charge per unit mass of soil. Soils with high cation exchange capacity is favorable as it holds many plant nutrients and this cation exchange capacity is expressed as centimol of positive charge per kilogram of soil (Soares and Alleoni 2008; Wiseman and Puttmann 2006; Adams and Evans 1979). The soils are having two charges: permanent charge CEC_P and pH-dependent charge CEC_v which depends on pH and the soil organic matter (Bache 1976; Bascomb

1964). The addition of organic matter generally causes increase in CEC_v and this increase is due to the presence of certain functional groups in the soil organic matter. The organic compounds with high molecular weight contribute less to cation exchange capacity compared to low molecular weight compounds (Alburquerque et al. 2014; Asai et al. 2009; Bonfante et al. 2010; Das and Varma 2011; McClellan et al. 2007; Lehmann and Rondon 2006). The contribution of soil organic matter to CEC is in the range 25–90% and the variation is mainly due to presence of functional group in soil organic matter and the soil type. There is a greater increase due to addition of soil organic matter to the cation exchange capacity in the coarse-textured soils than the medium- and fine-textured soils. Due to the addition of soil organic matter to mineral soil, there is greater increase of cation exchange capacity than in the surface soil (Schulz and Glaser 2012; Kammann et al. 2011; Peng et al. 2011). The soil organic matter has a cation exchange capacity of 150–250 Cmol(p^+) kg^{-1} and in the arable calcareous soil with high organic matter, the cation exchange capacity ranges from 230 + _ 47 (Wolf and Snyder 2003). In sandy forest soils, soil organic matter contribution to cation exchange capacity is very high in comparison to Vertisols derived from basalt. Stevenson (1982) worked on several laboratory methods to determine the relationship between soil organic matter and cation exchange capacity. The regression equation was developed for predicting the relationship between soil organic matter and cation exchange capacity (Hallsworth and Wilkinson 1958). The cation exchange capacity of soil organic matter varies and it depends on type of functional group present in soil organic matter and the pH of soil. The measure source of negative charge that contributes to cation exchange capacity is the carboxylic groups. The cation exchange capacity of soil organic matter in acid soils was estimated to be 134 Cmol(p^+) kg^{-1} and in chernozem it ranged upto 297 Cmol(p^+) kg^{-1}. The potential sites for cation exchange in soil organic matter are more than the measured as the many sites become unavailable due to the association with polyvalent cations (Table 7.3).

Table 7.3 Cation exchange capacity ($cmol_c$ kg^{-1}) of the various soil constituents

Soil constituents	Capacity ($cmol_c$ kg^{-1})
Kaolinite	1–5
Fe and Al oxides and hydroxides	5–40
Illite	20–40
Allophane/imogolite	20–50
Smectite	80–150
Vermiculite	150–200
Soil organic matter	>200

7.3.3 Adsorption and Complexation

Adsorption reaction due to soil organic matter are dependent mostly on pH as well as cation exchange capacity because similar types of organic carbon species are involved in adsorption reaction (Ahmed et al. 2015; Figueroa-diva et al. 2010; Frossard et al. 2002; Jones and Edwards 1998). The presence of functional groups (COOR, NH_2, OH, NHR, $CONH_2$) are very important for adsorption of ions on humus particles (Wu et al. 2012). The important mechanism for protection of soil organic matter from decomposition is its adsorption with clay particles. The positive relationship between soil organic carbon, clay content and soil surface area illustrates the significance of adsorption of soil organic matter on to the clay particles (Schaumann 2006; Schulten 2002). The interaction of soil organic matter with clay is governed by nature of soil organic matter and type of clay present. The interaction between soil organic matter and positively charged ions is through cation exchange reaction (between positively charged cation and negatively charged carbon group) (Cheng et al. 2014; Schwarz et al. 2012; Ghosh et al. 2000). The complexation of soil organic matter with inorganic material enhances the soil fertility as it increases the availability of soil phosphorus by blocking iron, aluminum, and calcium adsorption sites. Soil organic matter decreases the phosphorus adsorption in oxisols and the greater phosphorus adsorption was observed in cultivated soils (800 mgP/kg) than forest soils (560 mgP/kg) and it is attributed to greater amount of soil organic carbon in the forest soils (Bai et al. 2012). With the exception of few non-crystalline minerals, soil organic matter has the greatest capacity to form bonds with metals and it is associated by a positive association between solubility of metals with soil organic matter content as well as to high amounts of trace metals in organic rich soils compared with the non-organic soils (Sparks 2003). The increased concentration of soil organic matter decreases the concentration of cupric, zinc, and manganese in soil solution and also decreases the extraction of calcium by calcium chloride and acetic acid. The adsorption of copper was much stronger than zinc and manganese in the peat, solid humic acid, and acid washed peat (Klucakova 2012; Barancikova et al. 2003). The organic manures reduce the aluminum toxicity and increases the phosphorus availability and the important organic carbon groups in this complex reaction were low molecular weight aliphatic organic acids and soluble humic molecules as it complexes with the monomeric aluminum. The formation of complexes between polyvalent metal ions and humic substance is due to O-containing functional groups (enolic, phenolic, alcoholic, and carboxylic) as hydroxyl there is also the decreases the sorption of chlorinated aliphatic hydrocarbons and low molecular weight organic acids (fumaric, lactic, oxalic, citric, tartaric, propionic, butyric, acetic and formic acid) which are derived from leaves and from microbial biomass and also forms complex with AL^{3+}. Hydroxyl acids form stronger complexes than carbon groups. The presence of these functional groups in soil organic matter does not only determine sorption capacity but also have certain synergistic effects, such as aromaticity, polarity, and hydrophobicity.

7.4 Soil Biological Properties

7.4.1 Soil Organic Matter as a Driver of Biological Activity

The fundamental function of organic farming system is to supply high amounts of organic matter which provides metabolic energy and drives soil biological process. In the organic farming systems, there is basically the transformation of carbon compounds by macro and microorganisms and plants that provide energy and connects above and below surface energy by the formation of a cycle (Rossiter and Bouma 2018; Wade et al. 2018; Roper et al. 2017; Bonfante and Bouma 2015; Tiquia 2005). The plants assimilate carbon from atmosphere and form glucose and other complex plant biomolecules which, upon plant senescence, enter the soil through roots, litter, and root exudates (Zhang 2013; Zuber et al. 2018; Bashir et al. 2016). The plants supply energy to heterotrophs and, to a less extent, to chemotrophs (microbes, fungi, and earthworms) by the formation of recalcitrant organic matter (Adeniji and Babalola 2019) The carbon source acts as a source of energy and as long as net primary production exceeds respiration the organic carbon will accumulate in the soil (Miranda et al. 2019; Oburger and Jones 2018; Conrad et al. 2018; Mahanty et al. 2014; Dijkstra et al. 2013). The different organic farming systems provide various amounts of soil organic matter in soil, which reflects the balance between carbon produced and carbon leached (Gopalakrishnan et al. 2015). This balance occurs due to energy requirement of biota and is governed by certain factors (temperature, clay content, moisture, humidity, and rainfall). The transformation of labile soil organic matter into more complex form, that is, humus stabilizes this soil organic matter and can be used as a source of energy for longer period in an edaphic environment. The energy released from the soil organic matter decomposition is in the form of heat and the heat losses from 1 hectare is nearly equal to heat value of 1 metric ton coal and the highly productive organic matter soil releases heat of about 12 megagram of coal annually. The soil microorganisms play an immense role in the transformation of organic matter as these microbes carry 80–90% of total soil metabolism (Fernández-Gómez et al. 2019; Cui et al. 2019; Lamprecht et al. 2018; Pascual et al. 2018; Shen et al. 2014). The 1–5% of nitrogen and carbon are being preserved in the microbial tissue. A concept of microbial catabolic evenness (CE) was introduced by Degens et al. (2000) to measure soil microbial diversity by short term respiration response of soil over a certain range of organic compounds. They found a direct relationship between microbial catabolic evenness and soil organic pools and reported higher (CE) in pastures followed by agriculture and horticultural crops and the least was reported in the arable soils (Yuan et al. 2014). It was also found that, with the depletion of soil organic matter or carbon stock, there was greater decline in the microbial catabolic evenness.

7.4.2 Soil Organic Matter and Soil Microbial Population

Soil is species rich habitat on earth having diverse and abundant species which help in the formation and development of soil. The soil biodiversity is indicator of soil health, as greater biodiversity means greater soil stability in terms of certain functions, such as maintenance of soil structure, assimilation of organic wastes, and nutrient cycling (Miranda et al. 2019; Oburger and Jones 2018; Conrad et al. 2018; Mahanty et al. 2014; Bashir et al. 2016; Shen et al. 2014; Dijkstra et al. 2013; Wang et al. 2012; Bhatti et al. 2017). Soil organic matter, soil organic carbon, and soil biodiversity are closely related but distinct. Biodiversity means residing of certain organisms, such as bacteria, fungi, actinomycetes, protozoa, worms, vertebrates, and invertebrates (Oburger and Jones 2018; Conrad et al. 2018). All these organisms depend on soil organic matter for their energy, nutrients, and habitat. The topmost soil of earth, where concentration of organic matter and roots are higher, forms the largest habitat for these organisms (Bashir et al. 2016). A vast diversity of the organisms is present in the soil but only limited microorganism has been explored (Table 7.4).

7.4.3 Soil Enzyme Activity and Soil Organic Matter

Soil enzymes play a key role in organic matter decomposition and its recycling, with their activities being closely related to microbial activity, microbial biomass, soil physical property, and soil organic matter (Oburger and Jones 2018; Mahanty et al. 2014; Bashir et al. 2016; Dijkstra et al. 2013). These enzymes are either intracellular or extracellular, with intracellular being inside the cell in the cytoplasm bound by the cell wall. The extracellular enzymes are permanently immobilized and are being released into the soil on humic and clay colloids through hydrogen bonds, ionic bonds, covalent bonds, and other mechanism. These soil enzymes act as catalyst for decomposition of organic matter and effect agronomic production, environmental quality, and energy transformation (Wade et al. 2018; Rossiter and Bouma

Table 7.4 Number of species of soil flora and fauna and the percent explored from the soil

Group	Known species	Estimated total species	% known
Bacteria	13,000	1,000,000	1
Fungi	18,000–35,000	1,500,000	1–2
Protozoa	1500	200,000	7.5
Nematodes	5000	400,000	1.3
Ants	8800	15,000	58.7
Termites	1600	3000	53.3
Earthworms	3600	No estimate	No estimate
Mites	20,000–30,000	900,000	2.2–3.3
Collembola	6500	24,000	27.1

2018; Roper et al. 2017; Bonfante and Bouma 2015). Soil enzymes are considered best soil detectors because they respond to the soil sooner than physical and chemical parameters.

7.4.4 Soil Organic Matter as Important Nutrient Source

In considering the importance of organic matter as source of nutrients, it is to be mentioned that soil formation is closely related to diverse forms of organic substance on parent material. Soil organic matter provides all the essential nutrients, including primary nutrients such as nitrogen, phosphorus, and sulfur and micronutrients such as iron, manganese, zinc, copper, boron, molybdenum, and chlorine (Nurhidayati et al. 2018; Pravin et al. 2013; Masto et al. 2007; Laiho et al. 2004; Katyal et al. 2001). These nutrients are being made available during mineralization of organic matter during their growing season and the important fraction of soil organic matter fraction which supplies nutrients is particulate organic matter. Ninety percent of soil organic matter is made of carbon, hydrogen, and oxygen, while 50% of remaining elements is made of nitrogen, potassium, and silicon (Gwenzi et al. 2016; Haynes and Naidu 1998; Mahanty et al. 2014; Moco et al. 2009; Reeves 1997; Steller et al. 2008; Stevenson 1994; Von Lutzow et al. 2005). However, the application of fertilizers supplies a major nutrient available to plants, but the organic matter along with the soil microbes, store and cycle large amounts of nutrients required for growth (Liu et al. 2009). Most of the nutrients held in the soil organic matter are not easily assessable to plants and are resistant to decomposition. Only 1–5% of the soil organic matter is decomposed annually and it takes almost a decade for its complete decomposition (Molina-Herrera and Romanya 2015; Haynes and Naidu 1998). Soil organic matter acts as larger reservoir of macronutrients with 90–95% nitrogen and sulfur and 20–75% phosphorus. The 90–95% nitrogen is held in both available and fixed form. The 40–45% of organic nitrogen is quantified and identifiable as amino-sugars and amino acids and the remaining portion consists of unidentifiable structure. The soil Sulfur in organic form is mainly in the form of amino-acids, such as cysteine, cystine, and methionine. Phosphorus is mainly present in ester form and nitrogen is covalently bonded to C–S or C–O–S. The process of net phosphorus mineralization occurs if ratio of C:P is less than 100, whereas ratio of greater than 300 indicate net immobilization. The soil organic matter has impact on phosphorus availability through specific adsorption reaction because the humic fraction shows competitive character on oxide surfaces (Zhao et al. 2019; Liu et al. 2009; ErdalSakin 2012; Gama-Rodrigues et al. 2008; Geeves et al. 1995; Lal 2011; Zhang et al. 2006; Madejón et al. 2003; Powlson et al. 2001). Mineralization and transformation of organic source of phosphorus occur through extracellular hydrolysis or by the oxidation of organic carbon. Decrease in the soil organic carbon pertains to reduced nutrient supply and less than 1% organic matter is considered a threshold value below which there is no nutrient supply. The release of NPS from organic matter depends upon ratio of these elements to carbon. A narrow ratio of these elements to carbon usually allows fast nutrient release and a wide ratio reduces their availability (Guan et al. 2019; Hu et al. 2019; Ma et al. 2019; Cai et al. 2018). There are various schools of thought pertaining to nutrient status of soil organic matter, including its C:N:P:S with ratio of 100:10:1:1, 155:10:0.68:1.4, and 140:10:1.4:1.4. C:N:S ratio in the agricultural soils vary from other soils due to higher carbon mineralization of carbon and greater fertilizer input.

In view of the macronutrients, soil organic matter forms a number of chelates that make metal nutrient elements available over a wide range of pH. The micronutrient chelation has greater significance because of the nature of these elements to become fixed in high pH soils. The most chelates formed in the soil are of iron, copper, and zinc. In the plant's heme group forms the most common chelates, including chlorophyll and iron porphyrin. Oxalic and malic acids are reported to have high chelating properties. The root exudates and complex organic matter form the chelates that remain available to plants for a longer period. Ketogluconic acid has been reported as a highly chelating agent, but probably there are more chelating agents formed by organic matter (Shi et al. 2018; Du et al. 2018; Zhou et al. 2018; Liu et al. 2017; Hu et al. 2016; Guo et al. 2015; Wiatrowska et al. 2013). The organic matter supplied to high pH soils forms chelates and corrects lime-induced chlorosis. The carbon dioxide favors bicarbonate formation, which decreases iron uptake and translocation within plants.

7.5 Conclusion

The diverse nature of soil organic matter plays a defining role in determining the dimensions of various soil processes and properties, including its physical, chemical, and biological properties. This chapter revealed that interaction of soil organic matter with soil properties is very complex. The soil organic matter is considered as an important soil health indicator, as most of the soil properties depend on it. Almost all the soil properties were strengthened with the increase in the soil organic matter. The increase in soil organic matter had clear impact on the soil structure, water retention, thermal conductivity, available water capacity, zeta potential, exchangeable cations, soil fertility, erodibility, infiltration, soil aggregate formation, soil color, soil compaction, soil aeration, pH, buffering capacity, CEC, base saturation, and microbial population. The soil organic matter is an important factor in nutrient cycling, nutrient supply, especially nitrogen, phosphorus, sulfur, and micronutrients. The soil organic matter was more dominant where clay content was low. The important conclusion was that, with the addition of soil organic matter, we can improve many soil properties simultaneously. The certain issues that need to be readdressed in future are as follows: (a) application of soil organic matter to enhance soil health, (b) integrated nutrient management for sustainable agriculture, (c) carbon sequestration for mitigating climate change, and (d) organic residues management concerning recycling and environmental protection.

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