
Khan Towhid Osman

Soils

Principles, Properties and Management

Soil organic matter includes plant and animal residues at various stages of decomposition, ranging from fresh undecomposed materials through partially decomposed and short-lived products of decomposition to well-decomposed humus. Plant and animal residues contain sugars, celluloses, hemicelluloses, proteins, lignins, waxes, and lipids. When these materials are incorporated into soils, sugars, celluloses, and hemicelluloses, most proteins undergo rapid decomposition. With decomposition, the proportion of resistant compounds such as lignin gradually increases. Resistant decomposition products and newly synthesized substances accumulate in soil and form complexes with its mineral components. Humus is formed in the latter stage as a result of such continued decomposition, resynthesis, and complexation. Humus is a fairly stable substance and requires very long time, for example, centuries to millennia, to be completely decomposed. Most mineral soils contain less than 5% by weight of soil organic matter (SOM), but this little quantity of SOM has tremendous biological significance. It provides food for microorganisms, stores nutrients, retains water, acts as mulch, and performs as a soil conditioner and aggregating agent. It makes the soil friable and fertile. Soil organic matter contributes significantly to the sequestration of carbon.

7.1 Soil Organic Matter Is a Vital Component of Soil

Soil organic matter is an essential component of the soil; it affects the state and functioning of other soil components too. Loose materials on earth that do not contain organic matter are not soils. Some soils contain high organic matter, even more than 80% by weight; they are organic soils—the Histosols (Chap. 4). Most mineral soils contain <5% by weight SOM (Stanley 2000). Tropical soils (Oxisols and Ultisols) are known to have low organic matter contents, but Juo and Franzluebbers (2003) reported an average SOM content of about 2%.

By the phrase “soil organic matter,” we may perceive the whole range of living and dead organic materials present in the soil. Living organic materials are the plant roots and other soil biota—flora and fauna. Dead materials include plant and animal residues and their intermediate decomposition products. As a component of the soil and as chemical reactants, these dead materials are generally considered as soil organic matter. Surface litter (unless incorporated within the soil) is generally not included as part of the soil organic matter (Juma 1999).

7.2 There Are Three Categories of Soil Organic Matter

Three categories of soil organic matter are recognized on the basis of the stages of decomposition. The categories are fresh or undecomposed, partially decomposed, and fully decomposed organic matter.

Fresh or Undecomposed Organic Matter: Fresh soil organic matter includes freshly fallen leaves, twigs, branches, flowers, fruits, and dead animal tissue if they have been incorporated into the soil. These materials begin to decompose immediately after their incorporation. It becomes often very difficult to separate decomposed and undecomposed organic matter. For all practical purposes, fresh organic matter includes materials of which the origin and structure can be identified. It comprises about 1–10% of total SOM (Lickacz and Penny 2001).

Partially Decomposed Organic Matter: It includes organic residues in soil that have undergone decomposition to a considerable extent. The structure and origin of the materials may or may not be identified. It consists of gradually decomposing detritus and partially broken down plant and animal tissues. It comprises about 10–40% of total soil organic matter.

Fresh, undecomposed and partially decomposed organic matter together constitute the “active soil organic matter.” They are so called because they are easily attacked by soil

organisms, they are decomposed very fast, and they provide food and energy to heterotrophic soil organisms.

Fully Decomposed Organic Matter or Humus: Humus is said to be “completely decomposed organic matter.” It is not actually “completely” decomposed in the sense that it is still organic, and complete decomposition of organic matter produces CO₂ and water with some bases. It is “fully” decomposed in the sense that it has undergone decomposition for a considerable time, say some hundred or thousand years, and that further decomposition proceeds slow. Humus may be defined as a brown to black, amorphous, colloidal organic matter that has undergone decomposition to such an extent that further decomposition is very slow. Humus is composed of stable natural organic complexes formed by the products of biological decomposition and resynthesis. Humus is fairly resistant to decomposition due to its physical state and chemical nature. Humus is present as coating on soil particles, as gum within aggregates, and as organomineral complexes, which make them inaccessible to decomposing organisms. Again, humus contains refractory substances such as lignin and polyphenols. Because of these refractory substances, humus is called passive soil organic matter. It comprises about 40–60% of total SOM.

7.3 Composition of Soil Organic Matter Is Variable

Soil organic matter is a highly variable entity because different organic compounds are found in different plant and animal residues and different organic compounds predominate at different stages of decomposition. SOM includes materials that are added in plant and animal residues, those that are formed during decomposition, substances synthesized by microorganisms, and compounds in root exudates and microbial secretions.

Plant residues contain 15–40% cellulose, 10–43% hemicellulose, 25–40% lignin, 1–10% waxes and lipids, and 1–15% proteins (Schulze et al. 2005). After addition, microbial decomposition proceeds very fast in the initial stage and very slowly in the latter stages. Susceptible or “labile” substances such as sugars (Cheshire 1979), amino acids (Stevenson 1982), other organic acids (Stevenson 1967), and celluloses are quickly lost, and “stable” or resistant substances such as lignin increase in proportion. Some carbohydrates and proteins are newly synthesized by microorganisms for their body materials. These substances are also added to soils after their death. Microbial polysaccharides and proteins form complexes with lignin and other compounds rich in polyphenols and accumulate in humus (Coleman et al. 2004).

Some carbohydrates may be detrital, in that they originally entered the soil in plant debris, but most are thought to

be products of microbial synthesis in situ. Hydrolyzed products of soil polysaccharides are pentoses, hexoses, deoxyhexoses, hexosamines, and uronic acids (Jenkinson 1988). There is a considerable amount of amino acid polymers, such as peptides, and a small quantity of amino sugars and free amino acids. Peptides and polypeptides generally remain linked with other organic fractions and with clay and polyvalent cations. They are stable substances which predominate with lignins in humus. Humic substances are defined as condensed polymers of aromatic and aliphatic compounds produced by decomposition of plant and animal residues and by microbial synthesis. They are amorphous, dark-colored, and hydrophilic, with a wide range in molecular weight from a few hundreds to several thousands (Evangelou 1998). Three fractions of materials may be obtained during acid–alkali fractionation of humus. They are humic acid, fulvic acid, and humin (Kononova 1966). But these fractions do not represent any discrete group of compounds; they are actually products obtained in different steps of the fractionation procedure. These fractions, however, provide a convenient way of describing the composition of humus. Chemical characteristics of these fractions are mentioned below.

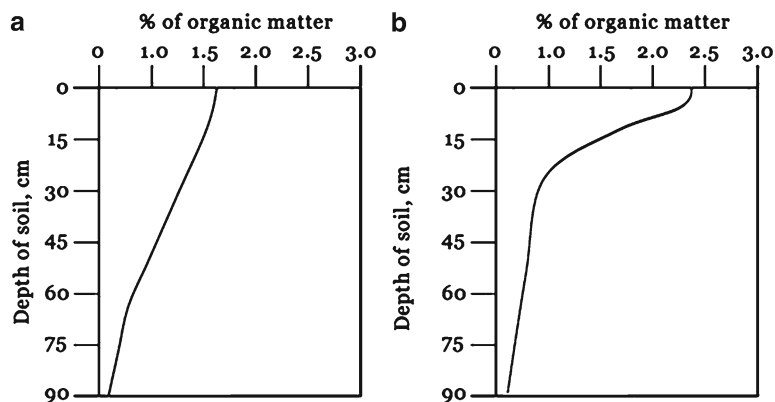
1. Humic acid—soluble in dilute alkali, but precipitates in acid solution
2. Fulvic acid—soluble both in alkali and acid solutions
3. Humin—insoluble both in alkali and acid solutions

Generally, humic and fulvic acids have a similar structure, but they differ in molecular weight and elemental and functional group contents. Fulvic acid is lower in molecular weight and contains more oxygen-containing functional groups and elemental oxygen, but less nitrogen and carbon per unit weight than humic acid (Schnitzer and Khan 1972; Sposito et al. 1976; Schnitzer 1991). According to Aswathanarayana (1999), humic acid contains 560, 47, and 355 g kg⁻¹ C, H, and O, respectively, while fulvic acid contains 457, 54, and 448 g kg⁻¹, respectively.

7.4 Many Factors Affect Soil Organic Matter Content

Many environmental, edaphic, and management factors affect soil organic matter content. Climate affects soil organic matter content on a global scale. Organic matter content increases with increasing rainfall up to a certain level beyond which it decreases. This may be attributed to the higher biomass accretion due to higher moisture supply. After a point, eluviation of organic matter increases. On the other hand, decomposition of organic matter increases as the temperature increases. The rate of decomposition doubles for every 8 or 9°C increase in mean annual temperature (Anonymous 2010). So, soil organic matter content decreases from lower to higher temperature regions. Soil texture, structure, water, air, etc., affect the organic matter content. Higher amount of

Fig. 7.1 Variation in SOM with depth in an agricultural (a) and in a forest soil (b)



biomass is produced in fine-textured fertile soils. Higher biomass adds larger amounts of organic matter. Decomposition of organic matter is faster in moist arable soils. Under saturated conditions, there is a deficiency of O_2 which reduces organic matter decomposition with a net result of accumulation of soil organic matter.

Soil organic matter content is the highest in the surface soil because organic inputs are generally the highest in the surface. It gradually decreases with depth in agricultural and grassland soils and abruptly, with some exceptions, in forest soils (Fig. 7.1). In some “buried” soils, subsoil may contain a higher organic matter content. Some soils as Spodosols contain illuvial humus accumulation in the B horizon.

Vegetation—natural or managed—has a profound bearing on the SOM level because different vegetation produces different amount of biomass and of varying decomposability. Cultivation reduces soil organic matter content. Forest and grassland soils are particularly rich in organic matter. When they are brought under agriculture, their organic matter is gradually reduced by enhanced decomposition. Tillage generally favors organic matter breakdown. However, manures and composts, fallowing, crop rotations, green manure, etc., may improve SOM levels, at least temporarily. Soils at the bottom of slopes generally have higher organic matter because these areas are generally wetter and better in fertility. Some organic matter is lost by runoff from soils of upper slopes.

7.5 Soil Organic Matter Performs Many Physical, Chemical, and Biological Functions

Organic matter performs many physical, chemical, and biological functions in soil. Physical functions mainly include enhancement of aggregation, aeration, water movement, and reduction of evaporation and thermal conductivity. Higher organic matter content gives a darker color. Organic residues accumulated on surface soil may act as mulch (Chap. 11). Organic matter improves soil structure and porosity (Chap. 5),

infiltration, water-holding capacity, and drainage (Chap. 6). Organic matter reduces runoff and erosion (Chap. 12). Humus can hold the equivalent of 80–90% of its weight in moisture and therefore increases the soil’s capacity to withstand drought conditions (Olness and Archer 2005).

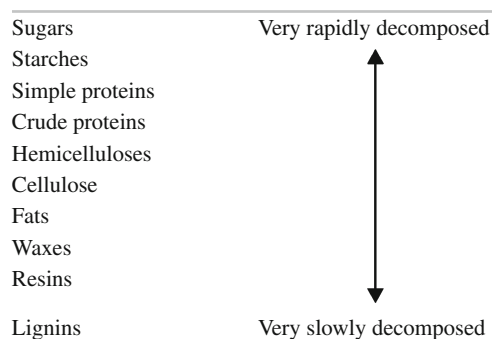
Chemical functions include enhancement of ion exchange, buffering, pedochemical weathering, chelation, and translocation of substances within the soil. Humus colloids have dissociable $-NH_2$, $-OH$, and $-COOH$ groups. Therefore, they are electrically charged particles with high surface area. Among various soil colloids, humus has the highest number of negative charges on its surface. Humus has, therefore, very high cation exchange capacity (Chap. 8). Humus colloids also contain some positive charges against which anions are adsorbed and exchanged. Several organic compounds in humus, particularly those having active groups like $-NH_2$, $-OH$, and $-COOH$, act in buffering which is an important property of the soil. Because of this property, soils do not suffer from sudden change in pH. Chelates are formed by complexation of humic substances with metals like Al, Fe, Mn, Zn, Cu, and some other heavy metals like Cd and Pb. The availability, absorption, redistribution, and leaching of these metals are regulated by chelation. Organic matter also forms complexes with pesticide residues and controls their mobility to water bodies, both surface and groundwater.

Biological functions include food for soil organisms and a storehouse of nutrients. When fresh organic residues are added to soils, they are attacked by the detritivores and the heterotrophic soil microorganisms. They utilize organic substances as their carbon and energy sources. However, the food quality of the residues depends on their chemical makeup. Some residues are high in carbohydrates and proteins; they are very rapidly consumed. Some others are rich in lignins; they are slowly degraded. Much of the plant nutrients are returned to the soil in the form of organic residues. Upon decomposition, these nutrients are released again to the available nutrient pool of the soil. Nutrients are recycled in this way through the soil organic matter (Chap. 14). Organic matter provides more than 90% nitrogen and about

50–60% phosphorus and sulfur. It releases nutrients at a slow pace to the growing roots, and it holds nutrients on their surfaces so that loss of nutrients from a soil rich in organic matter is minimum.

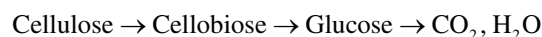
7.6 Humification Is a Complex Process of Decomposition and Resynthesis

Detritivorous soil animal and heterotrophic microorganisms such as fungi and many bacteria invade the plant and animal residues at the initial stage of soil organic matter breakdown. They fragment these materials and make them accessible to saprophytes. Organic compounds are released at different steps by breaking the tissue structures. The conversion of complex organic compounds into simpler organic compounds by biological processes is known as decomposition. Organic compounds added to soils undergo a series of decomposition reactions. For example, polysaccharides are first decomposed to their monomers (sugars) and then to CO_2 and water by aerobic decomposition. Complete decomposition of all organic compounds leads to the production of inorganic substances such as carbon dioxide, water, phosphates, sulfates, and bases. It is known as mineralization. Conversion of nitrogenous materials such as amino acids and proteins into ammonia, carbon dioxide, and water is also a mineralization process, but it is popularly known as ammonification. As earlier mentioned, plant and animal residues contain many different classes of organic compounds which undergo decomposition at variable rates and produce a variety of products depending on the stage of decomposition and condition of decomposition (Coleman et al. 2004). Decomposability of a particular compound may vary considerably depending on soil moisture and nutrients, microbial population, and climate. Generally, decomposability follows the following order:



Carbohydrates such as sugars, starches, celluloses, and hemicelluloses produce CO_2 and water when they are decomposed in the presence of O_2 . Under anaerobic conditions, intermediate products like CH_4 , alcohols, and organic acids are produced. Under further oxidation, they also produce

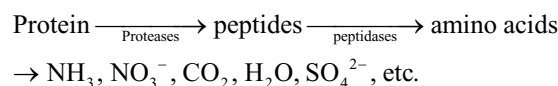
CO_2 and water. Cellulose is decomposed by many species of fungi and bacteria. The enzyme cellulase splits this long chain polymer of glucose to cellobiose which in turn is split to glucose by the enzyme β -glucosidase. Hemicelluloses are polymers of simple sugars such as pentoses, hexoses, and uronic acid. Their complete oxidation also yields CO_2 and H_2O .



Degradation of hemicellulose, lignin, and pectin follows similar pathways.

Bacteria of the genera *Achromobacter*, *Bacillus*, *Cellulomonas*, *Cellvibrio*, *Clostridium*, *Cytophaga*, *Vibrio*, *Pseudomonas*, *Sporocytophaga*, *Erwinia*, *Vibrio*, and *Lactobacillus*; fungi of the genera *Aspergillus*, *Chaetomium*, *Fusarium*, *Penicillium*, *Rhizoctonia*, *Rhizopus*, *Trichoderma*, and *Verticillium*; and actinomycetes of the genera *Micromonospora*, *Nocardia*, *Streptomyces*, and *Thermomonospora* are responsible for the decomposition of celluloses and hemicelluloses.

Protein is first degraded to peptides by the enzymes proteases and then into amino acids by the enzymes peptidases. These enzymes are produced by many species of *Clostridium*, *Proteus*, *Pseudomonas*, and *Bacillus*. Further decomposition yields NH_3 , NO_3^- , CO_2 , and water. This process, ammonification as mentioned earlier, occurs as a result of hydrolytic and oxidative enzymatic reaction under aerobic conditions by heterotrophic microbes.



The final stage of decomposition is characterized by gradual decomposition of more resistant organic compounds such as lignin for which actinomycetes and fungi play a major role (Stevenson 1985). Lignin is converted to phenylpropanes, polyphenols, and quinines. Some of the original lignin is left in soil. Bacteria of the genera *Flavobacterium*, *Pseudomonas*, and *Micrococcus*; fungi of the genera *Humicola*, *Fusarium*, *Fomes*, *Penicillium*, *Aspergillus*, and *Ganoderma*; and actinomycetes of the genera *Streptomyces*, *Nocardia*, etc., decompose lignin.

During decomposition of organic compounds, many intermediate products of decomposition may be encountered in soil at any given time. Soil organisms resynthesize some cellulose, amino acids, and proteins which are also added to soils after their death. Microbial cellulose and protein are believed to be more resistant to decomposition than those present in the original plant residues. Residual cellulose, lignin, and their derivatives, together with resynthesized compounds, form complexes with inorganic materials of the soil such as bases, metals, nutrients, and colloids to produce humus (Fig. 7.2). Formation of humus from organic

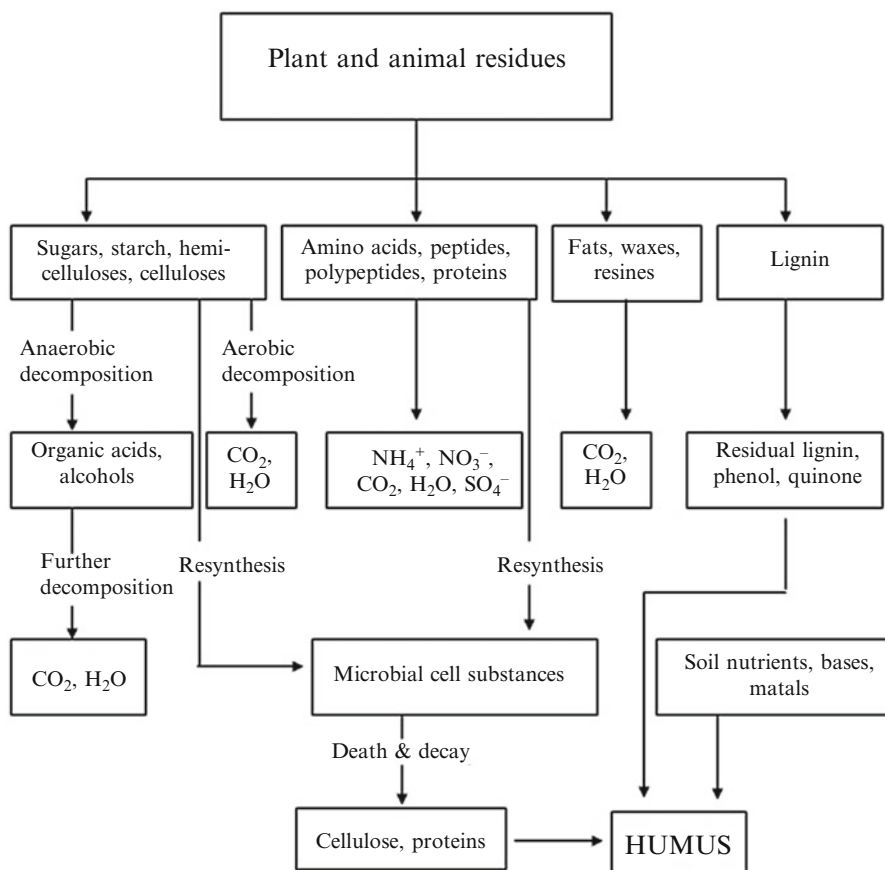


Fig. 7.2 Pathway of humification

residues in soil is called humification. Humus is more complex than original plant and animal residues, and humification is the combination of decomposition, resynthesis, and complexation. Humus contains approximately 45% lignin; 35% amino acids; 4% cellulose; 7% hemicellulose; 3% fats, waxes, and resins; and 6% other miscellaneous substances.

7.7 Managing Soil Organic Matter Is Necessary for Sustainable Soil Fertility

Decline in soil organic matter causes degradation of soil structure, reduction in porosity, water-holding capacity, and aeration and makes the soil compact and erodible. So, soil organic matter content should be maintained at a level necessary for favorable tillage and fertility. Organic matter status of most virgin soils (undisturbed, uncultivated) usually remains at a steady level for a long period. Cultivation opens the soils and oxidizes organic matter. Continuous cropping for a long time seriously declines SOM. Only a small fraction of crop residues added to soil remains as soil organic matter. So, addition of plenty of organic residues is needed for sustainable soil fertility.

As a general rule, mixing of residues and aeration of the soil associated with tillage increase organic matter decomposition and decrease soil organic matter content. However, conservation tillage methods (zero tillage, minimum tillage, mulch tillage) can be practiced for gradual improvement of SOM. Forage crops in rotations with cereals and oilseeds are beneficial for conserving SOM. Several long-term crop rotation studies have shown that crop rotations involving perennial forages tend to stabilize SOM. Inclusion of legumes further improves SOM. Greater proportion of the aerial biomass of the current crop should be left in field and incorporated within the soil. Huge amount of straw and stover are removed after harvest from corn, soybean, and other crop fields for use as fuel or livestock food. These materials may alternatively be composted and applied to fields as fertilizer and as conditioners. Manures, composts, and other organic supplements such as plant and animal residues, straw, sawdust, and oil cakes may be added to soil to supply plant nutrients at a slow rate to growing crops and improve SOM status. However, it may be difficult to collect huge amount of residues needed (about 10–20 t ha⁻¹). On farm composting from current crop residues, weeds, prunings and farm animal excreta may be a good practice. Inclusion of a legume like sun hemp, black gram, and cowpea in the cropping sequence

for a short period and plowing it down at before maturity is a good practice to supply N to the successive crop and add organic matter to the soil.

7.8 Carbon–Nitrogen Ratio Is an Important Index of SOM Decomposition

Carbon–nitrogen ratio is obtained by dividing the mass of carbon by the mass of nitrogen in plant tissues, plant and animal residues, or in soil. C/N ratio in soil is the ratio of its organic carbon to total nitrogen contents. This ratio has a significant bearing on organic matter decomposition, mineralization, ammonification, and nitrification in soil.

Most fresh plant materials contain about 40% carbon. If it has 1% nitrogen, the C/N ratio becomes 40:1. But, nitrogen content in plant residues varies from 0.5 to 1.5%. So, the C/N ratio varies among different plant materials.

The rate of decomposition of organic matter and the amount of humus formed are related to the C/N ratio of the residue. Organic residues of narrower C/N ratio are decomposed at a faster rate because nitrogen is utilized by decomposing microorganisms. At the initial stage of decomposition, there is a rapid disappearance of carbon in comparison to nitrogen (Olson 1963). Therefore, the C/N ratio starts declining with the advancement of decomposition. At a point when the later slow stage of decomposition is reached, the C/N ratio is stabilized around 10:1 to 15:1. Further decomposition of organic residue and further decrease in C/N ratio are extremely slow. Therefore, C/N in arable soil varies within a very narrow range, usually between 10:1 and 12:1. A higher C/N ratio in soil denotes the presence of a greater amount of undecomposed to partially decomposed organic matter. On the other hand, a smaller C/N ratio than 10:1 usually indicates greater nitrification in soil. The C/N ratio values of different organic residues obtained from different sources are given in Table 7.1.

7.9 SOM Fractions Represent Different Ages and Rates of Turnover

Soil organic matter is a heterogeneous mixture of diverse organic materials in various stages of decomposition. It can be separated into different fractions by physical and chemical fractionation procedures. These fractions are, however, not actual pure organic compounds but are often arbitrary mixtures separated by the procedures adopted. There are light fractions which are free and not complexed with mineral matter. These fractions currently undergo decomposition. There are fractions of soil organic matter stabilized in clay or silt sized organomineral complexes. There are metal chelates and recalcitrant organic compounds (Post and Kwon 2000). These fractions need much time to decompose.

Table 7.1 Average C/N ratio values of some organic residues

Residues	C/N ratio
Corn silage	35–45
Alfalfa	15
Cottonseed meal	7
Soybean meal	4–6
Food wastes	14–16
Legume hay	15–19
Pig manure	10–20
Poultry manure	5–15
Plant leaves	40–80
Wheat straw	100–150
Compost	15–20
Sawdust	170
Sewage sludge	5–16
Cow manure	10–30
Vegetable wastes	11–19

Source: <http://www.norganics.com/applications/cnratio.pdf>

The heterogeneity of different organic components in soil is reflected by their highly variable radiocarbon ages. A bulk SOM ^{14}C analysis only represents the mean ^{14}C concentration of the soil sample and does not depict the ages of the various fractions of soil organic matter. A reliable estimate of the age of soil carbon may be obtained if purified fractionation can be achieved. Rethemeyer et al. (2004) observed from a ^{14}C analysis that the black particles isolated from the plow horizon of an agricultural field in Germany represented from 12,350 to 21,360 years BP (before present). The oldest and most recalcitrant C pools dominate estimates by radiocarbon dating because of the long-term time frame (200–40,000 year) that this method measures (Goh 1991). For some sites under boreal, temperate, and tropical forests, the average age of bulk carbon in detrital and Oh/A-horizon organic carbon ranges from 200 to 1,200 years. In each case, this mass-weighted average includes components such as relatively undecomposed leaf, root, and moss litter with much shorter turnover times, and humified or mineral-associated organic matter with much longer turnover times. Recent analytical and experimental advances have demonstrated that molecular structure alone does not control soil organic matter stability: In fact, environmental and biological controls predominate (Schmidt et al. 2011).

The turnover rate of the different soil organic carbon compounds varies due to the complex interactions between biological, chemical, and physical processes in soil. However, there may be a continuum of soil organic carbon compounds in terms of their decomposability and turnover time (Post and Kwon 2000). The rate of turnover of an element in a pool may be predicted from the balance between its inputs (I) and outputs (O). It is generally indicated by the mean residence time (MRT) and the half-life ($T_{1/2}$). The MRT is defined as

the average time the element resides in the pool at steady state. It may again be taken as the average time required to completely renew the content of the pool at steady state. The half-life of SOM is the time required for half of the currently existing stock to decompose. The different C pools existing in the soil have different mean residence times, ranging from 1 year to a few years depending on the biochemical composition (lignin, e.g., is more stable than cellulose) to decades or more than 1,000 years (stable fraction). Some of the stable carbon fraction is physically protected by encapsulation of OM fragments by clay particles or soil macro- or microaggregates (Balesdent et al. 2000). Chemical protection refers to specific bonds of OM with other soil constituents (colloids or clays), but most often this concerns very stable organic compounds (FAO 2001).

The turnover of SOM may be expressed by the first-order model assuming constant zero-order input with constant proportional mass loss per unit time (Jenny 1980) as

$$\frac{\partial S}{\partial t} = I - kS,$$

where S is the organic matter stock in soil, t is the time, k is the decomposition rate, and kS is equivalent to output O . Assuming equilibrium ($I = 0$), the MRT can then be calculated as $MRT = I/k$ and $T_{1/2}$ as $MRT = T_{1/2} / \ln 2$ (Six and Jastrow 2002).

Actually, soil organic matter represents heterogeneous mixtures containing organic materials in all stages of decay and a variety of decomposition products of different ages and levels of complexity. Thus, the turnover of these components varies continuously, and any estimate of MRT for SOM as a whole merely represents an overall average value (Goh 1991).

Pools of SOM have characteristic turnover times of less than a year, years to decades, and over several hundred years (Parton et al. 1987). Most of the roughly 80–160 Pg C in surface detritus (Matthews 1997) and an estimated 200–300 Pg C in SOM are in forms that accumulate and decompose on time scales of a century or less (Schimel 1995; Potter and Klooster 1997). The remainder, constituting the majority of carbon stored in mineral soils, is stable on time scales of centuries to millennia (Trumbore 2000). Imagine, plants and animals that contributed materials for humus of our soils lived millions of years ago.

7.10 Soil Organic Matter Contributes to Carbon Sequestration

Soil carbon sequestration is the process of transferring carbon dioxide from the atmosphere into the soil through crop residues and other organic solids and in a form that is not immediately reemitted. It represents long-term storage of carbon in soil. This transfer or sequestering of carbon helps

offset emissions from fossil fuel combustion and other carbon-emitting activities while enhancing soil quality and long-term agronomic productivity. Soil carbon sequestration can be an effective option of mitigating CO₂ emission that combines with environmental conservation and soil fertility improvement (Smith et al. 2007).

Globally, soil stores approximately 1,500 Pg organic C and an additional 900–1,700 Pg inorganic C in the surface of 1 m soil. The atmosphere contains ~750 Pg C as carbon dioxide (Eswaran et al. 1993). Soil has a carbon stock three times that of the atmosphere. Thus, soil organic carbon (SOC) can play a significant role in mitigating greenhouse gas emissions. Soil C sequestration implies enhancing the concentration/pools of carbon through land-use conversion and adoption of recommended management practices in agricultural, pastoral, and forestry ecosystems and restoration of degraded and drastically disturbed soils. The SOC sequestration involves putting C into the surface 0.5–1 m depth through the natural processes of humification (Lal 2004). A wide range of soil and water management practices can be adopted to sequester atmospheric CO₂ in terrestrial ecosystems. The technical potential of C sequestration in terrestrial ecosystems is estimated at 5.7–10.1 Pg C year⁻¹. This includes carbon sequestration by vegetation and soils. Restoration of degraded and desertified soils is an important mitigation strategy because of its large technical potential for sequestering 1–2 Pg C year⁻¹ (Lal 2006).

Study Questions

1. Mention the chemical composition of soil humus. What do you mean by labile and stable soil organic matter? Why humus is stable in soil?
2. How do you distinguish between humification and mineralization? What are the characteristics of different fractions of humus? These are actually arbitrary fractions—why? Mention chemical composition of humic and fulvic acid.
3. Discuss factors that affect SOM content. What is the significance of SOM? Write sources of organic matter in soil.
4. Explain that humification is a microbial process. Mention some microorganisms involved in humification.
5. How older is the humus in a soil? Why soil is an important C sequester? What is the significance of C/N ratio of an organic amendment?

References

- Anonymous (2010) <http://www.dpipwe.tas.gov.au/inter.nsf/WebPages/TPRY-YW6YZ?open>. Accessed 12 Sept 2011
- Aswathanarayana U (1999) Soil resources and the environment. Oxford/IBH Publishing Co Pvt Ltd., New Delhi

- Balesdent J, Chenu C, Balabane M (2000) Relationship of soil organic matter dynamics to physical protection and tillage. *Soil Tillage Res* 53:215–230
- Cheshire MW (1979) *Nature and origin of carbohydrates in soil*. Elsevier, London
- Coleman DC, Crossley DA Jr, Hendrix PF (2004) *Fundamentals of soil ecology*, 2nd edn. Elsevier-Academic, San Diego
- Eswaran H, Vandenberg E, Reich P (1993) Organic carbon in soils of the world. *Soil Sci Soc Am J* 57:192–194
- Evangelou VP (1998) *Environmental soil and water chemistry: principles and applications*. Wiley, New York
- FAO (2001) *Soil carbon sequestration for improved land management*. Food and Agriculture Organization of the United Nations, Rome
- Goh KM (1991) Carbon dating. In: Coleman DC, Fry B (eds) *Carbon isotope techniques*. Academic, San Diego <http://www.norganics.com/applications/cnratio.pdf>. Accessed 5 Oct 2011
- Jenkinson DS (1988) Soil organic matter and its dynamics. In: Wild A (ed) *Russel's soil condition and plant growth*, 11th edn. English Language Book Society, London
- Jenny H (1980) *The soil resource—origin and behavior*. Springer, New York
- Juma NG (1999) *Introduction to soil science and soil resources, vol I, The pedosphere and its dynamics: a systems approach to soil science*. Salman Productions, Sherwood Park
- Juo ASR, Franzluebbers K (2003) *Tropical soils: properties and management for sustainable agriculture*. Oxford University Press, New York
- Kononova MM (1966) *Soil organic matter*. Pergamon, Oxford
- Lal R (2004) Soil carbon sequestration to mitigate climate change. *Geoderma* 123:1–22
- Lal R (2006) Enhancing crop yield in developing countries through restoration of soil organic carbon pool in agricultural lands. *Land Degrad Develop* 17:197–209
- Lickacz J, Penny D (2001) Soil organic matter. *Alberta Agriculture and Food Agdex* 536–1 (Online). [http://www1.agric.gov.ab.ca/\\$department/deptdocs.nsf/all/agdex890?opendocument](http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/agdex890?opendocument). Accessed 3 Sept 2011
- Matthews E (1997) Global litter production, pools, and turnover times: estimates from measurement data and regression models. *J Geophys Res* 102:18771–18800
- Olness A, Archer D (2005) Effect of organic carbon on available water in soil. *Soil Sci* 170:90–101
- Olson JS (1963) Energy storage and the balance of producers and decomposers in ecological systems. *Ecology* 44:322–331
- Parton WJ, Schimel DS, Cole CV, Ojima DS (1987) Analysis of factors controlling soil organic matter levels in Great Plain grasslands. *Soil Sci Soc Am J* 51:1173–1179
- Post WM, Kwon KC (2000) Soil carbon sequestration and land-use change: processes and potential. *Glob Chang Biol* 6:317–328
- Potter CS, Klooster SA (1997) Global model estimates of carbon and nitrogen storage in litter and soil pools—response to changes in vegetation quality and biomass allocation. *Tellus B Chem Phys Meteorol* 49B:1–17
- Rethemeyer J, Grootes PM, Bruhn F, Andersen N, Nadeau MJ, Kramer C, Gleixner G (2004) Age heterogeneity of soil organic matter. *Nuc Instrum Meth Phys Res B* 223–224:521–527
- Schimel DS (1995) Terrestrial ecosystems and the carbon cycle. *Glob Chang Biol* 1:77–91
- Schmidt MWI, Torn MS, Abiven S, Dittmar T, Guggenberger G, Janssens IA, Kleber M, Knabner IK, Lehmann J, Manning DAC, Nannipieri P, Rasse DP, Weiner S, Trumbore SE (2011) Persistence of soil organic matter as an ecosystem property. *Nature* 478:49–56
- Schnitzer M (1991) Soil organic matter—the next 75 years. *Soil Sci* 151:41
- Schnitzer M, Khan SU (1972) *Humic substances in the environment*. Marcel Dekker, New York, 327 pp
- Schulze WX, Gleixner G, Kaiser K, Guggenberger G, Mann M, Schulze E-D (2005) A proteomic fingerprint of dissolved organic carbon and of soil particles. *Oecologia* 142:335–343
- Six J, Jastrow JD (2002) Organic matter turnover. *Encyclopedia of soil science*. Marcel Dekker, New York
- Smith P, Martino D, Cai Z, Gwary D, Janzen H, Kumar P, McCarl B, Ogle S, O'Mara F, Rice C, Scholes B, Sirotenko O (2007) Agriculture. In: Metz B, Davidson OR, Bosch PR, Dave R, Meyer LA (eds) *Climate change 2007 mitigation. Contribution of working group III to the fourth assessment report of the intergovernmental panel on climate change*. Cambridge University Press, Cambridge
- Sposito GK, Holtzclaw M, Baham J (1976) Analytical properties of the soluble, metal complexing fractions in sludge-soil mixtures. II. Comparative structural chemistry of the fulvic acid. *Soil Sci Soc Am* 40:691
- Stanley ME (2000) *Soil environmental chemistry*. In: *Environmental chemistry*. CRC Press LLC, Boca Raton
- Stevenson FJ (1967) In: McLaren AD, Peterson GH (eds) *Soil biochemistry*, vol 1. Marcel Dekker, New York
- Stevenson FJ (1982) Nitrogen in agricultural soils. *Agron Monogr* no 22:67
- Stevenson FJ (1985) *Cycles of soil: carbon, nitrogen, phosphorus, sulfur, micronutrients*. Wiley Inter Science Publications, New York
- Trumbore S (2000) Age of soil organic matter and soil respiration: radiocarbon constraints on belowground C dynamics. *Ecol Appl* 10(2):399–411