Chapter 8

Soil Organic Matter: Significance, Sources and Functions

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Abstract

Soil organic matter (SOM) is a dynamic component in soil and acts as a source of food for microbes and inorganic nutrients for plants. It improves soil structure resulting in better aeration, water movement and increases resistance to soil erosion. Being highly porous and having high surface area, it improves nutrient and water holding capacity. Organic matter content in soil is a reflector of soil health. Sources of organic matter include animal manures, municipal sewage sludge, logging and wood manufacturing refuse, industrial organic residues, and food processing residues. Several soil factors are responsible for soil organic matter buildup including soil microbial activity, temperature, soil pH, soil moisture etc. Microorganisms, including bacteria, actinomycetes and fungi decompose organic matter in the soil. Carbon/nitrogen ratios (C:N ratio) of residues controls the rate of organic matter decomposition. In order to overcome current stagnation in agriculture and to increase profitability on a sustainable basis, understanding the dynamics of organic matter is

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the need of the day. This chapter is a discussion on the available sources of organic matter, factors affecting its buildup and its effects on soil and environment.

Keywords: Organic matter, Sources, Significance, C:N ratio, Decomposition

8.1. Introduction

Soil is the most important natural resource which serves as a natural medium for plant growth and a natural sink for variety of environmental pollutants. Soil is a complex medium which is composed of solid, liquid and gaseous components. In mineral soils, half volume is occupied by solids and rest half is occupied by pore space, shared jointly by water and gases. Solid portion of mineral soils is occupied by 48 % mineral particles and 2% by organic matter. Most agricultural soils contain organic matter in the top 25 cm of soil (Duxbury et al. 1989). The organic component of soil, mostly comprising dead organisms, plant matter and other organic materials at different stages of decomposition, plays a significant role in nutrient management in the soil as it acts as a reservoir or storehouse of plant nutrient. Although in mineral soils, OM is very low but still it can considerably modify a soils' physical properties and strongly affect its chemical and biological properties. Soil organic matter is a very dynamic and vital portion of the soil (Magdoff and Weil, 2004). It is a reservoir of nitrogen; it supplies large portions of the soil phosphorus and sulfur; protects against soil erosion; improves aggregate formation; and it loosens up the soil to provide better aeration and water movement. Organic matter must be readily decomposable and continuously replenished with fresh residues.

Organic material is decomposed by microorganisms; predominantly by bacteria, actinomycetes, and fungi (Holland and Coleman 1987). These decomposers produce enzymes that are the proteinous substances directly responsible for the decomposition, by reducing the activation energy, necessary to break the bond of the organic materials. Many different enzymes are required for decomposition of the complex variety of organic substances. Nitrogen, either from organic residue or nitrogen already in the soil, greatly affects the rate of decomposition. Residues with carbon/nitrogen ratios (C:N ratio) wider than about 30:1 will have a low decomposition rate due to deficiency of available N. Nutrient balance is one among others factors that promote optimum organic matter decomposition (Dalal and Mayer 1986; Rice 2002). Organic matter residues are collectively called humus, after the active decomposition has taken place.

Organic matter (humus) is a dynamic portion of soil and must be replenished continuously to maintain soil productivity. This can be supplemented by applying organic amendments, such as animal manures, municipal sewage sludge, logging and wood manufacturing refuse, industrial organic residues, and food processing residues. Crop residues comprise of about 70%, animal manures about 23%, logging and wood manufacturing wastes about 5%, and each of the other groups less than 1 percent of total residues. In many countries including Pakistan, some of the residues available are used for other purposes such as fodder for animals, building structures and fuel.

Overall organic matter plays a pivotal role in sustainable and profitable agriculture. Understanding the dynamics of organic matter may help in alleviating the current stagnation in various agricultural systems. This chapter aims to discuss the current sources of organic matter, factors affecting its buildup and its effects on soil and environment.

8.2. Sources of Soil Organic Matter

8.2.1. Animal manure

Animal manures supply most of the macronutrients as well as micronutrients necessary for plant growth. Its fertilizing effect on crops can be compared to that of mineral fertilizers. Application of manure in a certain year influences not only the first crop grown but its residual effect also benefits the succeeding crops in later crop seasons/years because of extended time span required for decomposition of the manure. Application of farmyard manure is synergistic to mineral fertilizers for various nutrients as it improves soil growth conditions as well as replenishes plant nutrients. Decomposition of farmyard manure by soil microorganisms results in the release of CO_2, water and plant nutrients, such as N, P, K and micronutrients. In general, after about one year, almost all the applied farmyard manure becomes part of soil organic matter and a small portion is transformed to humus, which is resistant to further microbial breakdown. Enhancement in soil organic matter adds to cation exchange capacity (CEC) of the soil, thus increasing its retention capacity for plant nutrients through adsorption. It improves soil structure which is less susceptible to compaction or erosion. Soil organic matter also raises water holding capacity of the soil. Improvement in soil organic matter decreases soil bulk density by improving total porosity. Besides improving physical, chemical and biological properties of soil, organic matter application also improves availability of micronutrients which are gaining increase importance because their deficiency is known to impair yield as well as quality of crop produce (Dhaliwal et al. 2013). Animal manure is used for maintaining and restoring fertility and productivity of soil since ancient time and is now considered an important and cheap method of recycling nutrients (Schjonning et al. 2002; Radke et al. 1988).

Although, composition of manures largely depends on the type of diet and animals (Eck and Stewart 1995; Probert et al. 1995) but collection, storage and application methods of manures are also important (Giller et al. 1997). Storage method has high influence on the composition of manure, even keeping all other factors constant. For instance, Sanford (1989) observed increase in N, P and K concentration by 108, 20 and 62%, respectively in buried manure compared to loosely heaped manure in open air. Application of manure to the soil can enhance the level of nutrients in soil. For example, an application of 3 tonnes of dry matter ha^{-1} would add macronutrients like N (35-82), P (7-21), K (32-163), Ca (30-74), and Mg (10-37) kg ha^{-1}, while micronutrients such as Fe, Mn, Cu, and Zn in the range of 11-67, 0.8-5.7, 0.02-0.26 and 0.15-0.65 kg ha^{-1} respectively. It is not possible that all the nutrients from the manure will be released in the applied season (Lupwayi et al. 2000). Only 28, 19 and 90% of N, P and K, release was observed respectively in the first season (Lupwayi and Haque 1999). Kaihura et al. (1999) and Warman and Cooper (2000) have reported an increase in soil ammonical and nitrate nitrogen i.e. total nitrogen in accordance with increasing rates of annual manure addition.

Animal manure in Pakistan consists mainly of animal dung and urine, FYM, poultry manure, crop residues, and slaughterhouse waste. None of these are being produced or marketed in an organized manner in the country. The farmers collect and use what is available on-farm. This is primarily FYM consisting mainly of animal droppings, straw and litter used in animal bedding and fodder residues. FYM has a variable nutrient value depending on the type of livestock and storage conditions. It has been estimated by the National Fertilizer Development Centre (NFDC) that over 1.5 million tonnes of nutrient are available from FYM in the country. Of this, nitrogen accounts for 726000, P_2O_5 for 191000 and K_2O about 617000 tonnes. About 50% of animal dung in Pakistan remains uncollected. Out of the collected animal dung, 50% is used as fuel in the form of dried cake. The remaining is usually heaped on top of ground surface with fodder residues and other house sweepings for manuring. The nitrogen of the manure undergoes transformations and mostly lost by volatilization and leaching. Therefore, the remaining manure material that is finally spread on the fields may have very low nitrogen content. Poultry farmers sell bird droppings directly to farmers. None of the poultry farmers maintains records about either sales or use. Most crop residues are used as animal fodder or as fuel, leaving very little for recycling. Although composting plants have been installed at Lahore and Islamabad, difficulties have been experienced in marketing the finished product because of high production and transportation costs.

8.2.2. Green manure

Green manuring is another strategy to add organic matter to soil. Green manure is referred to as “A cover crop, mostly legume, which is ploughed into the soil when it is still in lush green stage”. Green manuring is an important practice on some progressive agricultural farms because this practice adds organic matter and nutrients, particularly biologically fixed N, to the soil. Incorporation of green plants into soil as manure can add a reasonable amount of N and moisture and also serve as a carbon source for soil organisms including microbes and earthworms. After decomposition by the microorganisms in the soil, the constituents of green manure like organic acids and many nutrients become available to crop plants (Rasmussen and Collins 1991). Another benefit of green manure is that its addition suppresses weeds and most of the soil-borne plant diseases.

Crops grown for green manuring are referred to as soil fertility building crops. Green manures are a gift from nature and a suitable alternative to improve organic matter level in the soil that in turn improves soil physical and biological properties. These properties assist soil and crop plants with pest, disease and weed management. Addition of several green manure crops grown over a period of perhaps five to ten years can have prominent and significant effects on soil physical properties.

Green manures are either grown and used in situ, or used as green leaf manure. In the in-situ method, green manure crops are grown in a field prior to crop cultivation and then cut and buried when approximately 50% of all plants are flowering. The use of *janter* and *sunn hemp* is popular and well-practiced by most of the farmers. Because of their ability to grow fast and efficient nitrogen fixing capacity, these plants are grown to optimum vegetative stage and ploughed in to improve the living condition of the main crop.

8.2.3. Compost

Composting is a microbiologically mediated process, whereby manure and other organic wastes are partially converted into readily degradable organic matter and finally into stabilized contents. During this process, carbon of the organic matter is released partly as CO_2, incorporated into microbial cells or humified contents. The organic N, primarily present as proteins, is mineralized into inorganic N (NH_4-N and NO_3-N) during the composting process, which is then re-synthesized into humic substances and microbial biomass. The rate of organic C breakdown during compositing by bacteria, fungi, and actinomycetes depends on the stage of degradation, characteristics of materials and temperature (Epstein 1996; USDA 2010). Composting could convert organic wastes into humus like substances which are easy to handle, store and to apply, also safe for the environment. It could stabilize nutrients in manures while reducing the total biomass (Lasaridi and Stetiford 1999; Nahm 2005).

The organic materials like city waste, poultry manure, and wastes from cotton, sugar and rice industries could be made accessible in large amounts and if not managed properly and accumulated for long time, could adversely affect land, water and air environments. Additionally, because of their anecdotal composition, water percentage and bulk nature, the use and haulage of these organic wastes is a real concern in today's fuel conscious society. Pakistan lacks appropriate waste compilation and discarding system, so farmers use a variety of wastes without evaluating the effectiveness and economic feasibility (Arshad et al. 2004; Zahir et al. 2007).

Uninterrupted release and accumulation of different organic wastes constitute a real confront to environmentalists. Various remedies could be used but composting is the most economical, not only protecting the environment but also yielding an inexpensive and a quality soil amendment. Composting is the best solution for reducing the gigantic piles of organic wastes and yielding a value added product.

Direct use of fresh (un-composted) organic waste has many drawbacks due to wider C:N ratio compared to the composted material. Mature compost is normally superior to uncomposted organic materials, because well decomposed compost has a narrow C:N ratio, more concentrated nutrients, and is free from weed seeds, pathogens, and likely contaminants (Tahir et al. 2006).

8.2.4. Biochar

Biochar is a charcoal created by pyrolysis of biomass at high temperature in the absence of oxygen. It is considered a good soil amendment that has the potential to improve soil for sustainable crop production. Biochar has been used commonly in traditional as well as modern agricultural practices because of its very specific and unique properties among organic soil amendments. Beneficial effects of biochar on both functions of soil microbial and availability of soil water are highly and well documented (Pramod et al. 2010; Chan et al. 2007; Yeboah et al. 2009).

Biochar improves sustainability of soils by converting agro-wastes into a powerful soil booster that holds carbon and thus makes soils more fertile. It can preserve cropland diversity to enhance food security by discouraging deforestation. Some of the salient benefits include reduction in leaching of nitrate into the ground water; reduction in emissions of nitrous oxide to the atmosphere; improvement in soil fertility by increasing CEC and water holding capacity and proliferation of variety of beneficial soil microbes

Biochar is more persistent in soils compared with all other forms of organic matter commonly applied to soil. Biochar is considered long lasting and alternative management tool to farmyard manure because of its benefits associated with nutrient retention and soil fertility. This long lasting effect of biochar in soil makes it a prime candidate for the mitigation of climate change. Biochar has the potential to create a carbon sink, as about 50% of the original carbon is retained in the biochar during the process of conversion (Lehmann 2007).

Biochar offers a unique opportunity to improve soil fertility, either used alone, or in combination with compost and manure. Moreover, biochar application rates are reduced significantly when used with biochar as a soil amendment. A single application of biochar can provide benefits over many years because it persists in the soil for a long period. Without a doubt, all types of organic materials added to soil improve different soil properties and functions such as to retain several essential nutrients to plant growth, but one of the special features associated with biochar is its effectiveness in retaining most of nutrients in available form to plants compared to leaf litter, compost or manures (Lehmann 2007).

Biochar reduces soil acidity more than soil alkalinity. Biochar application to an acidic soils brings more benefits on crop growth than in alkaline soils. Nevertheless, it is possible to produce biochar suitable for alkaline soils with little or no liming capacity. Upon addition of biochar to an acidic soil, there is increase in pH in ranges that minimize detrimental effect of nutrient deficiencies on crop yields. Biochar made from manures and bones is exceptionally good as it has potential to reduce fertilizer requirements by holding soil nutrients in easily available form. This results in reduction of fertilization costs and retention of fertilizer (organic or chemical) in the soil for longer time. Biochar develops plentiful negative charge on its surfaces to hold nutrients and buffer acidity in the soil as does organic matter in general.

The stability of biochar provides basis to determine the environmental benefits of biochar due to two reasons: 1) How long carbon in biochar will remain sequestered in soil and contribute for mitigating climate change? 2) How long biochar can benefit soil and water quality? Characteristics of biochar vary depending upon the source material and method used to prepare biochar. Most biochars have both a small amount of easily decomposable fraction as well as much larger amount of stable fraction.

8.3. Decomposition of Organic Matter

Decomposition is a biologically mediated process that includes the physical breakdown and biochemical conversion of complex organic molecules of dead material into simpler organic and inorganic molecules (Juma 1998). When organic substances are manufactured by plants, energy from the sun through the process of photosynthesis is stored in these substances. When these substances are decomposed, the stored energy is again released. Carbon dioxide (CO_2), water, plant nutrients and energy are liberated in the decomposition process, different. The process of decomposition has an energy barrier, called activation energy, which must be overcome. When wood is burned, the activation energy is elevated. In nature, few reactions such as lightening are available to provide this heat energy. For most biological processes to occur under natural conditions, enzymes are a prerequisite to reduce this activation energy (Alvarez and Alvarez 2000).

8.3.1. Composition of organic matter

Organic matter (OM) comprises of carbon, hydrogen, oxygen, nitrogen, phosphorus, sulfur, and many other elements (Paustian 2002). Major fraction of OM consists of carbon atoms, linked together into carbon chains of numerous lengths and linkages and thus constitute the basic “frame” of organic compounds. The remaining elements fill out the frame to make different groups of organic matter substances called proteins, lignins, carbohydrates, oils, fats, waxes, and many other materials (Wander 2004). Humic substances are the dark brown, colloidal, amorphous, polymeric components of soil organic matter.

Soil humus is left after extensive chemical and biological breakdown of fresh plant and animal residues and makes up 60-70 percent of the total organic carbon in soils. Humus is often divided by solubility separations into fulvic acid and humic acid. Both fulvic acid and humic acid are soluble in dilute sodium hydroxide solutions, but humic acid will precipitate when the solution is made acidic. Humin is the portion of humus which is insoluble in dilute sodium hydroxide.

The nature of soil humus is extremely complex. In addition to humin, humic acid, and fulvic acid, some of other specific substances comprising soil humus are sugar amines, nucleic acids, phospholipids, vitamins, sulfolipids, and polysaccharides. All of these substances are of complex nature and uncertain origin. They may be residual from plant tissues, synthesized by microbes, or residues of microbial degradation.

8.3.2. Products of decomposition

In soils with sufficient aeration, the final products of decomposition are CO_2, $NH_4^{+,}$ $NO_3^{-,}$ $H_2PO_4^-$, $SO_4^{2-,}$ H_2O, resistant residues, and numerous other essential plant nutrient elements in smaller quantities (Alvarez and Alvarez 2000). If soil is not well aerated, less desirable products are formed. For example, in anaerobic conditions significant amounts of methane (CH_4), also called “swamp gas”, is produced, as well as some organic acids (R-COOH), ammonium (NH^{4+}), various amine residues (R-

NH_2), the toxic gases like hydrogen sulfide (H_2S), dimethyle sulfide, ethylene ($H_2C=CH_2$), and the resistant humus residues are formed.

8.3.3. Factors affecting organic matter decomposition

The most important conditions that alter the accumulation of soil organic matter are:

8.3.3.1. Temperature

Low temperature retards plant growth and organic matter decomposition. If temperature is high enough to produce considerable vegetation during the growing season, but are cold for long periods at other times of the year, organic matter accumulation in and on the soil, will be high. Continuous low temperature lowers soil humus because even though, humus persists, plant growth is lowered. Continuous moderate to warm temperature aid high plant production but also promote faster decomposition.

8.3.3.2. Soil moisture

Both plant growth and organic matter decomposition require moisture. Extremes of both arid (dry) and water logged (anaerobic) conditions reduce plant growth and microbial decompositions. Poorly drained soils with growing vegetation usually have relatively high humus contents; such conditions have been the cause of formation of some organic soils.

8.3.3.3. Nutrients

Lack of nutrients, particularly nitrogen, usually reduces plant growth more than it slows decomposition because microorganisms use the nutrients in the dead organic material before plant roots can absorb it (Duxbury et al. 1989).

8.3.3.4. Soil pH

For most common microorganisms, pH 6-8 is best suited for growth and are significantly reduced below pH 4.5 and above pH 8.5. Strongly acid soils are even more inhibiting to microbial growth than are strongly alkaline ones. Plants tolerate pH extremes more readily than microbes.

8.3.3.5. Soil texture

Soils higher in clays tend to retain larger amounts of humus. Most organic substances adhere to mineral surfaces by many kinds of bonds, particularly to clays. The many active bonding sites of minerals and humus include the =O, −OH, −Al −OH, −Fe −OH, and cation exchange sites of minerals, and the $-NH_3$, -SH , -OH , and –COOH portions of organic materials.

8.3.3.6. Other factors

Other decomposition inhibitors include toxic levels of elements (aluminum, manganese, boron, selenium, chloride), excessive soluble salts, shade, and organic phytotoxins (toxic to plants). The type of plant is also important, as legumes are more readily decomposed than grasses. Soil organic matter buildup is a resultant of all these effects plus the degree of mixing into the soil. Mixing the plant residues into soil (tillage) speeds up decomposition and lessens accumulation. Cultivation reduces vegetative growth (by destroying weeds) and speeds up decomposition by mixing.

8.3.4. Rate of decomposition and carbon: nitrogen ratio

Most nutrients needed by plants are also required by microorganisms that decompose organic matter. However, nitrogen concentration (which is in smaller proportion than carbon) most often controls the rate of organic matter decomposition because it is needed to build proteins in new bacterial and fungal populations. The nitrogen content in the microorganisms and in organic materials is given in proportion to the carbon content and is called the carbon: nitrogen ratio (C: N ratio) (Ge et al. 2013). A wide organic carbon: total nitrogen ratio indicates a material relatively in low nitrogen content. Table 8.1 lists some common organic materials and the percentages of the total weight that are organic carbon and total nitrogen. Bacteria requiring one kilogram of nitrogen for each four or five kilogram of carbon (C: N ratio of 4:1 or 5:1), are heavy users of nitrogen. If straw with its lower proportion of nitrogen (C: N ratio of 80:1) is incorporated into a soil low in nitrogen, bacteria will increase slowly because the straw is a low nutrient "food" for the decomposing microorganisms. The process of decay can be enhanced by adding more nitrogen (usually from fertilizer) to meet microbial and plant needs. Bacteria (or fungi) will use any available nitrogen in the soil. Plants growing in a nitrogen deficient soil are deficient in nitrogen because the soil microorganisms, which are more abundant and in more intimate contact, are able to use most available nitrogen before it can become accessible to plant root surfaces. The same is true for phosphorus and sulfur in organic residue and soil and to a lesser extent is true for other nutrients as well.

Table 8.1 C:N Ratio of Common Organic materials Applied to Agriculture Soils

Organic Material	Organic Carbon (%)	Total Nitrogen (%)	C: N Ratio
Crop Residues			
Alfaalfa (very young)	40	3.0	13: 1
Clovers (mature)	40	2.0	20: 1
Bluegrass	40	1.3	30: 1
Cornstalks	40	1.0	40: 1
Straw, small grain	40	0.5	80: 1
Sawdust	50	0.1	500: 1
Soil Microbes			
Bacteria	50	10.0	5: 1
Actinomycetes	50	8.5	6: 1
Fungi	50	5.0	10: 1
Soil Humus	50	4.5	11: 1

As progressive decay of organic matter continues, much of the carbon escapes into the atmosphere as carbon dioxide (CO_2). Eventually the easily decomposable residues decompose rapidly while resistant fraction of OM decompose slowly and persist in the soil for longer time. The food and energy source is now in short supply and some of the bacteria and fungi die. Their bodies, having high nitrogen content, are decomposed by other living organisms, evolving carbon as carbon dioxide and releasing some nitrogen to the soil solution. This "released" nitrogen is available to growing plants.

In soil, the oxidation or breakdown of chemical complexes in organic matter into plant available forms is known as minerlaiztion. This is the opposite of immobilization. If C: N ratio is 20:1 or narrower in plant residues, then there would be net mineralization of OM because sufficient nitrogen will be available meet the requirements of decomposing microorganisms. If plant residues have C: N ratios of 20:1 to 30:1, sufficient nitrogen will be available for decomposing microorganisms but not enough to result in much release of nitrogen for plant use. The first few weeks after incorporation, residues with C: N ratios wider than 30:1decompose slowly because they lack sufficient nitrogen for the microorganisms to use for increasing their numbers, resulting in the use of nitrogen already present in the soil. If environmental conditions are favorable, the rate of decomposition of plant residues is more rapid during the first two weeks after incorporation in to the soil. Sometimes residues with a wide C: N ratio may not have nitrogen immobilization, when incorporated into soils. If rates of decomposition are slow (large particle size, cool weather, quite dry), the need for the nitrogen by population of the decomposing micro-organisms is low (Rasmussen et al. 1991).

8.4. The Role of Soil Organic Matter

The importance of organic matter in soil is related to its control over fertility. Organic matter has a major influence on both physical and chemical fertility. Chemical fertility is concerned with the supply of nutrients to the growing crop, whereas physical fertility is concerned with the provision of soil conditions that allow plants to make optimum use of those nutrients. It involves the structure of the soil, or the physical arrangement of soil particles, whereby air and water supply to plants is optimal for the seasonal conditions and root penetration is not impeded. The third component of soil fertility is biological fertility which relates to the amount of organic matter in a soil and the activity of the microflora and microfauna that it supports. Cation exchange capacity of soil is improved due to the presence of organic matter. This soil chemical property is important in holding nutrients against leaching, and is particularly important for light textured soils. (Bell et al. 1998; Hudson 1994). Typically, soil population may consist of fungi, bacteria, actinomycetes, algae and protozoa, as well as the larger animals such as worms, molluscs, nematodes and small insects. Their importance in this context is their effect on soil properties, both direct and indirect, and this is related with the role of organic matter on the fertility of the soil.

8.4.1. Greenhouse gas control

Soil organic matter is also important as a possible sink/source for greenhouse gases, which trap radiated solar energy and thus keep the earth's surface at a temperature level necessary to support life. These atmospheric gases, mostly carbon dioxide (CO_2) but also methane (CH_4) and nitrous oxide (N_2O) being increased by anthropogenic activity such as burning fossil fuels and land clearing, and many scientists believe that significant global warming is attendant with sea level and regional changes. The consequences of such changes could be social, economic and environmental disastrous (Ryals and Silver 2013).

Carbon dioxide is the main gas contributing to this enhanced greenhouse effect, and its small but highly significant concentration in the atmosphere has increased by about 30% in the last two centuries. This has occurred largely because of the burning of coal, oil and natural gas and the clearing and burning of natural vegetation (Krull et al. 2004).

The condition of the soil, while being vital for agricultural production, is also important in terms of providing a long-term 'sink' for atmospheric carbon. In the form of carbon dioxide, this carbon is tied up (sequestered) through the process of photosynthesis by plants to give organic compounds that ultimately come to reside in the soil for varying lengths of time.

The soil ecosystem has the potential to sequester carbon for very long time periods. Depending on soil conditions, these compounds are eventually broken down and the carbon is returned to the atmosphere through decomposition, and respiration of the micro-organisms involved. Methane and nitrous oxide may also be released as a result of the decomposition (Corsi et al. 2012).

This 'sequestering potential' of soils becomes important in the overall strategy to reduce green-house gas emissions and ties up carbon dioxide in the form of soil organic matter. Increasing organic carbon in soils also has benefits in terms of productivity and sustainability. Soils that have less organic matter (through over cropping, for example), and may be in a degraded condition, have substantial sink capacity for sequestering more carbon dioxide. In a stable ecosystem the emission of the gas from soils (due to decomposition and respiration) is more or less balanced by H input to soils (due to photosynthesis). However, recent quantification of these processes shows that emissions are exceeding inputs as a result of clearing and cultivation of natural vegetation. As the soil carbon pool is approximately twice the size of the atmospheric pool, there is considerable scope for this to continue if land management practices are not improved.

8.4.2. Effect of organic matter on soil health

The amount of organic matter in soils is affected by soil type, previous cropping history, climate, tillage practices, the amount and kind of plant or animal material returned or removed, and crop residue burning. The most significant of these in the long term is the amount of organic material returned to, or removed from the soil. In this context, plant roots have an important role since, when they decompose, not only the humic substances are added to the soil, but also the nutrients are released throughout the root zone, thus benefiting both the structure and the uptake of nutrients by the subsequent crop.

In unfertilized soils (virgin soils), organic matter is the source of 90-95% of the nitrogen and is a major source of available phosphorus and sulfur, where humus is present in appreciable amounts ($\geq$2%). Organic matter supplies polysaccharides directly, or indirectly through microbial action, that greatly improves soil aggregation. Organic matter typically enhances water retention at field capacity, available water content in sandy soils, and rate of water infiltration in heavy textured soil. This latter effect is probably due mainly to soil aggregation, which produces larger soil pores. Organic matter acts as a chelating agent. Soluble chelates improve the retention and mobilization micronutrients and increase their availability to plants. Soil OM is source of carbon for many microbes that perform other beneficial functions in soil (e.g. free dinitrogen fixers, dinitrifires). As mulch on top of soil, organic matter reduces erosion, shades the soil (which prevents rapid moisture loss), and keeps the soil cooler in very hot weather and warmer in winter. Humus buffers the soil against a rapid change in acidity, alkalinity, and salinity; and damage by pesticides and toxic heavy metals. Surface organic matter acts as an insulator, retarding heat movement between the atmosphere and the soil. In hot summers, this benefits some plant roots, but in cool areas it slows soil warming in the spring.

Many benefits of organic matter in the soil are offset in certain conditions by detrimental influences. Organic matter is an energy and carbon source for many pathogens, ensuring their longer survival in the soils. Excessive amounts of organic matter are physically difficult to incorporate into the soils and hinder easy planting. Residues (or virgin vegetation on land being cleared) are often burned to reduce bulk. Although it is common practice (e.g. sugarcane and rice harvests), burning off crop residues is not desirable. Burning is harmful because it removes organic material that protects the soil against erosion, some ash that contains plants nutrients can be lost easily by wind or water erosion and most nutrients in the ash are soluble and some are easily leached through the soil. Numerous plants contain or produce phytotoxins (plant poisons: for example juglone from black walnuts), which make them undesirable as organic matter; so any and all plant materials should not be used indiscriminately in the soil. Unfortunately, the problem cannot always be avoided because the decomposition of many crop residues produces such toxins.

8.5. Conclusion

Sustainable productivity in any agricultural system, demands the maintenance of soil organic matter levels and the optimization of nutrient cycling. Humus, is the active fraction of organic matter, and it plays a very important function in aggregate stability and water infiltration. Maintaining soil organic matter content requires a balance between addition and decomposition. Intensive crop production globally is causing a reduction in soil organic matter content and consequently, a decline of soil fertility. Some part of the organic matter lost can be returned with improved land management practices. By adopting zero or minimum tillage practices, soil organic matter levels can be increased and agricultural soils can act as carbon sinks. Residue accumulation, including cover crops, farm yard manure, green manuring and crop residues improve the soil organic carbon and nutrient levels. Agricultural profitability can be substantially increased with careful management, preservation, and accumulation of soil organic matter.

References

Alvarez, R. and C.R. Alvarez (2000). Soil organic matter pools and their associations with carbon mineralization kinetics. Soil Sci. Soc. Am. J. 64: 184–189.

Arshad, M., A. Khalid, M.H. Mahmood and Z.A. Zahir (2004). Potential of nitrogen and L-tryptophan enriched compost for improving growth and yield of hybrid maize. Pak. J. Agri. Sci. 41: 16–24.

Bell, M.J., P.W. Moody, R.D. Connolly and B.J. Bridge (1998). The role of active fractions of soil organic matter in physical and chemical fertility of Ferrosols. Aust. J. Soil Res. 36: 809-819.

Chan, K. Y., L. Van Zwieten, I. Meszaros, A. Downieand and S. Joseph (2007). Agronomic values of green-waste biochar as a soil amendment. Aust. J. Soil Res. 45: 629–634.

Corsi, S., T. Friedrich, A. Kassam, M. Pisante and J. de Moraes Sà (2012). Soil Organic Carbon Accumulation and Greenhouse Gas Emission Reductions from Conservation Agriculture: A literature Review. Integrated Crop Management Vol.16. Food and Agriculture Organization of the United Nations. Rome.

Dalal, R.C. and R.J. Mayer (1986). Long-term trends in fertility of soils under continuous cultivation and cereal cropping in Southern Queensland. II. Total organic carbon and its rate of loss from the soil profile. Aust. J. Soil Res. 24: 281–292.

Dhaliwal, S.S., J.S. Manchanda, S.S. Walia and M.K. Dhaliwal (2013). Differential response of manures in transformation of DTPA and total zinc and iron in rice transplanted on light textured soils of Punjab. Int. J. Sci. Environ. Technol. 2: 300–312.

Duxbury, J.M., M.S. Smith and J.W. Doran (1989). Soil organic matter as a source and sink of plant nutrients. In: D.C. Coleman, J.M. Oades and G. Uehara, (Eds.), Dynamics of soil organic matter in tropical ecosystem, University of Hawaii Press, USA. pp. 33-67.

Eck, H.V. and B.A. Stewart (1995). Manure. In: J.E. Rechcigl (Ed.) Environmental aspects of soil amendments. Lewis Publishers, Boca Raton, Florida, pp. 169–198.

Epstein, E. (1996). The Science of Composting. Technomic Publishing Company, Lancaster, PA, USA.

Ge, S., H. Xu, M. Ji and Y. Jiang (2013). Characteristics of Soil Organic Carbon, Total Nitrogen, and C/N Ratio in Chinese Apple Orchards. Open J. Soil Sci. 3: 213-217.

Giller, K.E., G. Cadisch, C. Ehaliotis, E. Adams, W.D. Sakala and P.L. Mafongoya (1997). Building soil nitrogen capital in Africa. In: R.J. Buresh, P.A. Sanchez, F. Calhoun (Eds.), Replenishing Soil Fertility in Africa, Soil Science Society of America Special Publication 51. Madison, WI, USA. pp. 151–192.

Holland, E.A. and D.C. Coleman (1987). Litter placement effects on microbial and organic matter dynamics in an agro-ecosystem. Ecology 68: 425–433.

Hudson, B.D. (1994). Soil organic matter and available water capacity. J. Soil Wat. Con. 49: 189–194.

Juma, N.G. 1998. The pedosphere and its dynamics: a systems approach to soil science. Volume 1, Edmonton, Canada, Quality Color Press Inc. pp 315.

Kaihura, F.B.S., I.K. Kullaya, M. Kilasara, J.B. Aune, B.R. Singh and R. Lal (1999). Soil quality effects of accelerated erosion and management systems in three ecoregions of Tanzania. Soil Tillage Res. 53: 59–70.

Krull, E., J. Skjemstad and J. Baldock (2004). Functions of Soil Organic Matter and the Effect on Soil Properties: A Literature Review. Report for GRDC and CRC for Greenhouse Accounting. CSIRO Land and Water Client Report. Adelaide, Australia.

Lasaridi, K.E. and E. Stetiford (1999). Composting of source separated MSW: An approach to respirometric techniques and biodegradation kinetics. International Symposium on "Composting of organic matter", August 31 – September 6, Kassandra-Chalkidiki, Greece.

Lehmann, J. (2007). A handful of carbon. Nature 447: 143–144.

Lupwayi, N.Z. and I. Haque (1999). Leucaena hedgerow intercropping and cattle manure application in the Ethiopian highlands, 3: Nutrient balances. Biol. Fert. Soils 28: 204–211.

Lupwayia, N.Z., P.E. Olsena, E.S. Sandeb, H.H. Keyserb, M.M. Collinsa, P.W. Singletonb and W.A. Ricea (2000). Inoculant quality and its evaluation. Field Crops Res. 65: 259–270.

Magdoff, F. and R.R. Weil (2004). Soil Organic Matter in Sustainable Agriculture. CRC Press, 398 pp.

Nahm, K.H. 2005. Factors influencing nitrogen mineralization during poultry litter composition and calculations for available nitrogen. World's Poul. Sci. J. 61: 238–253.

Paustian, K. (2002). Organic matter and global cycle. In: Encyclopedia of soil science, New York, USA, Marcel Dekker Inc. pp. 895–898

Pramod J., A.K. Biswas, B.L. Lakaria and A.S. Rao (2010). Biochar in agriculture – prospects and related implications. Current Sci. 99: 1218–1225.

Probert, M.E., J.R. Okalebo and R.K. Jones (1995). The use of manure on smallholders' farms in semi-arid eastern Kenya. Exper. Agric. 31: 371–381.

Radke, L.F., D.A. Hegg, J.H. Lyons, C.A. Brock, P.V. Hobbs, R. Weiss and R. Rasmussen (1988). Airborne measurements on smokes from biomass burning. In: P. V. Hobbs and M.P. McCormick. (Eds.), Aerosols and Climate. Deepak Publishing, Hampton, Va. pp. 411–422.

Rasmussen, P. E. and H. P. Collins (1991). Long-Term Impacts of Tillage, Fertilizer, and Crop Residue on Soil Organic Matter In Temperate Semiarid Regions. In: Nyle C. Brady (Ed.) Advances in Agronomy, Volume 45. Academic Press, USA. pp. 93–134.

Rice, C.W. (2002). Organic matter and nutrient dynamics. In: Encyclopedia of Soil Science. New York, USA, Marcel Dekker Inc. pp. 925-928.

Ryals, R. and W.L. Silver (2013). Effects of organic matter amendments on net primary productivity and greenhouse gas emissions in annual grasslands. Ecol. Appl. 23: 46–59.

Sanford, R.L. Jr. (1989). Fine root biomass under a tropical forest light gap opening in Costa Rica. J. Trop. Ecol. 5: 251–256.

Schjonning, P., S. Elmholt, J. Munkholm and K. Debosz (2002). Soil quality aspects of humid sandy loams as influenced by organic and conventional long-term management. Agri. Ecosys. Environ. 88: 195–214.

Tahir, M., M. Arshad, M. Naveed, Z.A. Zahir, B. Shaharoona and R. Ahmad (2006). Enrichment of recycled organic waste with N fertilizer and PGPR containing ACC-deaminase for improving growth and yield of tomato. Soil and Environ. 25(2): 105-112.

USDA. (2010). Composting. Part 637, National Engineering Handbook, NRCS, U.S. Department of Agriculture, Washington, DC, USA.

Wander, M. (2004). Soil organic matter fractions and their relevance to soil function. In: Magdoff, F. and R.R. Weil, (Eds). Soil Organic Matter in Sustainable Agriculture, CRC Press, USA.

Yeboah, E., P. Ofori, G.W. Quansah, E. Dugan and S.P. Sohi (2009). Improving soil productivity through biochar amendments to soils. Afr. J. Environ. Sci. Technol. 3: 34–41.

Zahir, Z.A., M. Naveed, M.I. Zafar, H.S. Rehman, M. Arshad and M. Khalid (2007). Evaluation of composted organic waste enriched with nitrogen and L-tryptophan for improving growth and yield of wheat (*Triticum aestivum* L.). Pak. J. Bot. 39: 1739–1749.