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REVIEW ARTICLE

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Role of Agricultural Conservation in Organic Matter Mineralization

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ABSTRACT

In geology, mineralization is the deposition of economically important metals in the formation of ore bodies or "lodes" by various process The term can also refer to the process by which waterborne minerals, such as calcium carbonate (calcite), iron oxide (hematite or limonite) or silica (quartz), replace organic material within the body of an organism that has died and was buried by sediments Mineralization may also refer to the product resulting from the process of mineralization. For example, mineralization (the process) may introduce metals (such as iron) into a rock. That rock may then be referred to as possessing iron mineralization. The polymetallic Cu–Au–Ag–Zn ± Pb, Cu–Au and Cu deposits in the Kapan, Alaverdi and Mehmana mining districts of Armenia and the Nagorno–Karabakh region form part of the Tethyan belt. They are hosted by Middle Jurassic rocks of the Lesser Caucasus paleo-island arc, which can be divided into the Kapan Zone and the Somkheto–Karabakh Island Arc. Mineralization in Middle Jurassic rocks of this paleo-island arc domain formed during the first of three recognized Mesozoic to Cenozoic metallogenic epochs. The Middle Jurassic to Early Cretaceous metallogenic epoch comprises porphyry Cu, skarn and epithermal deposits related to Late Jurassic and Early Cretaceous intrusions. Whether nitrogen is mineralized or immobilized depends on the C/N ratio of the plant residues.

In general plant residues entering the soil have too little nitrogen for the soil microbial population to convert all of the carbon into their cells. If the C: N ratio of the decomposing plant material is above about 30:1 the soil microbial population may take nitrogen in mineral form (e.g. nitrate). This mineral nitrogen is said to be immobilized. This may cause nitrogen deficiency in plants growing in the soil. As carbon dioxide is released via decomposition the C: N ratio of the organic matter decreases, and the microbial demand for mineral nitrogen is decreased. When the C: N ratio falls below about 25:1 further decomposition results in simultaneous mineralization of nitrogen which is in excess to that required by the microbial population.
Key words: Metal, Mineralization, Soil and Organic Matter.

INTRODUCTION

PRINCIPLES OF agricultural conservation

Conservation agriculture makes use of soil biological activity and cropping systems to reduce the excessive disturbance of the soil and to maintain the crop residues on the soil surface in order to minimize damage to the environment and provide organic matter and nutrients. It is based on four principles: minimal mechanical soil disturbance, mainly through direct seeding; permanent soil cover, organic matter supply through the preservation of crop residues and cover crops; crop rotation for biocontrol and efficient use of the soil profile; minimal soil compaction. Although the principles are not new (except for that of minimal disturbance to the soil), it is the fact that they are applied together in conservation agriculture that generates positive outcomes. All the practices (minimal tillage, soil cover and crop rotation) are combined for synergy and added value. In the past, farmers may have tried but abandoned the use of cover crops or zero tillage because of weed problems or yield declines. There is also a need for improved weed control and rotations for biocontrol of pests and diseases and nutrient uptake. Integration of the conservation agriculture principles provides a win–win situation for both people and the environment, which has catalyzed successful expansion of the area under conservation agriculture worldwide. Conservation agriculture aims to: provide and maintain optimal conditions in the root zone (maximum possible depth for crop roots) in order to enable them to grow and function effectively and without hindrance in capturing plant nutrients and water; ensure that water enters the soil so that: (i) plants have sufficient water to express their potential growth; and (ii) excess water passes through soil to groundwater and stream flow, not over the surface as runoff where it can cause erosion. There is greater potential for increased cropping efficiency as more water is held in the soil profile than under conventional systems; release beneficial biological activity in the soil in order to: (i) maintain and rebuild soil architecture for enhanced water entry and distribution within the soil profile; (ii) compete with potential soil pathogens; (iii) contribute to decomposition of organic materials to soil organic matter and various grades of humus; and (iv) contribute to the capture, retention and gradual release of plant nutrients; avoid physical or chemical damage to roots and soil organisms that would disrupt their effective functioning.

ORGANIC MATTER DEPOSITION

The reduction of soil disturbance through zero-tillage, the use of cover crops and the preservation of crop residues on the soil surface result in increased activity of the soil and in the accumulation of organic matter, mainly in the topsoil.

Soil organic matter is any material produced originally by living organisms (plant or animal) that is returned to the soil and goes through the decomposition process (Plate 1). At any given time, it consists of a range of materials from the intact original tissues of plants and animals to the substantially decomposed mixture of materials known as humus (Figure 1). Most soil organic matter originates from plant tissue. Plant residues contain 60–90 percent moisture. The remaining dry matter consists of carbon (C), oxygen, hydrogen (H) and small amounts of sulphur (S), nitrogen (N), phosphorus (P), potassium (K), calcium (Ca) and magnesium (Mg). Although present in small amounts, these nutrients are very important from the viewpoint of soil fertility management. Soil organic matter consists of a variety of components. These include, in varying proportions and many intermediate stages, an active organic fraction including microorganisms (10–40 percent), and resistant or stable organic matter (40–60 percent), also referred to as humus. Forms and classification of soil organic matter have been described by Tate (1987) and Theng (1987) for practical purposes, organic matter may be divided into aboveground and belowground fractions. Aboveground organic matter comprises plant residues and animal residues; belowground organic matter consists of living soil fauna and microflora, partially decomposed plant and animal residues, and humic substances.

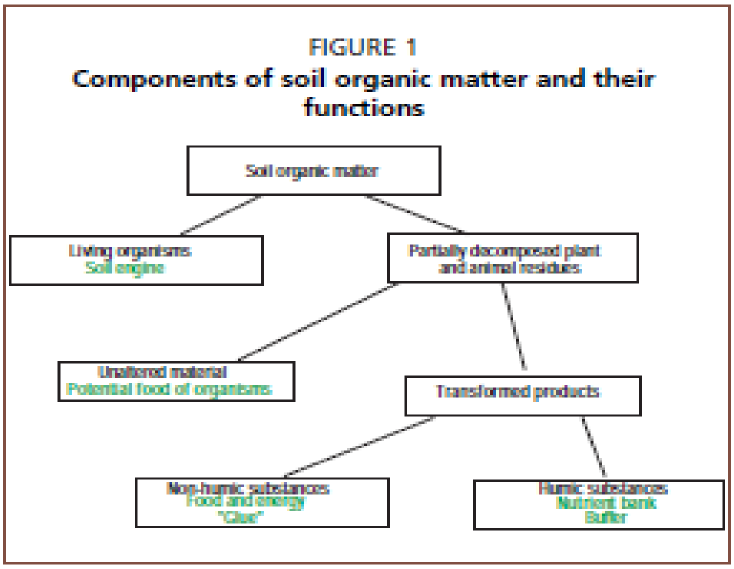

Fig 1. Show components of soil organic matter.

Decomposition of organic matter is largely a biological process that occurs naturally. Its speed is determined by three major factors: soil organisms, the physical environment and the quality of the organic matter (Brussaard, 1994). In the decomposition process, different products are released: carbon dioxide (CO_2), energy, water, plant nutrients and resynthesized organic carbon compounds. Successive decomposition of dead material and modified organic matter results in the formation of a more complex organic matter called humus (Juma, 1998). This process is called humification. Humus affects soil properties. As it slowly decomposes, it colours the soil darker; increases soil aggregation and aggregate stability; increases the CEC (the ability to attract and retain nutrients); and contributes N, P and other nutrients. Soil organisms, including micro-organisms, use soil organic matter as food. As they break down the organic matter, any excess nutrients (N, P and S) are released

into the soil in forms that plants can use. This release process is called mineralization. The waste products produced by micro-organisms are also soil organic matter. This waste material
is less decomposable than the original plant and animal material, but it can be used by a large number of organisms. By breaking down carbon structures and rebuilding new ones or storing the C into their own biomass, soil biota plays the most important role in nutrient cycling processes and, thus, in the ability of a soil to provide the crop with sufficient nutrients to harvest a healthy product. The organic matter content, especially the more stable humus, increases the capacity to store water and store (sequester) C from the atmosphere.

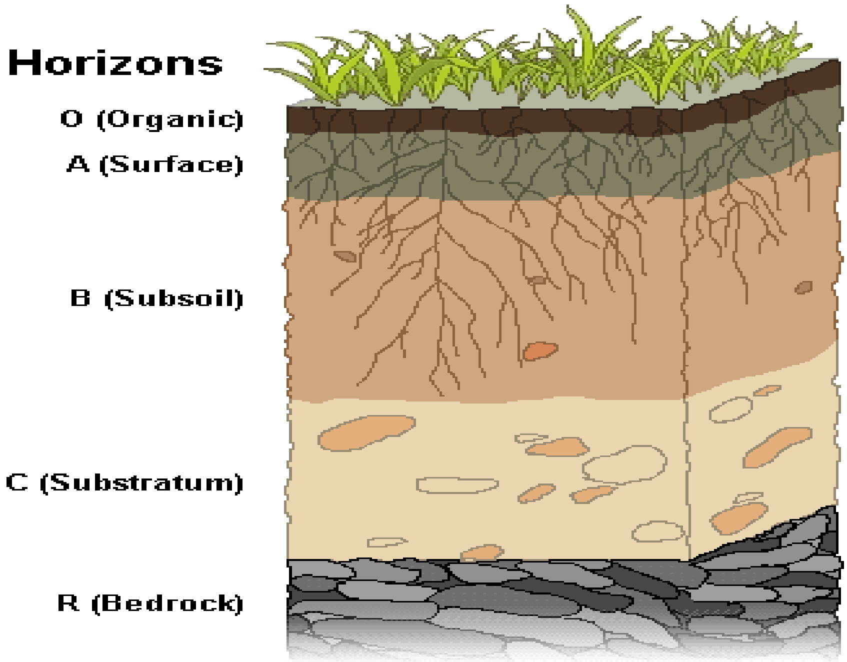

Fig 2. Humus has a characteristic black or dark brown color and is organic due to an accumulation of organic carbon. The three major horizons are: (A) surface horizon, (B) subsoil and (C) substratum. Some soils have an organic horizon (O) on the surface. Hard bedrock, which is not soil.

Natural factors influencing the amount of organic matter

In natural humid and subhumid forest ecosystems without human disturbance, the living and non-living components are in dynamic equilibrium with each other the litter on the soil surface beneath different canopy layers and high biomass production generally result in high biological activity in the soil and on the soil surface. Mollison and Slay (1991) distinguished the following five mechanisms in continuous soil cover of living plants, which together with the soil architecture facilitates the capture and infiltration of rainwater and protects the soil; litter layer of decomposing leaves or residues providing a continuous energy source for macro- and micro-organisms; the roots of different plants distributed throughout the soil at different depths permit an effective uptake of nutrients and an active interaction with microorganisms; the major period of nutrient release by micro-organisms coincides with the major period of nutrient demand by plants; nutrients recycled by deep-rooting plants and soil macrofauna and microfauna. This equilibrium creates almost closedcycle transfers of nutrients between soil and the vegetation adapted to such site conditions, resulting in almost perfect physical and hydric conditions for plant growth, i.e. a cool microclimate, increased evapotranspiration, good rooting conditions with good porosity and sufficient soil moisture. This facilitates water infiltration and prevents erosion and runoff. Thus, it results in clean water in the streams emanating from the area, a relatively smooth variation in stream flow during the year, and recharge of groundwater. In human-managed systems, the soil biological activity is influenced by the land use system, plant types and the management practices. Chapter 4 outlines the influence of land management practices. The environmental and edaphic factors that control the activity of soil biota, and thus the balance between accumulation and decomposition of organic matter in the soil, are described below.

SOIL MOISTURE AND WATER SATURATION

Soil organic matter levels commonly increase as mean annual precipitation increases. Conditions of elevated levels of soil moisture result in greater biomass production, which provides more residues, and thus more potential food for soil biota. Soil biological activity requires air and moisture. Optimal microbial activity occurs at near “field capacity”, which is equivalent to 60-percent water-filled pore space (Linn and Doran, 1984). On the other hand, periods of water saturation lead to poor aeration. Most soil organisms need oxygen, and thus a reduction of oxygen in the soil leads to a reduction of the mineralization rate as these organisms become inactive or even die. Some of the transformation processes become anaerobic, which can lead to damage to plant roots caused by waste products or favorable conditions for disease-causing organisms.

SOIL TEXTURE

Soil organic matter tends to increase as the clay content increases. This increase depends on two mechanisms. First, bonds between the surface of clay particles and organic matter retard the decomposition process. Second, soils with higher clay content increase the potential for aggregate formation. Macro aggregates physically protect organic matter molecules from further mineralization caused by microbial attack (Rice, 2002).

TEMPERATURE

Several field studies have shown that temperature is a key factor controlling the rate of decomposition of plant residues. Decomposition normally occurs more rapidly in the tropics than in temperate areas.

TOPOGRAPHY

Organic matter accumulation is often favored at the bottom of hills. There are two reasons for this accumulation: conditions are wetter than at mid- or upper-slope positions, and organic matter is transported to the lowest point in the landscape through runoff and erosion. Similarly, soil organic matter levels are higher on north facing slopes (in the Northern Hemisphere) compared with south-facing slopes (and the other way around in the Southern Hemisphere) because temperatures are lower (Quideau, 2002).

SALINITY AND ACIDITY

Salinity, toxicity and extremes in soil pH (acid or alkaline) result in poor biomass production and, thus in reduced additions of organic matter to the soil. For example, pH affects humus formation in two ways: decomposition, and biomass production. In strongly acid or highly alkaline soils, the growing conditions for micro-organisms are poor, resulting in low levels of biological oxidation of organic matter (Primavesi, 1984). Soil acidity also influences the availability of plant nutrients and thus regulates indirectly biomass production and the available food for soil biota. Fungi are less sensitive than bacteria to acid soil conditions.

VEGETATION AND BIOMASS PRODUCTION

The rate of soil organic matter accumulation depends largely on the quantity and quality of organic matter input. Under tropical conditions, applications of readily degradable materials with low C: N ratios, such as green manure and leguminous cover crops, favor decomposition and a short-term increase in the labile nitrogen pool during the growing season.

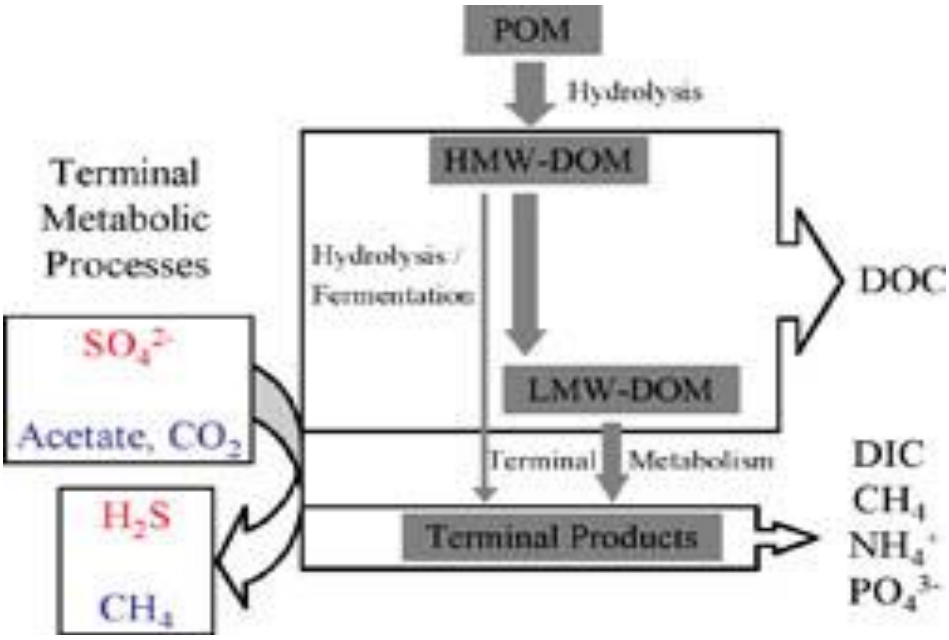

Fig. 3. Microbial mineralization of organic matter in aquatic habitats.

HUMAN INTERVENTIONS THAT INFLUENCE SOIL ORGANIC MATTER

Various types of human activity decrease soil organic matter contents and biological activity. However, increasing the organic matter content of soils or even maintaining good levels requires a sustained effort that includes returning organic materials to soils and rotations with high-residue crops and deep- or dense-rooting crops

Practices that decrease soil organic matter

Any form of human intervention influences the activity of soil organisms (Curry and Good, 1992) and thus the equilibrium of the system.

INCREASED CARBON SEQUESTRATION

World soils are important reservoirs of active C and play a major role in the global carbon cycle. As such, soil can be either a source or sink for atmospheric CO2 depending on land use and the management of soil and vegetation (Lal, 2005) The conversion of native ecosystems (e.g. forests, grasslands and wetlands) to agricultural uses, and the continuous harvesting of plant materials, has led to significant losses of plant biomass and C (Davidson and Ackerman, 1993), thereby increasing the CO_2 level in the atmosphere. Organic matter content of the soil is increased through the decomposition of roots and the contribution of vegetative residues on the surface. This organic material decomposes slowly, and thus the liberation of C to the atmosphere also occurs slowly. In the total balance, net fixation or sequestration of C takes place; the soil is a net sink of C.

PRINCIPLES OF CONSERVATION AGRICULTURE

Conservation agriculture makes use of soil biological activity and cropping systems to reduce the excessive disturbance of the soil and to maintain the crop residues on the soil surface in order to minimize damage to the environment and provide organic matter and nutrients. It is based on four principles: minimal mechanical soil disturbance, mainly through direct seeding; permanent soil cover, organic matter supply through the preservation of crop residues and cover crops; crop rotation for biocontrol and efficient use of the soil profile; minimal soil compaction. Although the principles are not new (except for that of minimal disturbance to the soil), it is the fact that they are applied together in conservation agriculture that generates positive outcomes. All the practices (minimal tillage, soil cover and crop rotation) are combined for synergy and added value. In the past, farmers may have tried but abandoned the use of cover crops or zero tillage because of weed problems or yield declines. There is also a need for improved weed control and rotations for biocontrol of pests and diseases and nutrient uptake. Integration of the conservation agriculture principles provides a win–win situation for both people and the environment, which has catalyzed successful expansion of the area under conservation agriculture worldwide.

CONCLUSIONS

The maintenance of soil organic matter levels and the optimization of nutrient cycling are essential to the sustained productivity of agricultural systems. Both are related closely to the bioturbating activities of macrofauna and the microbially-driven mobilization and immobilization processes, which the activities of large invertebrates also encourage. Maintaining soil organic matter content requires a balance between addition and decomposition rates. As changes in agricultural practices can engender marked changes in both the pool size and turnover rate of soil organic matter, it is important to analyse their nature and impacts. Crop production worldwide has generally resulted in a decline in soil organic matter levels and, consequently, in a decline of soil fertility. Converting grasslands and forestlands to arable agriculture results in the loss of about 30 percent of the organic C originally present in the soil profile. On reasonably fertile soils with reliable water supply, yields in long-term arable agricultural systems have been maintained at very high levels by applying substantial amounts of fertilizer and other soil amendments. In low-input agricultural systems, yields generally decline rapidly as nutrient and soils organic matter levels decline. However, restoration is possible through the use of fallow lands, mixed crop–livestock and agroforestry systems, and crop rotations. Traditional mould-board plough and disc-tillage cropping systems tend to cause rapid decomposition of soil organic matter, leave the soil susceptible to wind and water erosion, and create plough pans below the cultivation depth. By contrast, reduced- or zero-tillage systems leave more biological surface residues, provide environments for enhanced soil activity, and maintain more intact and interconnected large pores and more soil aggregates, which are better able to withstand raindrop impact. Water can infiltrate more readily and rapidly into the soil with reduced tillage and this helps protect the soil from erosion. In addition, organic matter decomposes less rapidly under reduced-tillage systems. No-tillage systems have proved especially useful for maintaining and increasing soil organic matter. Crop rotation is the basis for the sustainability of direct sowing systems. A production system that includes cover crops, legumes for N fixation, crop rotation and no tillage can be adapted regionally and, therefore, contribute to the sustainability of soil management in the region. Where rainfall intensities are very high, or biomass management options are limited by a water shortage, maintenance of soil surface cover by crop canopies or crop residues during periods of high erosion risk is essential. With improved land management, at least part of the organic matter lost can be restored. The increase in soil organic matter in the absence of tillage can transform agricultural soils into carbon sinks. The relatively low levels of active organic matter fractions in zero-tillage systems have highlighted the extreme dependence of such systems on the maintenance of high levels of surface protection by crop residues. Residue accumulation, including cover crops and crop residues, increases the levels of some soil nutrients and soil organic C. The active fraction of organic matter plays a very important role in aggregate stability and rainfall infiltration. Building up active C levels in the soil in rainfed cropping systems may have a greater impact in reducing surface crusting and improving rainfall infiltration capacity than would simply changing to zero-tillage systems. Management practices designed to maximize C inputs and to maintain a high proportion of active C should be seen as essential steps towards more sustainable cropping systems.

In biology, mineralization refers to a process where an inorganic substance precipitates in an organic matrix. This may be due to normal biological processes that take place during the life of an organism such as the formation of bones, egg shells, teeth, coral, and other exoskeletons. This term may also refer to abnormal processes that result in kidney and gall stones

Biomineralization, also known as biologically-controlled mineralization, occurs when crystal morphology, growth, composition, and location is completely controlled by the cellular processes of a specific organism. Examples include the shells of invertebrates, such as Molluscs and Brachiopods. Additionally, mineralization of collagen provides the crucial compressive strength for the bones, cartilage, and teeth of vertebrates.[4] See also biomineralization.

Organo mineralization

This type of mineralization includes both biologically-induced mineralization and biologically-influenced mineralization.

Biologically-induced mineralization occurs when the metabolic activity of microbes (e.g. bacteria) produces chemical conditions favorable for mineral formation. The substrate for mineral growth is the organic matrix, secreted by the microbial community, and affects crystal morphology and composition. Examples of this type of mineralization include calcareous or siliceous stromatolites and other microbial mats. A more specific type of biologically-induced mineralization, remote calcification or remote mineralization, takes place when calcifying microbes occupy a shell secreting organism and alter the chemical environment surrounding the area of shell formation. The result is mineral formation not strongly controlled by the cellular processes of the metazoan host (i.e. remote mineralization), and may lead to unique or unusual crystal morphologies. Mineralization can be subdivided into different categories depending on the following: the organisms or processes that create chemical conditions necessary for mineral formation, the origin of the substrate at the site of mineral precipitation, and the degree of control that the substrate has on crystal morphology, composition, and growth. These subcategories include: biomineralization, organo mineralization, and inorganic mineralization, which can be subdivided further. Biologically-influenced mineralization takes place when chemical conditions surrounding the site of mineral formation are influenced by abiotic processes (e.g. evaporation or degassing). However, the organic matrix (secreted by microorganisms) is responsible for crystal morphology and composition. Examples include micro- to nano-meter scale crystals of various morphologies. Inorganic mineralization is a completely abiotic process. Chemical conditions necessary for mineral formation develop via environmental processes, such as evaporation or degassing. Furthermore, the substrate for mineral deposition is abiotic (i.e. contains no organic compounds) and there is no control on crystal morphology or composition. Examples of this type of mineralization include cave formations, such as stalagmites and stalactites. Biological mineralization can also take place as a result of fossilization.

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