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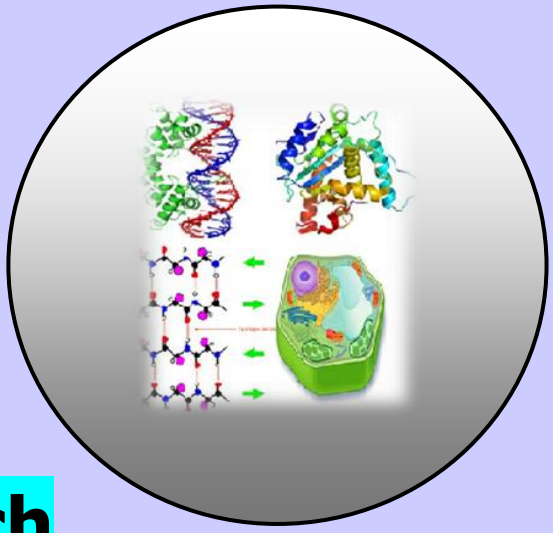

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REVIEW ARTICLE

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Carbon Cycling in Nature: A Review

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ABSTRACT

Abiotic and biotic controls on decomposition and mineralization determine nutrient availability to autotrophs. *Decomposers* ***are an important group, which have the special function within a community of breaking down dead or decaying matter into simpler substances with the release of inorganic salts, making them available once more to the primary producers.*** *Primary decomposers* ***are those organisms that attack the freshly dead organic matter. These include earthworms and some species of arthropods and fungi. Fungi are particularly important in the initial decomposition of fibrous and woody material.*** *Secondary decomposers* ***are those organisms that live on the waste products of other decomposers and include bacteria and many species of fungi. As ecosystems develop and the pool of soil organic matter increases, decomposition becomes an important source of nutrients, particularly N and P Decomposition is the breakdown of complex organic matter from detritus associated with consumption by detritivores for energy and nutrient consumption Fragmentation is the progressive breakup of detritus into smaller bits, associated with consumption of dead organic matter by detritivores Conversion of organic forms of nutrients to inorganic forms is called mineralization A typical mineral soil contains between 2 and 5 per cent organic matter. This is made up of*** *living organisms* ***such as plant roots, earthworms, insects, fungi and bacteria. On death these then decompose along with any other organic matter that is incorporated, either naturally such as leaves or by the addition of organic matter from elsewhere such as compost, farmyard manure, spent mushroom compost, coir and bark. Many of the living organisms are responsible for the decomposition of the*** *dead organic matter*. ***This is eventually broken down into its component parts becoming carbon dioxide, water, and minerals; all of which is recycled. There also persists for a very long time a group of organic compounds collectively known as*** *humus*. ***We measure geochemical parameters in water and sediment samples, including concentrations of nutrients, redox species (e.g., sulfate, sulfide, reduced iron, dissolved inorganic carbon, etc.), organic matter (e.g., DOC, volatile fatty acids) and dissolved gases (e.g., CH4, N2O, H2) concentrations.***
Key words: Carbon Cycle, Soil, Mineralization and Organic Matter.

INTRODUCTION

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. 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 (Burke et al., 1989). These subcategories include: biomineralization, organomineralization, and inorganic mineralization, which can be subdivided further. However, usage of these terms varies widely in scientific literature because there are no standardized definitions.

Biomineralization

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 (Mikutta and Kaiser, 2011)

Organomineralization

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 (Hartz et al., 200a).

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.

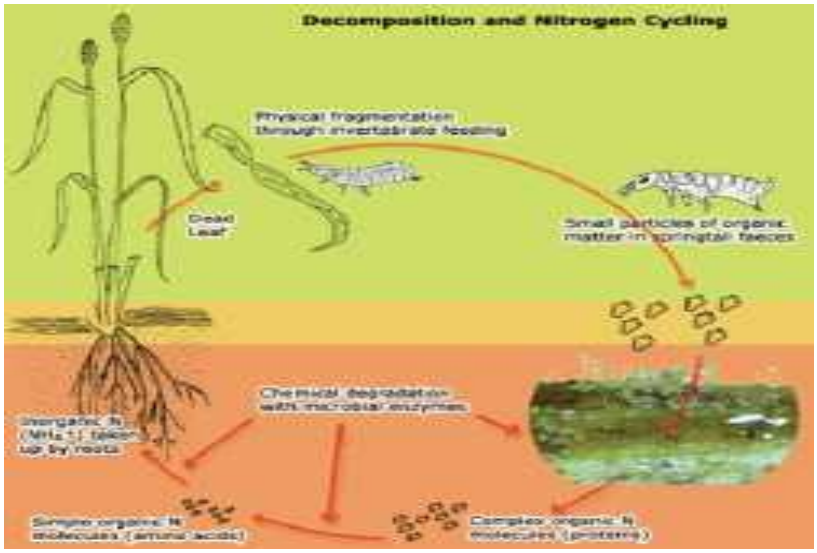

Fig 1. Decomposition soil organic mineralization.

Inorganic Mineralization

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.

Anaerobic carbon cycling in Lakes Fryxell and Vanda

The decomposition (or mineralization) of organic matter recycles carbon and essential nutrients in terrestrial and aquatic environments. The basic processes involved in organic matter decomposition are fundamentally similar in all ecosystems, but variations in environmental factors can drive differences in mineralization rates and efficiencies (the amount of recycled organic matter relative to that which is deposited in sediments). Organic matter decomposition involves processes such as hydrolysis, fermentation, and terminal metabolism that are mediated by microorganisms. Organic matter mineralization rates are influenced by many factors, including organic matter reactivity, redox conditions and the availability of terminal electron acceptors, bulk ion concentration and composition, microbial community composition, and temperature. Bulk organic matter is a complex mixture of biomaterials with distinct reactivities; some materials (e.g. carbohydrates) degrade rapidly while others (e.g. lignin) are more resistant to degradation. The relative abundance of reactive versus recalcitrant compounds influences mineralization rates.

In Lakes Fryxell and Vanda, the bottom waters are anoxic, as are the sediments. These two lakes have different sulfate concentrations (lower in Fryxell than Vanda), which drive differences in both microbial community structure and activity. The presence or absence of sulfate determines to a large extent the relative production of CH_4 versus CO_2 during anaerobic degradation of organic carbon. In high sulfate sediments (e.g., marine sediments), sulfate is the primary oxidant and CO_2 the primary product of organic carbon mineralization; methanogenesis becomes important in such habitats only after sulfate is depleted.

In low sulfate sediments (e.g., freshwater sediments), methanogenesis is the dominant anaerobic terminal metabolic pathway and both CH_4 and CO_2 are produced. The key methanogens in most habitats are hydrogenotrophic methanogens, which convert $CO_2 + H_2$ to CH_4, and acetoclastic methanogens, which split acetate to CH_4 and CO_2. In some cases, methanogenesis can be fueled by alternate substrates such as methylated amines, formate, or methanol. Homoacetogens, which convert H_2 and CO_2 to acetate, may play an important role in anaerobic carbon cycling as well, though this process is more poorly understood than sulfate reduction or methanogenesis. The role of microbial community composition on mineralization rates is less clear, but seasonal changes in microbial community structure may influence the rates and products of mineralization. Temperature influences mineralization rates directly by influencing microbial activity but may also affect distinct types of microorganisms to varying degrees. For example, homoacetogenesis appears to be favored over hydrogenotrophic methanogenesis at low temperature, so variable environmental temperatures can strongly regulate carbon flow under sulfate-depleted conditions.

A diverse microbial community mediates organic carbon mineralization in anaerobic habitats. Particulate organic matter is first hydrolyzed to high molecular weight dissolved organic matter (HMW-DOM) **(**left, figure 1**).** This HMW-DOM is further hydrolyzed and fermented to low molecular weight dissolved organic matter (LMW-DOM), which may undergo additional fermentation (primary fermentation) to generate alcohols, amino acids, and volatile fatty acids (VFA), including acetate. The products of primary fermentation may undergo secondary (2º) fermentation to smaller VFAs or they may be converted to hydrogen (H_2), CO_2, and CH_4. Finally, the products of 2º fermentation are terminally metabolized to CH_4 and/or CO_2. Secondary fermentation reactions are critical in methanogenic habitats because methanogens require simple (C_1, C_2) substrates. Sulfate reducers usually out-compete methanogens for primary substrates (H_2, acetate), so in sulfate-containing water or sediments, sulfate reduction rates usually exceed methane production rates by a significant margin. Competition for CO_2 and H_2 between hydrogenotrophic methanogens and acetogens may further regulate methane production in the environment.

Methane dynamics in anoxic habitats

A fascinating intersection of the sulfur and carbon cycles in anoxic habitats involves the anaerobic oxidation of methane (AOM). In stark contrast to other processes in the global CH_4 cycle (e.g. methanogenesis; aerobic methanotrophy), AOM is somewhat of a microbiological and biogeochemical enigma. AOM occurs in the anoxic sediments and water columns of both freshwater and marine systems. However, the pathway(s) of AOM and the controls on AOM in the environment are unclear, and our understanding of the diversity and associations of microorganisms involved in AOM is incomplete. In marine sediments, measurements of AOM rates and modeling results suggest that up to 98% of the CH_4 produced is oxidized anaerobically near the SO_4^{2-}-CH_4 interface. Similarly, rates of AOM in the water column of hypersaline lakes effectively reduces (by up to 98%) the efflux of CH_4 to the atmosphere. The generally accepted biochemical mechanism of AOM in marine sediments involves syntrophic coupling between a CH_4 oxidizer and a sulfate reducing bacterial (SRB) partner to effectively reverse the methanogenic CO_2 reduction pathway (i.e. CH_4 is oxidized to CO_2 and electrons, released as either H_2 or as an organic compound).

Much of the available biomarker and molecular ecological data from marine systems supports the syntrophic consortium hypothesis and putative methanotrophic *Archaea*, and SRB partners have been identified in several environments. However, other molecular biological and biomarker data that suggests the involvement of multiple archaeal and bacterial groups in AOM, some of which are not associated with a syntrophic partner. Recent evidence documents the coupling of AOM and denitrification, so AOM may be supported by electron acceptors other than sulfate. It is likely that additional electron acceptors for AOM remain to be discovered. These data underscore the current poor understanding of the microbiological and biogeochemical conditions that support this globally critical process.

MATERIAL AND METHODS

The organic matter reduces the effectiveness of common soil additives (lime/cement) in stabilization projects. The researchers developed a technique using UV-Vis spectroscopy to measure the harmful organic matter in another project (0-5540). This project consisted of purchasing three UV-Vis instruments, equipping them with software to measure the organic matter and doing two trainings with the semnan department of desert science Four laboratories analyzed 20 natural soil samples and three laboratory standards to determine repeatability and reproducibility between the laboratories. Researchers also continued testing real project soils to see what mitigation techniques researchers could use. Researchers determined that three replicates need to be run to achieve 95 percent confidence that the measured value is the true value. Researchers determined that soils with organic matter below 1.5 percent can be safely treated, and soils with an organic matter to Eades and Grim optimum lime (OM:EG) ratio less than 0.5 have the greatest potential for mitigation with additional lime application. Additionally, calcium chloride added to the soil with the lime improved the formation of pozzolanic reaction products and strengths of some soils. This work illustrates the complex nature of organic interactions with soil stabilizers and the many questions left unresolved.

RESULTS

So far, our results are quite intriguing. We show that: (1) the rate of methanogenesis is ~30X higher in Fryxell bottom waters and sediments than in Vanda; (2) sulfate reduction occurs in both the water column and sediments of Fryxell but only in the sediments of Vanda; the sulfate reduction rate is ~14X higher in Vanda sediments than in Fryxell sediments; and, (3) AOM occurs in Fryxell in zones where sulfate is rapidly being consumed but highest AOM rates occur where sulfate concentrations are very low (**Fig 2**). Though methanogenesis in Fryxell occurs exclusively in the sediments, AOM occurs in both the upper layers of the sediments and in the water column (**Figure 2**).

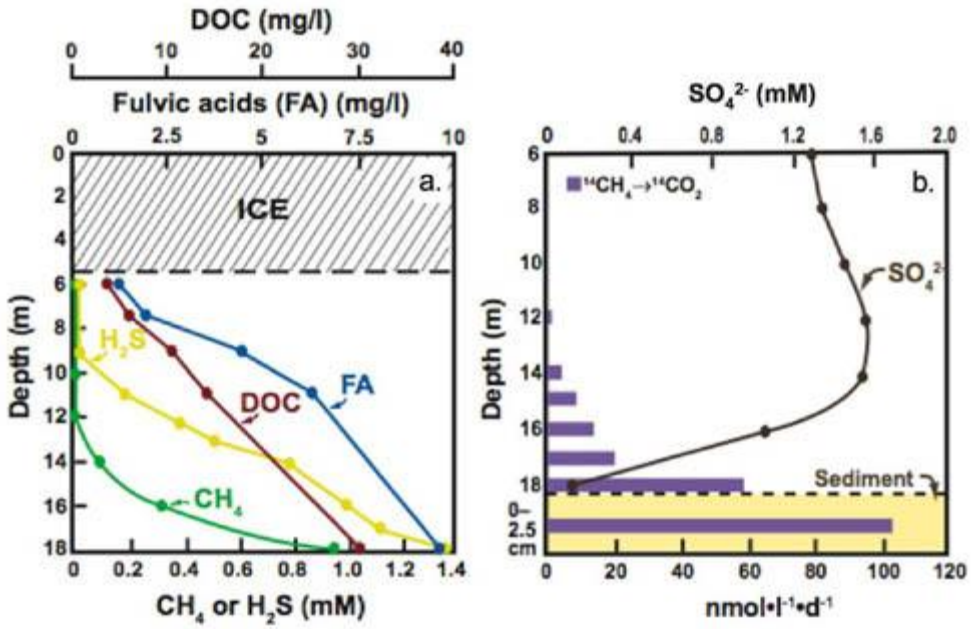

Fig. 2 Show the geochemistry (a) and rates of AOM relative to sulfate concentration (b) in the water column and surficial sediments; fulvic acids.

In organic gardening, all nutrients are supplied through the process of mineralization. As organic matter is decomposed by the microorganisms that digest the cellulose and hemi-cellulose, minerals contained within the cells of the animal or plant tissues are released into the soil. After the microorganisms have digested all digestible cells, they die. Since their bodies consist mostly of proteins, the proteins are broken down by enzymes, releasing more nutrients, mostly nitrogen (N), into the soil. The rate of mineralization is dependent on temperatures in the soil. Under laboratory conditions, mineralization rates are measured at room temperature, 72 degrees. Moist soil samples are held in temperature-controlled containers for several days, then the amount of available nitrogen in the soil is measured. This process is repeated until the figures are stable. Mineralization rates are faster at temperatures above room temperature and significantly slower at temperatures below room temperature. At 72 degrees, the mineralization of compost is between eight and 10 percent. Mineralization of organic matter stops when soil temperatures approach the freezing point. The rate of mineralization has a major effect on plant growth. Because soils are cooler in the early spring, the rate of growth is often reduced for early spring crops such as peas, cabbage, broccoli, cauliflower, lettuce and spinach. Cooler soils mean fewer nutrients becoming available. This problem can be minimized by selecting south-facing slopes for early spring and late fall crops. Planting the crops on ridges is another method of encouraging early warming of soils. A soil raised above a natural grade warms faster than a soil that is level on grade. Covering the area to be planted with a sheet of clear polyethylene several weeks before planting, followed by ridging and covering the ridges with black plastic mulch, is labor intensive but will stimulate early mineralization. Soils warm very rapidly under clear plastic due to the greenhouse effect. However, anticipate early growth of spring weeds, requiring light cultivation or spraying with horticultural vinegar.

If existing soils contain less than three percent organic matter, an initial application of four cubic yards of compost or animal manure the first year followed by repeated applications at two cubic yards in successive years (or on alternate years for sandy soils) can be adequate. In silt or clay loam soils, these levels may be excessive, requiring greater dependency on soil test results. Initially, compost or animal manure should be incorporated to a depth of six to eight inches, deeper if possible. Because organic matter reduces the bulk density of soils, deep incorporation promotes deep rooting, making crops more tolerant to drought. As deep incorporation of organic matter promotes deep rooting, the roots that penetrate this region will continue to maintain the organic matter concentration in that region. Repeated applications of compost or animal manure should be incorporated only in the upper three inches of soil. This results in concentrating the nutrients in the region where seed germination occurs and where roots of new transplants initiate growth. Leaching will move nutrients deeper into the soil as the growing season progresses.

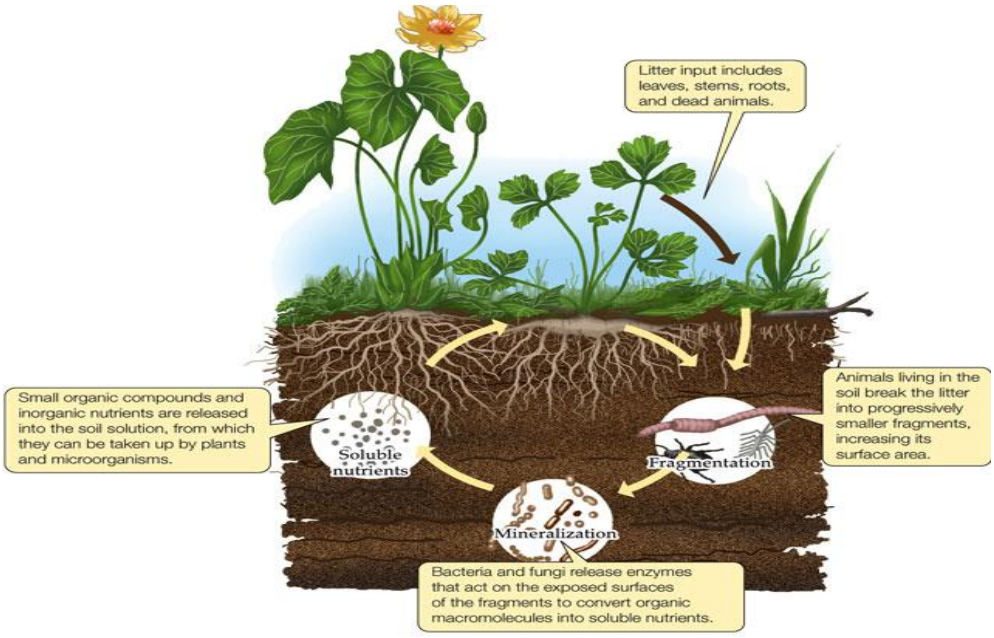

Fig 3. Fragmentation is the progressive breakup of detritus into smaller bits, associated with consumption of dead organic matter by detritivores Conversion of organic forms of nutrients to inorganic forms is called mineralization

CONCLUSION

Nutrient cycling - the movement of nutrients within ecosystems, as they undergo biological, chemical, and physical transformations; the rate of nutrient cycling depends on the nature of the element, and environmental controls over transformations. Rates of cycling estimated using the mean residence time the influence of climate on rates of decomposition is greater than its influence on primary productivity Retention of nutrients in an ecosystem is related to uptake into biological and physical pools and to the stability of the nutrient forms.

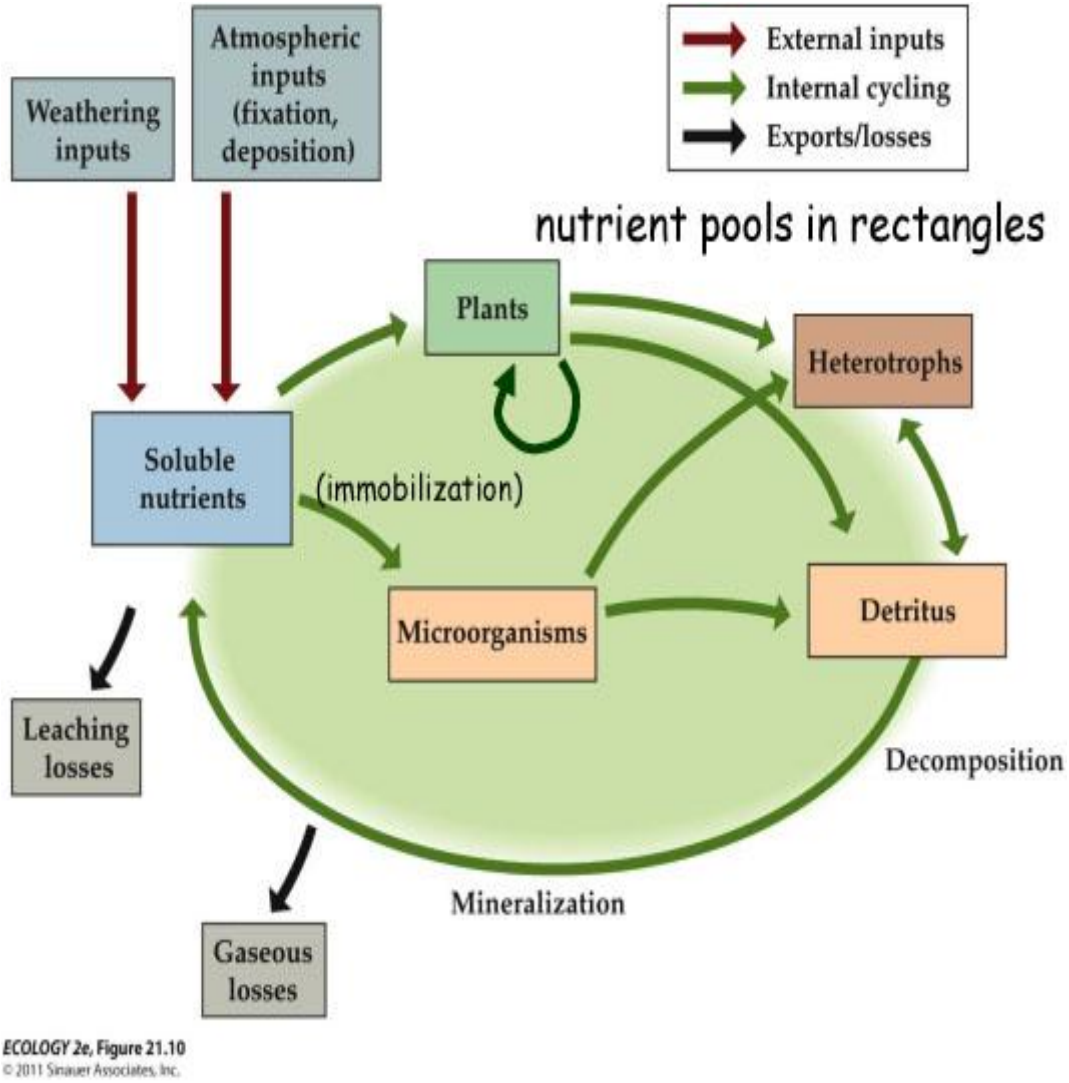

Fig 4. Show simple mineralization in soilare lost from an ecosystem when.

* They leach out of the root zone, and into groundwater and streams,
* lost as gases
* converted into chemical forms that cannot be used by organisms (e.g. occlusion of phosphorus, formation of a chemically stable, biologically unusable form
* biomass is removed (e.g. wind, removal by humans- logging, haying)

Soils have an innate ability to supply crops with plant-available nitrogen throughout a growing season, a process known as nitrogen (N) mineralization. This supply of plant-available N comes from soil microbes decomposing organic matter into ammonium (NH_4^+), which is then quickly transformed into nitrate (NO_3^-) via nitrification. These forms of nitrogen (NH_4^+ and NO_3^-) are the preferred forms of nitrogen for plant uptake. However, the challenge to growers is how best to synchronize plant uptake with both the rate and timing of N mineralization from organic amendments, in order to gain maximum possible benefit for crop yield.

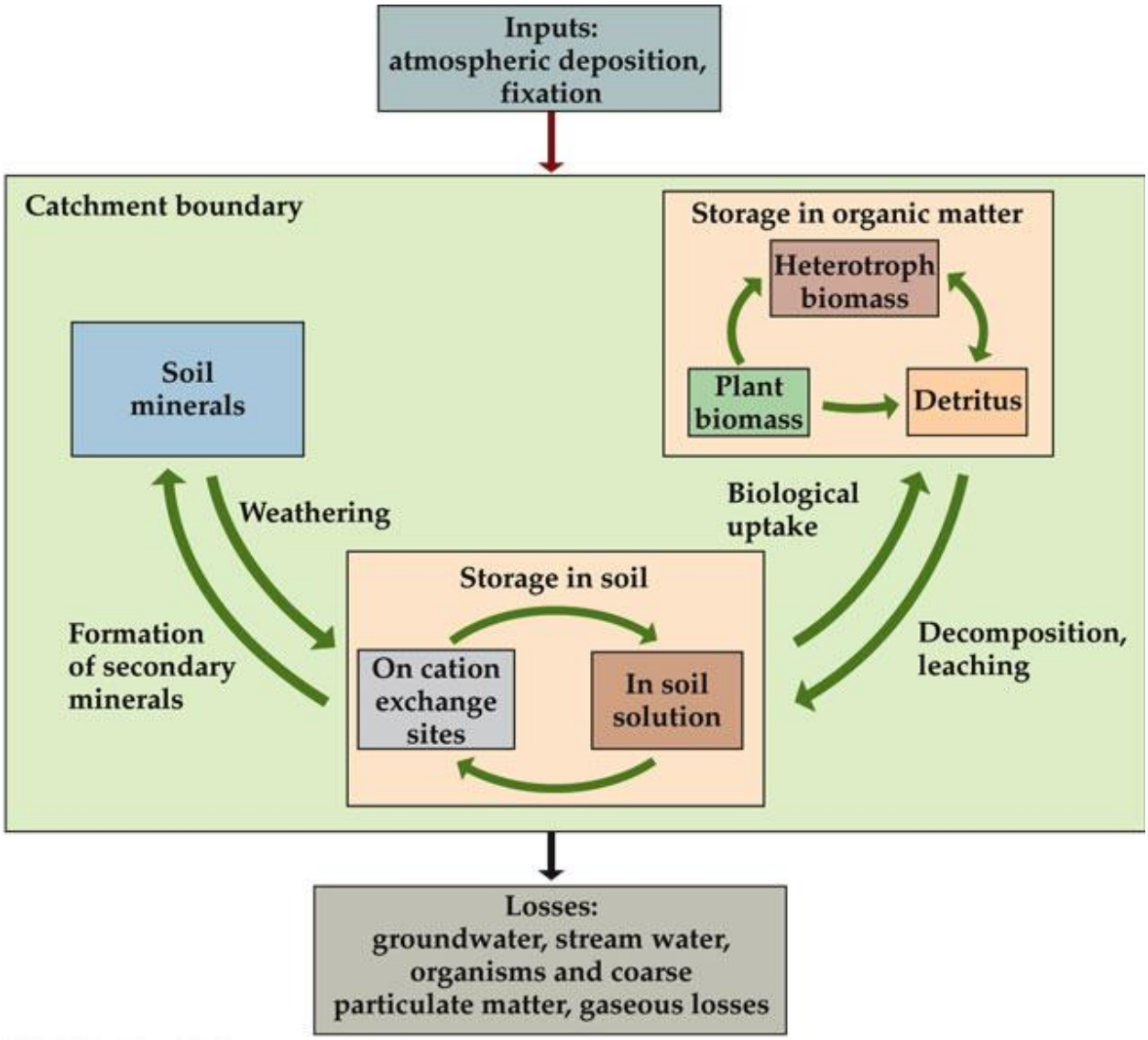

Fig 5. Show soil mineral realation to soil secondary mineral.

Click the graphic at left to explore the factors that affect the mineralization of organic N sources in soil. Soils with higher clay content have been shown to have higher nitrogen mineralization rates (Colman and Schimel, 2013). This can be partially attributed to the fact that higher clay content soils tend to have higher organic matter contents. Higher clay soils also have increased moisture retention, which increases mineralization rates, as is discussed later. Recent studies have explored the possibility of certain characteristics of clay minerals to protect organic matter from mineralization, but the results are unclear on the overall effect on N mineralization to find your soil texture you can use this website or use the Soil Web app for I Phones.

A higher total soil N content results in higher N mineralization rates. However, since soil N content is related to soil organic matter content, it is not a fixed characteristic of a soil. You can increase your total soil N content through continuous inputs of organic materials, although it takes several years for the benefits to be apparent.

An increase in soil temperature increases biological activity which, in turn, increases the N mineralization rate of incorporated organic materials. This effect is small at soil temperatures less than 90°F, but then increases dramatically up to 105°F. Although there are significant differences in soil temperature across the state, soil temperatures are usually less than 90°F. However, when temperature is coupled with soil moisture, you can see rates more than double at optimal moisture contents.

Nitrogen mineralization rates will generally increase as soil moisture increases. This is due to a redistribution of organic materials throughout the soil, which makes them available to more soil microbes to be mineralized. Although the N mineralization rate plateaus after it reaches this optimum moisture content, saturated conditions encourage denitrification. Denitrification will occur due to decreased transport of gases (i.e. oxygen), which encourages anaerobic conditions and increased production of nitrous oxide. Therefore, to maximize mineralization and minimize losses, soil moisture should be kept in a "sweet spot", as illustrated in the figure to the left. This optimal moisture content, where the N mineralization rate begins to plateau, will vary according to soil texture, structure, and aggregation and is therefore difficult to standardize using straightforward measures of soil moisture content.

There are ten common species of earthworm in Britain that vary in size from *Lumbricus terrestris*, which can be in excess of 25 cm, to the many small species less than 3 cm long (see Figure 18.1). The main food of earthworms is dead plant remains. Casting species of earthworms are those that eat soil, as well as organic matter, and their excreta consist of intimately mixed, partially digested, finely divided organic matter and soil. Many species never produce casts and only two species regularly cast on the surface giving the worm casts that are a problem on fine grass areas, particularly in the autumn (see Figure 18.2). It has been estimated that in English pastures the production of casts each year is 20–40 t/ha, the equivalent of 5 mm of soil deposited annually. This surface casting also leads to the incorporation of the leaf litter and the burying of stones. However, *L. terrestris* is the organism mainly responsible for the burying of large quantities of litter by dragging plant material down its burrows.

The network of burrows which develops as a result of worm activity is an important factor in maintaining a good structure, particularly in uncultivated areas and in soils of low clay content. Some species live entirely in the surface layers of the soil others move vertically establishing almost permanent burrows down to two meters.

Earthworm activity and distribution is largely governed by moisture levels, soil pH, temperature, organic matter and soil type. Most species tend to be more abundant in soils where there are good reserves of calcium. Earthworm populations are usually lower on the more acid soils, but most thrive in those near neutral. Worm numbers decrease in dry conditions, but they can take avoiding action by burrowing to more moist soil or by hibernating. Each species has its optimum temperature range; for *L. terrestris* this is about 10°C, which is typical of soil temperatures in the spring and autumn in the UK. Soils with low organic matter levels support only small populations of worms. In contrast, compost heaps and stacks of farmyard manure have high populations. In oak and beech woods where the fallen leaves are palatable to worms, their populations are large and they can remove a high proportion of the annual leaf-fall.

This also happens in orchards unless harmful chemicals such as copper have reduced earthworm populations. Light and medium loams support a higher total population than clays, peat and gravelly soils. Slugs, snails and arthropods (such as millipedes, springtails and mites), and nematodes are also found in high numbers and play an important part in the decomposition of organic matter. Several species are also horticultural pests (see Horticultural pests).

Bacteria

Bacteria are present in soils in vast numbers. About 1000 million or more occur in each gram of fertile soil. Consequently, despite their microscopic size, the top 150 mm of fertile topsoil carries about one tonne of bacteria per hectare. There are many different species of bacteria to be found in the soil and most play a part in the decomposition of organic matter. Many bacteria attack minerals; this leads to the weathering of rock debris and the release of plant nutrients. Detoxification of pesticides and herbicides is an important activity of the bacterial population of cultivated soils. Soil bacteria are inactive at temperatures below 6°C, but their activities increase with rising temperature up to a maximum of 35°C. Bacteria which are actively growing are killed at temperatures above 82°C, but several species can form thick-walled resting spores under adverse conditions. These spores are very resistant to heat and they survive temperatures up to 120°C. Partial sterilization of soil can kill the actively growing bacteria, but not the bacterial spores. The growth rate and multiplication also depends upon the food supply. High organic matter levels support high bacteria populations so long as a balanced range of nutrients is present. Bacteria thrive in a range of pH 5.5–7.5; fungi tend to dominate the more acid soils. Aerobic conditions should be maintained because the beneficial organisms, as well as plant roots, require oxygen, whereas many of the bacteria that thrive under anaerobic conditions are detrimental.

Fungi

The majority of fungi live saprophytically on soil organic matter. Some species are capable only of utilizing simple and easily decomposable organic matter whereas others attack cellulose as well. There are some important fungi that can decompose lignin, making them one of the few primary decomposers of wood and fibrous plant material. Several fungi in the soil are parasites and examples of these are discussed in Horticultural diseases and disorders. Fungi appear to be able to tolerate acid conditions and low calcium better than other micro-organisms and are abundant in both neutral and acid soils. Most are well adapted to survive in dry soils, but few thrive in very wet conditions. Their numbers are high in soils rich in plant residues but decline rapidly as the readily decomposable material disappears. The bacteria persist longer, where present, and eventually consume the fungal remains.

The rhizosphere

The rhizosphere is a zone in the soil that is influenced by roots. Living roots change the atmosphere around them by using up oxygen and producing carbon dioxide (see respiration). Roots exude a variety of organic compounds that hold water and form a coating that bridges the gap between root and nearby soil particles. Micro-organisms occur in greatly increased numbers and are more active in proximity to roots. Some actually invade the root cells where they live as symbionts. The *Rhizobium spp*. of bacteria lives symbiotically with many legumes (see nitrogen cycle).

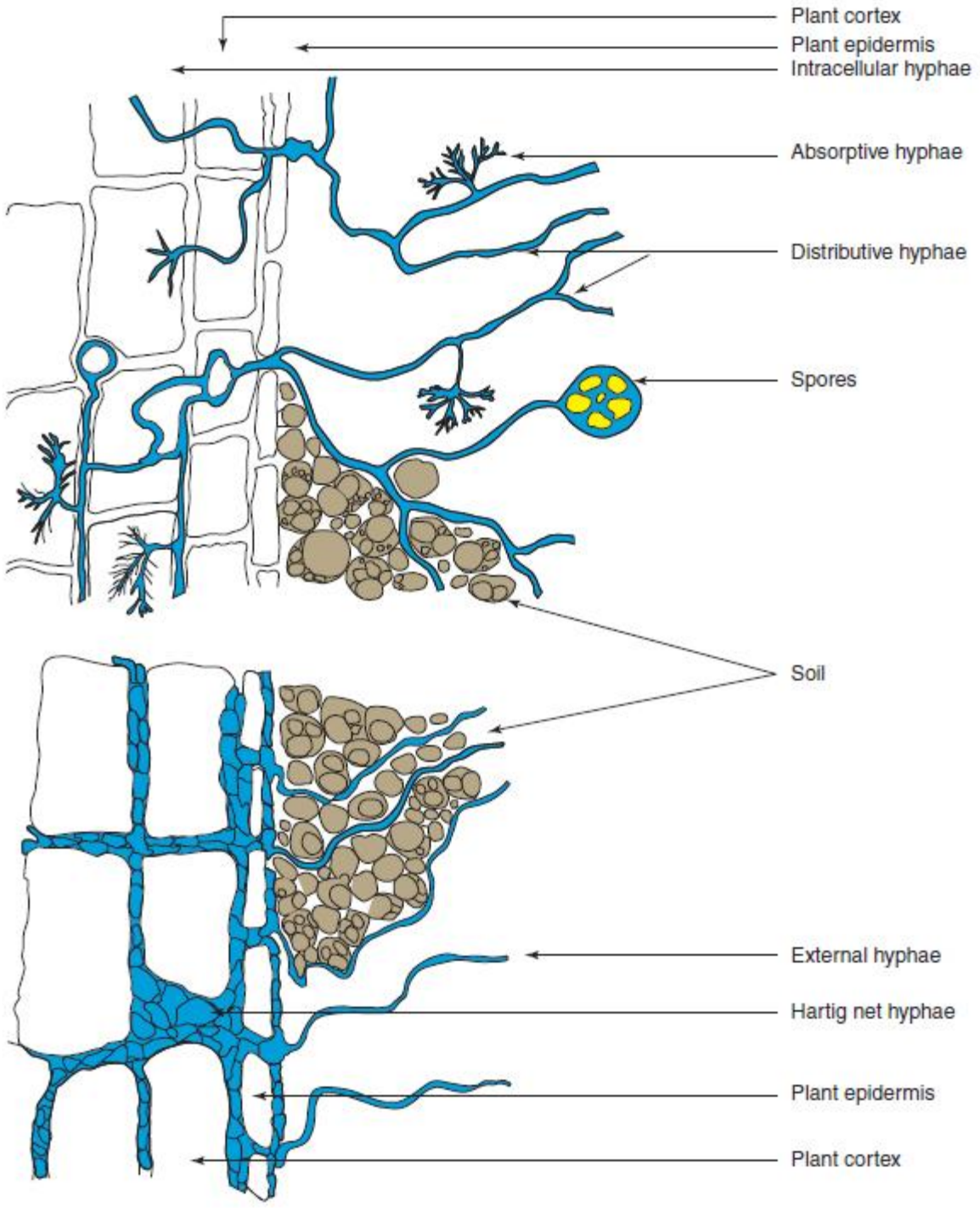

Fig 6. Mycorrhizal structures. Ectomycorrhizae, top found mainly around tree roots have most of their structure on the outside whereas the Endomycorrhiza have most of their hyphae on the inside of the very wide range of plants with which they are symbiotic

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