# Chapter 1
# Soil: The Living Matrix

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## 1.1 Introduction

Around the world, farmers are very intelligent and know the characteristics of soil. They know many things about the soil that scientists do not, and scientists know many things that farmers do not, so these two groups of workers must work together. This is true of North American, European, and Asian countries. Farming practices are based on empirical experience; some of these practices may not stand up to scientific testing, but others obviously must do.

The importance of soil structure as a factor in soil fertility is becoming increasingly clear. If a plant is to grow, its roots must spread so that their delicate structures of root hairs can get access to plant nutrients. They also only thrive if there is an adequate supply of water and air. In several countries with plantations of sugarcane, the continuous high yields obtained through irrigation and the extensive application of manure and fertilizers have created problems. Chemical analyzes of the soils from such areas show that common plant nutrients are still present, but that something has happened to the soil that is interfering with its productivity. At first it was thought that the cane itself is deteriorating, but this is not likely, as it propagates vegetatively. Instead, unfavorable conditions for beneficial soil microorganisms may have been produced. The deterioration of the soil structure seems to play a direct part in this, because soil microorganisms have an important influence on the soil structure. Soil organic matter – the formation, decomposition, and transformation of which are caused by microorganisms – is of great importance to sustainable soil fertility and soil structure.

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More experiments on soil structure and other physical properties of soils, such as permeability, porosity, and moisture retention capacity, are desirable. Soil fertility depends on a large number of complex factors, not all of which are known. Physical properties of the soil are no less important than chemical properties. The clay fraction determines many physical and chemical properties of soils. The properties of clays are determined by their mineralogical compositions. X-ray studies and differential thermal analyses of clays have now become necessities in soil laboratories. The electrochemical properties of clays are fundamentally important to understanding soil behavior. This chapter introduces the various types of soil and their functions, as well as the pollution of the soil with heavy metals, which is detrimental to the health of the soil.

## 1.2 Soil Taxonomy and Classification

A soil taxonomist distinguishes soils partly on the basis of the kind of diagnostic horizon(s) present in each soil. The current soil taxonomy (classification) was adopted in 1965; a simplified account of this classification system follows below (see US Soil Survey Report 1972, 1975).

*Order*. This is the most general category. All soils fit into one of ten orders.

*Suborder*. Suborders within a soil order are differentiated largely on the basis of soil properties and horizons resulting from differences in soil moisture and soil temperature. Forty-seven suborders are presently recognized.

*Great group*. Soil great groups are subdivisions of suborders. The 185 great groups found in the US, and 225 worldwide, have been established largely on the basis of differentiating soil horizons and soil features. The soil horizons include those that have accumulated clay, iron, and/or humus, and those that have pans (hardened or cemented soil layers) that interfere with water movement or root penetration.

*Subgroup*. Each soil great group is divided into three kinds of subgroups: one representing the central (typic) segment of the soil group; a second that has properties that tend toward other orders, suborders, or other great groups (intergrade group); and a third that has properties that prevent its classification as typic or intergrade. About 970 subgroups are known in the United States.

*Family.* Subgroups contain soil families, which are distinguished primarily on the basis of soil properties important to the growth of plants or the behavior of soils when used for engineering purposes. These soil properties used include texture, mineral reactions (pH), soil temperature, precipitation pattern of the area, permeability, horizon thickness, structure, and consistency. About 4,500 families have been identified in the United States.

*Series.* Each family contains several (similar) soil series. The 10,500 or more soil series in the United States have narrower ranges of characteristics than a soil family. The name of the soil series has no pedogenic (i.e., related to soil formation) significance; instead, it represents a prominent geographic name of a river, town, or area near where the series was first recognized. Soil series are differentiated on the basis of observable and mappable soil characteristics, such as color, texture, structure, consistency, thickness, reactions (pH), and the number and arrangement of horizons in the soil pedon as well as their chemical and mineralization properties. Terms describing surface soil texture, percentage slope, stoniness, saltiness, erosion, and other conditions are called *phases*. Mapping units are created by adding phase names to series names. All mapping units are polypedons. Prior to 1971, soil type was a mapping unit that was used to denote a subdivision of a series indicating the series name and surface texture. Soil type is no longer official nomenclature; it has been replaced by series phase.

The *prime land* means the best land. The definition of prime land will change depending on the use of the land, and full agreement as to exactly how "prime" should be defined is unlikely, even for a specific land use. For farmland use, it is proposed that prime land should meet all the following requirements: adequate natural rainfall or adequate and good-quality irrigation water for intended use; mean annual temperature >32°F (0°C) and mean summer temperature >46°F (8°C); lack of excessive moisture – flooding should not occur more often than once every two years; water table should be below the rooting zone; soil should not be excessively acidic, alkaline, or saline; soil permeability should be at least 0.38″ $h^{-1}$ (1.0 cm $h^{-1}$) in the upper 20″ (51 cm); the amount of gravel, cobbles, or stones should not be excessive enough to seriously interfere with power machinery; any restricting layer in the soil should be deep enough to permit adequate moisture storage and unhampered root growth, and; the soil should not be excessively erodible.

The objectives of soil surveys and taxonomy are to facilitate growth on soils that have never been grown on before, and to learn enough about certain soils to predict how they would respond when irrigated with a specific quantity of irrigation water of known quality. This objective also emphasizes the inclusion of a rational means of transferring technology from one soil to another, interpretations that allow the prediction of land use for every soil mapped, and that the survey should serve as a scientific database. Soil surveying has developed into a specialized subject. A survey report contains information on not only the characteristics of the soil and its profile, but also the existing and potential uses of the land, the yields obtained by the farmer or by experimental stations under different systems of management, erosion and drainage conditions, and the potential for reclamation or its suitability for irrigation, where these are necessary. Soil maps and survey reports form the basis for planning the utilization of the land, and they have also been found useful in road and building projects.

## 1.3 Soils of the Humid Tropics and Subtropics

The term "tropics" generally refers to areas of the world with high rainfall, dense forests, and many infertile soils. The tropics occur at low elevations within the equatorial zone, while the subtropics extend to the latitudes of 30°N and 30°S. Fifty-one percent of the world's soils occur in the tropics and subtropics. Lowlands in the tropics have a mean annual temperature of greater than 75°F (24°C), and the mean monthly temperature of the coldest month is more than 65°F (18°C). In the low-lying subtropics, the mean annual temperature is between 62 and 75°F (17 and 24°C), and the coldest month averages between 50 and 65°F (10 and 18°C).

Freshly deposited alluvium and soils that are stony, shallow, eroded, poorly drained, or deep and sandy can be found in all humid regions throughout the world. Soils of minimal soil development can be found in temperate, subtropical and tropical regions. The primary differences between the characteristics of soil in the tropics and subtropics and their characteristics in temperate regions result from differences in temperature and major geological events such as glaciations. In the tropics and subtropics, soil temperatures are high every day of the year, whereas in most temperature regions, freezing of the soil interrupts the chemical weathering of minerals and soil profile development, even though there is some physical weathering by freeze–thaw effects. In general, for every 18°F (−10°C) rise in temperature above freezing, the chemical reaction rate is doubled, which means that tropical soils weather much faster than temperate or arctic ones. Weathering in the tropics can be at least eight times faster than in the Arctic and Antarctic regions, and four times faster than in temperate regions. Weathering rates in subtropical regions average about half those of the tropics. Products that remain from the decomposition – iron, aluminum, and some silica – recrystallize to form hydrous oxides of iron, aluminum, and sometimes titanium, plus some kaolinite clay. In soils of the tropics, many composite particles the size of sand granules consist of altered minerals cemented together by iron, in contrast with the composition and structure of sand particles in temperate and arctic regions, which are mostly primary minerals such as quartz and feldspars. Predominant soil orders that develop only in the tropics and subtropics are Oxisols, Ultisols and Vertisols.

Organic matter is rapidly lost from tropical soils following the clearing and cultivation of land because mixing and aeration increase the rate of decomposition; organic matter loss is a primary cause of decreasing crop yields in the tropics. A decrease in soil organic matter results in soil structure deterioration, lower plant nutrient reserves from organic matter, and a reduced cation exchange capacity. Ninety percent of all soils in Western Africa, Latin America and India are deficient in available phosphorus. Particularly large amounts of phosphorus fertilizers are needed on Oxisols, Ultisols, and Vertisols, as well as on tropical soils that have developed from volcanic and parent materials. Rates of phosphorus as high as 143–1,069 pounds per acre (160–1,197 kg $ha^{-1}$) are needed to increase food crop yields.

Oxisols have a total cation exchange capacity of less than 10 meq per 100 grams of soil; when compared with other soils containing the same levels of clay and organic matter, this is lower than soils from any of the other nine soil orders. Since plant-available potassium is stored as part of the overall soil exchange system, levels of potassium are often deficient for the satisfactory growth of many tropical crops. Oxisols and Ultisols may require treatment with lime to correct the soil pH or to reduce the toxic effects of aluminum. Vertisols do not need lime because they usually develop from calcareous materials in a wet–dry climate, and the high clay content and the subhumid climate retard the loss of lime by leaching. Vertisols are not acid enough to develop toxic levels of aluminum. Oxisols and Ultisols have more kaolinite, more gibbsite and more goethite than soils from the other soil orders. These clay minerals do not absorb lime cations, calcium or magnesium as strongly as montmorillonite, which predominates in soils from the drier temperate regions. Tropical soils with pH values of less than 5 are not productive because of deficient levels of nitrogen, phosphorus and frequently potassium, as well as some micronutrients; high soil-solution aluminum and high exchangeable aluminum, which are toxic to the roots of many plants, such as cotton, tomato, alfalfa, celery, barley, corn, grain sorghum, and sugar beets; high exchangeable manganese, which is toxic to many crops; as well as serious calcium, magnesium and molybdenum deficiencies. Shifting cultivation is the pragmatic solution to the problems of cropping tropical soils used in primitive conditions: land is cleared and burned, planted with crops until the soil fertility is exhausted, then abandoned to return to native woody vegetation and rejuvenation, while a new forested site for planting is sought.

In arid and semiarid areas, crop production depends on the conservation of soil moisture. Data on soil water available for plant growth during the growing season form the scientific basis for deciding upon improved cropping systems.

## 1.4 Chemical and Colloidal Properties

Soil pH is one of the most indicative measurements of the chemical properties of a soil. All (bio)chemical reactions in soils are influenced by proton ($H^+$) activity, which is measured by the soil pH. The pH values of most natural soils vary between <3.00 (extremely acid) and 8.00 (weakly alkaline). The solubilities of various compounds (e.g., heavy metals) in soils are influenced by soil pH, as well as by microbial activity and the microbial degradation of pollutants. Optimum pH values for pollutant-degrading microorganisms range from 6.5 to 7.5. Soil pH is influenced by various factors: the nature and type of the inorganic and organic constituents that contribute to the soil's acidity, the soil/solution ratio, the salt or electrolyte content, and the $CO_2$ partial pressure.

The term "heavy metal" refers to any metallic chemical element that has a relatively high density and is toxic or poisonous. Heavy metals are at least five times as dense as water, and light metals have densities that are lower than this. Examples of light metals include sodium, magnesium, and potassium. Examples of heavy metals include mercury, cadmium, thallium, lead, copper, aluminum, arsenic, chromium, and mercury. Fertilizers contain lead and arsenic. Pesticides contain lead, arsenic and mercury. Sewage sludge contains cadmium, arsenic and lead. Irrigation water can transport dissolved metals to agricultural fields, where metals such as cadmium can be incorporated into plants. Copper occurs naturally in soil and plants. It occurs in rocks, soil, water, sediments, and air. Its average concentration in the soil is about 50 parts copper per million parts (ppm) soil. Lead is by far the most the most common contaminant of soils. Lead is virtually a permanent resident in soil. Organic matter, can bind to metals very effectively; for example, the number one source of lead contamination is lead-based paint, which chipped or scraped are off building exteriors over periods of decades or centuries. Other sources are gasoline, exhaust, motor oil, automobiles, tires, industrial activities, coal combustion, and pesticides. Mercury occurs in two forms: organic and inorganic. Inorganic forms most often occur when mercury is combined with chlorine, sulfur or oxygen. Organic forms occur when mercury combines with carbon. Metallic forms of mercury are not absorbed by plants, but are converted by microorganisms to organic forms such as methyl mercury that are taken up by plants. Aluminum toxicity is one of the most common factors that limit plant growth and development in many acid soils. Aluminum is found in clay soils, in aluminum silicates and aluminum oxides, and plays a role in soil acidity.

## 1.5 Soil Water

All soils contain water under natural conditions. The amount of water can be very low in air-dried soils. The optimum water content for microbial processes is 40–60% of the maximum water-holding capacity, or corresponds to the water content that is held in soil at suction pressures of –0.01 to –0.031 MPa. The spaces between soil particles are known as the soil pores; these are filled either with air or water (resulting in a soil solution) depending on the pore size and the water saturation of the soil. Depending on their equivalent diameters, soil pores can be divided into wide coarse (<50 μm), tight coarse (10–50 μm), medium (0.2–10 μm), and fine (<0.2 μm) pores. Pore sizes are assigned in accordance with adaptation to the water content at characteristic metric pressures. Equivalent diameters of 50 and 10 m correspond to water contents of the soil at field capacity 96 and 30 kPa, respectively, while an equivalent diameter of 0.2 m corresponds to the water content at the permanent wilting point (1,500 kPa). The amount of water available to plants and microorganisms lies between the field capacity and the permanent wilting point. Water stored at metric pressures of >1,500 kPa is accessible to neither fine plant roots nor microorganisms. Before undertaking an irrigation project, a soil survey is carried out. The history of irrigation shows that many soils have been damaged or ruined due to a rise in the water table and salinity or alkalinity. The main purpose of a soil survey, however, is to provide an inventory of soil resources. The scope of a soil survey is determined by the purpose in mind (Wilke 2005).

## 1.6 The Living Matrix

The ground is filled with life. Soils are dynamic biological systems and are certainly not static substrates; they support the lives of microbes, plants, and animals. Although microorganisms are invisible to the naked eye, they are very important and useful to the plant world. In fact, life on Earth would cease without their existence.

In the golden era of microbiology, the study of soil organisms soon became an area of interest to a large number of early bacteriologists, and the pioneering investigations of Winogradsky, Omeliansky, and Beijerinck still stand as major contributions to our knowledge of the bacterial population (Hilgard 1911). At the same time, it became apparent to soil chemists that the surface crust of the Earth is not merely a static phytochemical matrix upon which green plants grow; it is also a biological system that is in continuous dynamic equilibrium. In the realm of pure science, information on the ecology, function, and biochemistry of microflora has grown considerably, so that a clear picture of soil biology is beginning to emerge. Microflora are important to the ability of humans to feed themselves. For its microbial inhabitants, the soil functions as a unique ecosystem to which the organism must adapt and from which it must obtain sustenance. The rhizosphere is the compartment from which plants acquire their water and nutrients and a hot spot of microbial and animal activity. This compartment can only be understood in the context of whole soil functioning, from soil genesis to nutrient cycling, including exchanges with water and the atmosphere. In order to emphasize the diversity that results from combining the interactions of very diverse and complex communities of organisms in different types of rock material under various climatic and topographic conditions over timescales that can vary from decades to thousands or even millions of years, many soil scientists prefer to speak of "soils" rather than "the soil." The fate of the soil is linked to five important and relevant questions:

- What are the functions of microorganisms in soil genesis?
- What are the roles played by microorganisms in energy and matter fluxes and their transformations within functioning soils?
- As soil genesis and functioning involve a complex and tightly integrated biocoenosis, which kinds of biotic interactions do soil microorganisms participate in?
- What are the functions of microorganisms in specific domains of soils that are highly influenced by biotic or abiotic factors?

The more complex microorganisms, including algae, fungi and protists, are eukaryotes (i.e., they have a true nucleus). Evolutionary studies have revealed that there is a great diversity of eukaryotic organisms as compared to prokaryotic microorganisms. These organisms show characteristic features and are beneficial in many ways to mankind (see Table 1.1). Based on their nutritional requirements, prokaryotes can be categorized as photoautotrophs, photoheterotrophs, chemolithoautotrophs and chemolithoheterotrophs (Table 1.2).

Finally, considering that soils are difficult media to work on, especially for microbiologists, which approaches to study the microorganisms in soil that take the wide structural and functional diversity of soil microbes into account, but avoid diving too far into details that do not provide explanations for emergent properties and processes that are characteristic of soils, can be employed by soil microbiologists (Buscot and Varma 2005)? Soil formed soon after a volcanic eruption or the retreat of a glacier or water, the initial mother substrate, generally exhibits a reduced capacity to carry an abundant plant and animal biocoenosis. Microorganisms such as bacteria, algae, and their associations with fungi in biofilms of lichen are early colonizers. If the basic substrate is loose, the microbial community, in the form of biological crusts, will provide stabilization and suppress erosion. When the mother substrate consists of a hard rocky material such as granite or limestone, the initial process of soil formation consists of weathering. Both of the basic mechanisms of weathering, – the fractionation of the substrate and its gradual chemical

**Table 1.1** Comparison of the main types of microorganisms

| Microorganisms | Characteristics | Beneficial roles |
|---|---|---|
| Prokaryotes | | |
| Bacteria | Rigid cell wall, divided by binary fission, some capable of photosynthesis | Recycle biomass, control atmospheric composition, components of phytoplankton and soil microbial populations |
| Archaea | Rigid cell wall, unusual membrane structure, photosynthetic membrane, lack chlorophyll | Produce and consume low molecular weight compounds, aid bacteria in recycling dead biomass, some are extremophiles |
| Eukaryotes | | |
| Fungi | Rigid cell wall, single-cell forms (yeast), reproducing by budding, multicellular forms (hyphae, mycelium), no photosynthetic members | Recycling biomass, stimulate plant growth |
| Algae | Rigid cell wall, photosynthetic | Important component of phytoplankton |

**Table 1.2** Nutritional aspects of microbial diversity

| Nutritional type | Energy source | Carbon source | Examples |
|---|---|---|---|
| Photoautotroph | Light | Carbon dioxide($CO_2$) | Photosynthetic bacteria (green sulfur and purple sulfur bacteria), cynobacteria, extreme halophiles |
| Photoheterotroph | Light | Organic compounds | Purple nonsulfur and green nonsulfur bacteria |
| Chemolithoautotroph | Inorganic compounds | Carbon dioxide($CO_2$) | *Nitrosomonas*, *Nitrobacter* |
| Chemolithoheterotroph | Organic compounds | Organic compounds | Most bacteria, fungi, and all animals |

transformation – are bound together. Fractionation enhances the contact surface between the substrate and the environment, which in turn increases the chemical activity and transformation rate. As microorganisms represent the largest biotic fraction in the soil in terms of both biomass and number of organisms, and as they are tightly associated with this huge fractal surface, they play a key role in biogeochemical cycles, including those of climate-relevant gases.

## 1.7 Soils and Plant Nutrition

Analyzing the total N, the C/N ratio, and inorganic N (ammonium, nitrate) provides an insight into the nitrogen supply to soil microflora and plants. The total N content ranges from <0.02% (subsoils) to > 2.5% (peats). A-horizons of mineral soils contain 0.06–0.5% N. Nitrogen, phosphorus, and/or potassium deficiency may limit the microbial decomposition of pollutants in soil. Optimum conditions are achieved at a C:N:P ratio of 100:10:2. Nitrogen is an important nutrient for plants and soil microorganisms. Ammonium and nitrate in the soil are the N sources that are immediately available to plants. These are produced by the mineralization of organic compounds or are added to the soil as fertilizer. Besides ammonium and nitrate, nitrite may also be present, although usually at very minor levels except in neutral and alkaline soils that have recently been treated with ammonium salts or ammonium-forming fertilizers.

Soil phosphorus is, like nitrogen, potassium, calcium, and magnesium, an important nutrient for soil organisms and plants. It exists as inorganic and organic fractions (the proportions of each fraction can vary between 5 and 95%). The soil organic P fraction is derived from plant residues, soil flora, and soil fauna tissues and residues that resist rapid hydrolysis. Inorganic fractions consist of Ca, Al, and Fe phosphates. The most prominent phosphate mineral in soils is apatite. The total concentration in soil is generally in the range from 200 to 800 mg $kg^{-1}$. A considerable amount of P is also bound in the amorphous mineral fraction. Soil microbes are involved in the mineralization of P from organic debris. Extracellular phosphatases are produced by microorganisms and roots and contribute to the mineralization of organic P. Phosphorus deficiency can limit the growth of plants and the microbial decomposition of pollutants in soil.

Without using very large quantities of fertilizers, it would not be possible to maintain agricultural production at the levels that are currently required. Because of this, Europe, America, and Japan have been using fertilizers for a long time. In Japan, roughly half of the plant food comes from bulky organic manures and half from fertilizers. Most of their straw is used to prepare manures and composts, and the Japanese have one of the highest consumptions of fertilizers per unit area of arable land. Bulky organic manures are also a major source of plant food in Europe and America. All practicable measures should be adopted to increase their supply in India too, but fertilizers are required to supplement them. Farmyard manure and composts have their virtues, but we cannot afford to make a fetish of them.

Certain chemical elements known as micronutrients or trace elements are crucial to the growth and health of plants in very small quantities, but are toxic to them at higher levels. When these elements are not taken up by the plants symptoms of diseases appear. Deficiencies of manganese, zinc, and copper are widespread in citrus trees. Such diseases are cured by applying the deficient element to the soil and spraying the trees. Some of these trace elements are now being incorporated in fertilizer mixtures.

## 1.8 Soil Organic Matter

Soil organic matter is one of the most important indicators of soil quality. It influences many soil properties, including nutrient supply (N, P, S), cation exchange capacity, adsorption of pollutants, infiltration and retention of water, soil structure, and soil color, most of which in turn affect soil temperature. Soil organic matter consists of microbial cells, plant and animal residues at various stages of decomposition, stable humus (humic acids, humins) synthesized from residues by microorganisms, and highly carbonized compounds (e.g., charcoal, graphite, coal). Soil organic matter is thus a complex mixture of heterogeneous organic compounds (including sugar, starch, protein, carbohydrates, lignin, waxes, resins, and organic acids) derived from plants, microorganisms and animal residues that are formed through the decomposition, synthetic, and polymerization reactions. The process of organic matter decay in the soil begins with the decomposition of sugars and starch from carbohydrates, which quickly break down as saprophytes initially invade the dead plant. Proteins decompose into amino acids. Organic matter is an essential source of nutrients for all heterotrophic soil organisms, which in turn hold a key position in the humification and mineralization of humic substrates that lead to the production of stable humus, degradable organic compounds, and carbon dioxide.

## 1.9 Soil Texture

Fine earth can be split into three particle size fractions: the sand fraction, with an equivalent diameter of 50 or 63–2,000 μm; the slit fraction (2–50 or 63 μm); and the previously mentioned clay fraction (<2 μm). The proportion of each fraction in fine earth defines the texture of the soil, which is a crucial property as it determines the volume available for the two other soil phases, the gaseous (soil–air) and aqueous (soil–water or soil solution) phases. Sandy soils not only have a higher total volume of water and air, they allow better water percolation and evaporation, resulting in rapid shifts in soil moisture versus soil aeration. Breaking down clay and sand still further leads to the synthesis of nanomaterials, which in turn has a considerable impact on the plant and animal life. The soil texture and soil pore size are also important as they determine the distributions of soil organisms. The classification of organisms used by soil biologists refers to the sizes of soil particles and soil pores (Fig. 1.1).

## 1.10 Permafrost Soils

Permafrost, which is defined as a subsurface frozen layer that remains frozen for more than two years, makes up more than 20% of the land surface of the earth, including 82% of Alaska, 50% of Russia and Canada, 20% of China, and most of the surface of Antarctica (Williams and Smith 1989; Storad 1990). Permafrost poses unique challenges to its resident biota because of the permanently cold temperature of the soils, averaging 10–12°C, and the length of time over which the soils were frozen, which ranges from a few thousand to even 2–3 million years. Antarctica has an area of 14 million $km^2$; however, exposed permafrost soils cover a mere 49,000 $km^2$, or about 0.35% of the entire continent (Campbell and Claridge 2008). In Antarctica, the soil climate and permafrost properties are strongly influenced by the surface radiation balance, since the thermal regime of the soil is dependent upon the gains and

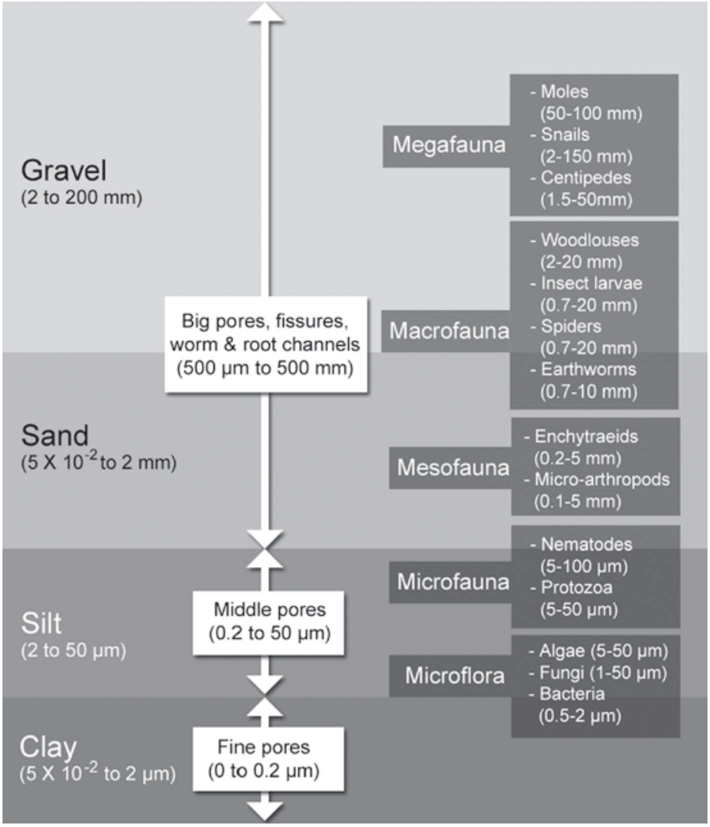


**Fig. 1.1** Classification of soil biota in relation to soil pore and particle size, as used in soil biology (modified from Buscot and Varma 2005)

losses of radiation from the soil surface. Soils with dark-colored surfaces have low albedo values (approximately 5% at Scott Base), while soils with light-colored surfaces have much higher albedo values (26% at Northwind Valley) (Balks et al. 1995; Macculloch 1996). These soils are formed mainly from Precambrian to Lower Paleozoic basement rocks, intruded by granites and peneplained by weathering and glacial erosion, with overlying sediments of sandstones, siltstones, coal measures and tillites. Biodiversity is extremely low, and diminishes with increasing severity of climatic conditions. Primary producers are bryophytes, lichens, cyanobacteria and algae, and terrestrial fauna include collembolans, mites, and groups of microscopic organisms. Two important pedological processes that operate in Antarctica soils are oxidation and salinization. Coarse particle reduction takes place mainly at the soil surface, with particle size decreasing through granular disintegration and abrasion. Within the soil, coarse particles are nearly always angular and unstained, indicating low cryoturbic activity. The organic regime is significant everywhere in Antarctica, owing to the paucity of biological communities. For soil morphological properties, see Campbell and Claridge (2008). The soils of Antarctica are mostly formed in the absence of biological processes and, as a consequence of the prevailing low temperatures, are underlain everywhere by permafrost, with the active layer varying in thickness from about one meter in northern areas to a few centimeters or less in the soils of the inland edge of the Transantarctic Mountains. The permafrost is generally ice-cemented, but in aged and dehydrated soils may be loose. Because of extreme aridity, chemical weathering processes are assisted by salts, which allow unfrozen saline solutions to be present on grain surfaces and cracks in rock particles, even at very low temperatures. Weathering comprises the breakdown of ferromagnesian minerals, releasing iron and cations into the soil matrix. The iron oxidizes and is precipitated on grain surfaces, giving rise to the red coloring of aged sols. The cations, especially calcium and magnesium, combine with nitric and sulfuric acids that arrive in precipitation to form part of the thick salt horizons found in older soils. The concentrated salt solutions react with silica, which is also released by weathering to form secondary clay minerals and in some cases zeolites.

Culture-dependent and culture-independent methods have revealed that permafrost harbors diverse and novel microbial communities. The future challenge for studies of permafrost microbiology is to begin to address the ecology of these unique microbial ecosystems. The knowledge gained from culture-independent surveys of microbial diversity can be used to design targeted strategies in order to determine if phylogenetic groups detected by molecular strategies are part of the viable microbial community. The application of technologies such as stable isotope probing and FISH–microautoradiography could identify active microorganisms and better define the functioning and maintenance of permafrost microbial ecosystems at ambient subzero temperatures (Jeewon and Hyde 2008; Solaiman 2008; Solaiman and Marschner 2008; Marschner 2008). As microbial activities in situ are expected to be minute and extremely slow, new methods and techniques specific to the permafrost environment will be required. Developing methods for detecting and characterizing the active bacteria and archaea in permafrost will lead to the differentiation of the active microbial populations that are presumed to exist in permafrost from cryopreserved microbial fossils that may have remained frozen for geological timescales.

A database on non-lichenized fungi from Antarctica has been created in the United Kingdom (see http://www.antarctica.ac.uk/bas_research/data/access/fungi/, as well as Gilichinsky et al. 2007; Ruisi et al. 2007; Somjak et al. 2007; Ozerskaya et al. 2008). The mycobiota of arctic permafrost have been studied over the last decade (Panikov and Sizova 2007). The most common fungi belong to the genera *Acremonium*, *Alternaria*, *Arthrinium*, *Aspergillus*, *Aureobasidium*, *Bispora*, *Botrytis*, *Chaetophoma*, *Chrysosporium*, *Cladosporium*, *Fusarium*, *Geomyces*, *Geotrichum*, *Gliocladium*, *Lecythophora*, *Malbranchea*, *Monodictys*, *Mucor*, *Paecilomyces*, *Penicillium*, *Phoma*, *Rhinocladiella*, *Scopulariopsis*, *Stachybotrys*, *Sphaeronaemella*, *Sporotrichum*, *Thysanophora*, *Trichoderma*, *Ulocladium*, *Valsa*, *Verticillium*, *Xylohypha*, as well as sterile mycelia with sclerotia. Permafrost fungal microfauna provide evidence of the existence of extremotolerant organisms that are capable of retaining their viability and developing under the conditions present in extreme ecological niches and that show high adoptive potential.

Microorganisms are usually found in a dormant state under frozen and permafrost conditions (endo-and exospores, cysts, non-spore antibiotic cells, etc.). High numbers of viable microorganisms have been counted. The detected phylotypes form eleven established lines of descent for bacteria and one entirely new sequence that was not assigned to any of the known groups. Most of the clones belonged to the alpha (20%) and delta (25.6%) subdivisions of the *Proteobacteria*, with fewer from the beta (9.3%) and gamma (4.7%) subdivisions, groups that are typically isolated from soil by culture methods. Most of the permafrost-derived clones (77%) had sequence similarities of less than 95–80% with those in the database, indicating a predominance of new genera and families (Panikov 2008). It is true that the anammox process has not been investigated in permafrost soils, however, “marine” anammox 16 rRNA sequences have been identified in Siberian frozen alluvial sandy loam from the Middle Pleistocene epoch 300,000–400,000 years ago (Penton and Tiedje 2006). The anammox process was found to be responsible for up to 19% of the total nitrogen production in Greenland sea ice, but was not detectable in annual sea ice, perhaps due to increased stability (Rysgard and Glud 2004). A novel cold-adapted nitrite-oxidizing bacterium was isolated from a Siberian permafrost sample (Alawi et al. 2007). The detection of anammox activity in sea ice suggests that this may be an active process in permafrost, where anammox bacteria have also been identified. In the context of current warming trends, a thorough characterization of the nitrogen cycle in permafrost soils is needed in order to quantify effects on organic matter mineralization and ultimately carbon dioxide release as a positive feedback mechanism for global warning.

Long-term survival strategies in permafrost are thought to fall into two main categories. In the first, microbes maintain viability by entering a dormant state in which they can resist damage to cellular insults; in the second, microbes maintain viability by metabolizing and repairing damage at rates sufficient to equal or exceed the rate of death due to environmentally induced damage. In situ permafrost bacteria, which are further characterized by thickened cell walls, altered structure of cytoplasm, and compact nucleoids, showed similarities to cyst-like resting forms of non-spore-forming bacteria. The survival mechanisms may include reducing the polar polysaccharide capsular layer, decreasing the fractional volume of cellular water, increasing the fraction of ordered cellular water, or extracting energy by catalyzing the redox reactions of ions in thin aqueous films in the permafrost (Gilichinsky 2002). Those that fall into latter category, such as the observed changes in the genome and in gene expression, are primarily directed toward the maintenance of molecular motion and resource efficiency for continued growth in frozen conditions. Long-term survival is closely tied to cellular metabolic activity and DNA repair, which over time proves to be superior to dormancy as a mechanism for sustaining bacterial viability (Johnson et al. 2007). Specific sets of cold-induced proteins (CIPs) are considered to facilitate and allow cell growth at low temperatures. CIPs can be classified into cold-shock proteins (CSPs) and cold-acclimation proteins (CAPs). Bacteria that contain these proteins include *Psychrobacter* and *Exiguobacterium* (Bakermans et al. 2007). The adaptive nature of permafrost bacteria at near-freezing temperatures is governed by cellular physiological processes through the regulation of certain cellular proteins. It is possible that proteins synthesized at low temperatures may support temperature homeostasis, protect other proteins from denaturation and damage, and enable the cells to adapt to near- or below-freezing temperatures.

Most planets of the solar system, as well as their moons, asteroids and comets, are cryogenic in nature, and so the cryosphere is a common phenomenon in the cosmos. This is why the cells found in the Earth's cryosphere, as well as their metabolic by-products and biosignatures (biominerals, biomolecules and biogases), provide a range of analogs that could be used in the search for possible ecosystems and potential inhabitants of extraterrestrial cryogenic bodies. If life ever existed on other planets during their early stages of development, then it may have consisted of primitive cell forms. Similar to life on Earth, such primitive life may have been preserved on other cosmic bodies deep within their ice or permafrost layers. The orbits of both Earth and Mars lie between those of Mercury and Venus (which are close to the Sun and therefore dehydrated) and the bodies of the Jupiter system (which mostly consist of volatile hydrogen, methane, and water). Biota from the Greenland ice sheet (120,000 years old) and the Antarctic ice sheet (<400,000 years old) have been widely studied to depths of more than 3 km (Miteva et al. 2004; Miteva and Brenchley 2005; Mitrofanov et al. 2007).

The age of the oldest glacial ice, as well as immured bacteria, is still under discussion: >500,000 years old in the Guliya ice cap on the Tibetan Plateau; >2 million years old at the bottom of the Vostok ice core; or even >8.1 million years old (Bidle et al. 2007). The surface conditions in the Antarctic desert – intense levels of solar radiation, an absence of snow and vegetation cover, and ultralow temperatures, which can be as low as −60°C – share similarities with those on Mars.

On Earth, most volcanoes are located in areas where oceanic and continental plates are colliding. Despite active volcanism, permafrost often exists on slopes of high-elevation or high-latitude volcanoes (Palacios et al. 2007). The fundamental question is: do ecological niches such as volcanoes and associated environments contain microbial communities? The task is to find thermophilic microorganisms associated with volcanoes that were deposited with the products of eruption and then survived in permafrost after the scoria and ash froze. Cores extracted from a borehole into young volcanic deposits contained biogenic $CH_4$ and viable bacteria, including thermophilic anaerobes. Among these were methanogens growing on $CO_2$ plus $H_2$. Thermophiles may survive in permafrost and even produce biogenic gases.

## 1.11 Soil Pollution

Mining, manufacturing, and the use of synthetic products (e.g., pesticides, paints, batteries, industrial waste, and applications of industrial or domestic sludge to the land) can result in heavy metal contamination of urban and agricultural soils. Heavy metals also occur naturally, but rarely at toxic levels. Potentially contaminated soils can occur at old landfill sites (particularly those that accepted industrial wastes), old orchards that used insecticides containing arsenic as an active ingredient, fields that previously had wastewater or municipal sludge applied to them, areas in or around mining waste piles and tailings, industrial areas where chemicals may have been dumped on the ground, or areas downwind from industrial sites (Table 1.3).

Excess heavy metal accumulation in soils is toxic to humans and other animals. Chronic exposure (exposure over a longer period of time) to heavy metals is normally due to food chain transfer. Acute (immediate) poisoning from heavy metals is rare through ingestion or dermal contact, but is possible. Chronic problems associated with long-term heavy metal exposures include:

- Lead: mental lapses
- Cadmium: affects kidney, liver, and the GI tract
- Arsenic: skin poisoning, affects the kidneys and the central nervous system

The most common problems from cationic metals (metallic elements whose 2+ forms in soil are positively charged cations) come from mercury, cadmium, lead, nickel, copper, zinc, chromium, and manganese. The most common problems from anionic compounds (elements whose forms in soil are combined with oxygen and are negatively charged) come from arsenic, molybdenum, selenium, and boron (see Tables 1.4 and 1.5).

**Table 1.3** Heavy metal pollutants in sewage

| Heavy metal | Maximum concentration in sludge (mg/kg or ppm) | Annual pollutant loading rates (kg/ha/yr) | Annual pollutant loading rates (lb/A/yr) | Cumulative pollutant loading rates (kg/ha) | Cumulative pollutant loading rates (lb/A) |
|---|---|---|---|---|---|
| Arsenic | 75 | 2 | 1.8 | 41 | 36.6 |
| Cadmium | 85 | 1.0 | 1.7 | 39 | 34.8 |
| Chromium | 3,000 | 150 | 134 | 3,000 | 2,679 |
| Copper | 4,300 | 75 | 67 | 1,500 | 1,340 |
| Lead | 420 | 21 | 14 | 420 | 375 |
| Mercury | 840 | 15 | 13.4 | 300 | 268 |
| Molybdenum | 57 | 0.85 | 0.80 | 17 | 15 |
| Nickel | 75 | 0.90 | 0.80 | 18 | 16 |
| Selenium | 100 | 5 | 4 | 100 | 89 |
| Zinc | 7,500 | 140 | 125 | 2,800 | 2,500 |

**Table 1.4** Environmental quality standards for soil pollution

| Item | Environmental quality standards |
|---|---|
| Cadmium | 0.0l mg $l^{-1}$ in sample solution, and less* than 1mg $kg^{-1}$ in soil for agricultural land |
| Lead | 0.0l mg $l^{-1}$ or less* in sample solution |
| Chromium (VI) | 0.05 mg $l^{-1}$ or less* in sample solution |
| Arsenic | 0.0l mg $l^{-1}$ or less* in sample solution, and less than 15 mg $kg^{-1}$ in soil for agricultural land (paddy field only) |
| Total mercury | 0.0005 mg $l^{-1}$ or less* in sample solution |
| Alkyl mercury | Not detectable in sample solution |

*The above standards are not applicable to (1) the soil in those places where natural toxic substances exist, such as the vicinities of mineral veins, and (2) the soil in those places designated for the storage of toxic materials, such as waste disposal sites

**Table 1.5** Environmental quality standards for soil pollution

| Item | Environmental quality standards |
|---|---|
| Cadmium | 0.01 mg $l^{-1}$ in sample solution and less[a] than 1 mg $kg^{-1}$ in soil for agricultural land |
| Total cyanide | Not detectable in sample solution |
| Organic phosphorus[b] | Not detectable in sample solution |
| Lead | 0.01 mg $l^{-1}$ or less[a] in sample solution |
| Chromium (VI) | 0.05 mg $l^{-1}$ or less[a] in sample solution |
| Arsenic | 0.01 mg $l^{-1}$ or less[a] in sample solution, and less than 15 mg $kg^{-1}$ in soil for agricultural land (paddy field only) |
| Total mercury | 0.0005 mg $l^{-1}$ or less[a] in sample solution |
| Alkyl mercury | Not detectable in sample solution |
| PCB | Not detectable in sample solution |
| Copper | Less than 125 mg $kg^{-1}$ in soil for agricultural land (paddy field only) |
| Dichloromethane | 0.02 mg $l^{-1}$ or less in sample solution |
| Carbon tetrachloride | 0.002 mg $l^{-1}$ or less in sample solution |
| 1,2-Dichloroethane | 0.004 mg $l^{-1}$ or less in sample solution |
| 1,1-Dichloroethylene | 0.02 mg $l^{-1}$ or less in sample solution |
| *cis*-1,2-Dichloroethylene | 0.04 mg $l^{-1}$ or less in sample solution |
| 1,1,1-Trichloroethane | 1 mg $l^{-1}$ or less in sample solution |
| 1,1,2-Trichloroethane | 0.006 mg $l^{-1}$ or less in sample solution |
| Trichloroethylene | 0.03 mg $l^{-1}$ or less in sample solution |
| Tetrachloroethylene | 0.01 mg $l^{-1}$ or less in sample solution |
| 1,3-Dichloropropene | 0.002 mg $l^{-1}$ or less in sample solution |
| Thiram | 0.006 mg $l^{-1}$ or less in sample solution |
| Simazine | 0.003 mg $l^{-1}$ or less in sample solution |
| Thiobencarb | 0.02 mg $l^{-1}$ or less in sample solution |
| Benzene | 0.01 mg $l^{-1}$ or less in sample solution |
| Selenium | 0.01 mg $l^{-1}$ or less[a] in sample solution |
| Fluorine | 0.8 mg $l^{-1}$ or less[a] in sample solution |
| Boron | 1 mg $l^{-1}$ or less[a] in sample solution |

[a]For environmental limits concerning the concentrations of cadmium, lead, chromium(VI), arsenic, total mercury, selenium, fluorine, or boron in liquid samples, when the soil contamination occurs away from the groundwater level and the concentrations of the substances do not exceed 0.01 mg, 0.01 mg, 0.05 mg, 0.01 mg, 0.0005 mg, 0.01 mg, 0.8 mg, and 1 mg, respectively, under the original conditions, then the limits per liter of liquid sample are 0.03 mg, 0.03 mg, 0.15 mg, 0.03 mg, 0.0015 mg, 0.03 mg, 2.4 mg, and 3 mg, respectively

[b]"Organic phosphorus" refers to parathion, methyl parathion, methyl demeton, and EPN

The above standards are not applicable to (1) soil in those places where natural toxic substances exist, such as the vicinities of mineral veins, and (2) soil in those places designated for the storage of toxic materials, such as waste disposal sites

Polycyclic aromatic hydrocarbons (PAHs, a group of more than 100 different compounds) are often found at contaminated sites, particularly in connection with tar contaminations at former gasworks. They also exist as diffuse contamination in urban areas and alongside roads, where they arise from the impregnation of wood with creosote and the incomplete combustion of hydrocarbons.

## 1.12 Conclusion

Cultivators (agriculturists/horticulturists, and foresters) know that there are many kinds of soils. Soil surveys enable us to determine their characteristics, types, and distributions, and to classify them. Soil surveys are very important for the planned utilization of land. They give valuable information on the possible uses of the land and their comparative advantages and disadvantages. The results of experiments carried out with one variety of soil have little significance with respect to another variety.

The scientific study of the soil as a natural body originated with a Russian, V.V. Dokuchaiev. Previously, two philosophical approaches were employed in soil studies. One originated with a German chemist, Liebig, who considered the soil to be merely a reservoir of plant nutrients. Plants withdraw nutrients from the soil, which must then be replenished. Maps were prepared showing the contents of the total and available plant nutrients in surface soil. Such chemical estimations are still performed and are very useful, but they do not provide a scientific basis for classification. According to the other point of view, soils were classified on the assumption that each geological formation gives rise to a characteristic soil, and so a map of the surface geology can be translated (with due interpretation) into a soil map. It has, however, since been found that different soils develop from the same geological formation, and that climate, vegetation, and relief all have important effects on soil formation.

The scientific classification of soils now centers round the characteristics of the soil profile – a vertical section of the soil in which a sequence of genetically related horizons that reflect the processes that form the soil can be seen. Many of the alluvial soils of India have genetically related horizons, but alluvial soils that do not have them are also classified in soil surveys.

## References

Alawi, M., Lipski, A., Sanders, T., Pfeiffer, E. M., & Spieck, E. (2007). Cultivation of a novel cold-adapted nitrite oxidizing betaproteobacterium from the Siberian Arctic. *Int Soc Microb Ecol, 1*, 256–264.

Bakermans, C., Tollaksen, S. L., Giometti, C. S., Wilkerson, C., Tiedje, J. M., & Thomashow, M. F. (2007). Proteomic analysis of *Psychrobacter cryohalolentis* K5 during growth at subzero temperatures. *Extremophiles, 11*, 343–354.

Balks MR, Campbell DI, Campbell IB, Claridge GGC (1995) Interim results of 1993/94 soil climate, active layer and permafrost investigations at Scott Base, vandal and Beacon Heights, Antarctica, Antarctica Research Unit Special Report No. 1, University of Waikato, Antarctica

Bidle, K., Lee, S., Marchant, D., & Falkowski, P. (2007). Fossil genes and microbes in the oldest ice on Earth. *Proc Natl Acad Sci, 104*, 13455–13460.

Buscot, F., & Varma, A. (2005). *Microorganisms in soils: roles in genesis and functions*. Germany: Springer.

Campbell, I. B., & Claridge, G. G. C. (2008). Antartica permafrost soils. In M. Rosa (Ed.), *Permafrost soils* (pp. 17–31). Berlin: Springer.

Gilichinsky, D. (2002). Permafrost as a microbial habitat. In G. Bitton (Ed.), *Encyclopedia of environmental microbiology* (pp. 932–956). New York: Wiley.

Gilichinsky, D. A., Wilson, G. S., Friedmann, E. I., Mckay, C. P., Sletten, R. S., Rivkina, E. M., et al. (2007). Microbial populations in Antarctic Permafrost: biodiversity, state, age and implication for astrobiology. *Astrobiology, 7*, 275–311.

Glinka, K. D. (1927). *Dokuchaieev's ideas in the development of pedology and cognate sciences* (p. 1). Leningrad, USSR: Russian Pedological Institute Academy of Sciences.

Hilgard, E. W. (1911). *Soils* (pp. 487–549). New York: The MacMillan Company.

Jeewon, R., & Hyde, K. D. (2008). Detection and diversity of fungi from environmental samples: traditionalversus molecular approaches. In A. Varma & R. Oelmueller (Eds.), *Advanced techniques in soil microrobiology* (pp. 1–151). Germany: Springer.

Johnson S, Hebsgaard M, Christensen T, Mastepanov M, M Nielsen R, Munch K, Brand T, Gilbert M, Zuber M, Bruce M, Ronn M, Gilichinsky, Gilichinsky D, Froese D and Willerslev E (2007) Ancient bacteria show evidence of DNA repair. *Proc Natl Acad Sci* USA *104*, 14401–14405.

MacCulloch RJI (1996) The microclimatology of Antarctica soils. Thesis M.Sc. (Hons), University of Waikato, Hamilton, New Zealand

Miteva, V. I., & Brenchley, J. E. (2005). Detection and isolation of ultrasmall microorganisms from a 120, 000-year old Greenland glacier ice core. *Appl Environ Microbiol, 70*, 7806–7818.

Milteva, V., Sheridan, V., & Brenchley, J. (2004). Phylogenetic and physiological diversity of microorganisms isolated from a deep Greenland glacier ice core. *Appl Environ Microbiol, 71*, 7806–7818.

Mitrofanov, I., Zuber, M., Litvak, M., Demigod, N., Sanin, A., Boynton, W., et al. (2007). Water ice permafrost on Mars: the layering structure and surface distribution according to HEND/ Odyssey & MOLA/MGS data. *Geophys Res Lett, 34*, L18102.

Ozerskaya, S., Kochkina, G., Ivanushkina, N., & Gilichinsky, D. A. (2008). Fungi in permafrost. In R. Margesin (Ed.), *Permafrost soils. Soil biology series* (pp. 85–95). Germany: Springer.

Palacios, D., Zamorano, J. J., & Andres, N. (2007). Permafrost distribution in tropical stratovolcanoes: popocatepetl and iztaccihuatl volcanoes (Mexico). *Geophys Res Abstr, 9*, 05615.

Panikov, N. S. (2008). Microbial activity in frozen soils. In M. Rosa (Ed.), *Permafrost soils* (pp. 119–147). Berlin: Springer.

Panikov, N. S., & Sizova, M. V. (2007). Growth kinetics of microorganisms isolated from Alaskin soil and permafrost in solid media frozen down to –35°C. *FEMS Microbiol Ecol, 59*, 500–512.

Penton, C. R., & Tiedje, J. M. (2006). Molecular evidence for the broad distribution of anaerobic ammonium-oxidizing bacteria in freshwater and marine sediments. *Appl Environ Microbiol, 71*, 6142–6149.

Ruisi, S., Barreca, D., & Selbmann, L. (2007). Fungi in Antarctica. *Rev Environ Sci Biotechnol, 6*, 127–141.

Rysgard, S., & Glud, R. N. (2004). Anaerobic nitrogen production in arctic sea ice. *Limnol Oceangr, 49*, 86–94.

Soil Survey Staff, Soil Taxonomy: a basic system of oil classification for making and interpreting soil surveys, Soil Conservation Service, USDA, Washington, DC, Agriculture Handbook 436 (December 1975)

Soil Survey Staff,. (1972). *Soil Series of the United States, Puerto Rico, and the Virgin islands: their taxonomic classification*. Washington, DC: USDA.

Somjak, S., Frisvad, J., & Gunde-Cimerman, N. (2007). Penicillium mycobiota in arctic glacial ice. *Antonie Van Leeuwenhoek, 92*, 43–51.

Solaiman, Z., & Marschner, P. (2008). DGGE and RISA protocols for microbial community analysis in soil Microrobiology. In A. Varma & R. Oelmueller (Eds.), *Advanced techniques in soil microrobiology* (pp. 167–180). Germany: Springer.

Solaiman, Z. (2008). Measuement of microbial mass and activity in soil. In A. Varma & R. Oelmueller (Eds.), *Advanced techniques in soil microrobiology* (pp. 201–212). Germany: Springer.

Storad, B. C. (1990). Forever frozen. *ASU Res, 5*, 22–25.

Wilke, B.-M. (2005). Determination of chemical and physical properties. In R. Margesin & F. Schinner (Eds.), *Manual of soil analysis: monitoring and assessing soil bioremediation* (Soil biology series, pp. 47–95). Germany: Springer.

Williams, P. J., & Smith, M. W. (1989). *The frozen earth. Fundamentals of geocryology (Studies in polar research*. Cambridge: Cambridge University Press.