

1 What Are Soils?

François Buscot¹

1 Introduction

Soil is often defined as the earth surface layer exploited by roots. This kind of definition is not the most appropriate to introduce a volume on soil microorganisms as these are also found in soil compartments not colonized by roots. Making this point, Paul and Clark (1996) gave the examples of microbial denitrification, observed much below the rooting depth, and of the numerous bacteria and fungi that colonize small pores and micro-aggregates not accessible to roots or even root hairs.

Another definition (see, for example, Wild 1993) refers to soil genesis by mentioning the intervening factors, i. e., the parent material, the relief, the climate, the organisms involved and time. This approach is more appropriate as it emphasizes that soil edification is a biologically driven process. It also inherently points out the complexity and especially the heterogeneity of the resulting medium. In order to mark the diversity that results from combining the interaction of very diverse and complex organism communities on different types of rock material under variable climatic and topographic conditions and over a time scale (the unit of which may vary from decades to thousands or even millions of years), many soil scientists avoid using the term “soil”, but prefer to speak of “soils”.

The line that results from genesis-based definitions of soils and from the complex and heterogeneous soil functions that such definitions underline has deeply inspired the structure of this volume. If we follow this line, we have to consider at least five questions when addressing the fate of soil microorganisms:

- What are the functions of microorganisms in soil genesis?
- What are the roles played by microorganisms in the energy and matter fluxes and in their transformation within functioning soils?

¹University of Leipzig, Institute of Botany, Department of Terrestrial Ecology, Johannisallee 21–23, 04103 Leipzig, Germany, e-mail: buscot@uni-leipzig.de, Tel: +49-341-9738581, Fax: +49-341-9738599

- As the soil genesis and functioning involve complex and tightly integrated biocoenoses, in which kind of biotic interactions do the soil microorganisms participate?
- What is the function of microorganisms in specific domains of soils that are highly influenced by biotic or abiotic factors?
- Finally, considering that soils are difficult media to work on, especially for microbiologists, which approaches can be used by soil microbiologists, taking the wide structural and functional diversity of soil microbes into account, but avoiding going too far into details that do not provide explanations for emergent properties and processes characteristic of soils?

In the introductory chapter, we will summarize some basic traits of soil genesis and functioning and try to indicate at which stages the processes that are detailed in the different parts and chapters of the book are involved. This first chapter will not replace general soil science books (see, for example, Brady 1990), but aims to be a guideline providing an integration of the matter detailed in the book and pay the correct tribute to the role played by microorganisms for soil genesis and functions.

2

Soil Genesis

2.1

Rock Weathering or Decay

At the beginning of each soil formation, for example, after a volcanic eruption or a glacier or water retreat, the initial mother substrate, in general, displays a reduced capacity to immediately carry an abundant plant and animal biocoenosis. Up to this stage, however, microorganisms such as bacteria, algae and their associations with fungi in biofilms of lichens belong to the early colonizers (see Chap. 2). If the basic substrate is loose, the microbial community, constituting biological crusts, will provide stabilization and avoid erosion. Such crusts form also at the surface of some developed soils. They are analyzed in detail in Chap. 15.

Moreover, if the mother substrate consists of a hard rocky material such as granite or limestone, the initial process of soil formation consists of weathering. Both basic mechanisms of weathering, i. e., the substrate fractionation and its gradual chemical transformation, are bound together. Fractionation enhances the contact surface between substrate and environment, which, in turn, increases chemical reactivity and transformation

rate. Each time a monolith is divided into 1000 fractions, the ratio between its surface and its volume increases by an order of magnitude of at least 10. Such a surface increase factor may appear low. However, one has to keep in mind that the smallest particles resulting from weathering are clay minerals that have an equivalent diameter less than 2 μm . At this stage of fractionation, the contact surface is tremendous. According to the mineral type, 1 g of clay has a surface varying from 93 to 800 m^2 (Gisi et al. 1997). As clay particles are negatively loaded, they display a considerable potential for binding and exchanging cations that may be crucial nutrients, but also toxic substances such as heavy metals (see Chap. 16).

In Chap. 3, Gorbushina and Krumbein point out two important traits of weathering and its consequences. The first trait is that even if the basic mechanisms of weathering are of a physical and chemical nature, they are largely biologically driven, with a predominant role of the microorganisms, especially at the initial stage. To take this biological component into account, the authors propose that “wear down” might be a more appropriate term than weathering. This view is in agreement with van Breemen et al. (2000), who has recently used the term “rock eating fungi”. The second trait concerns the exchange surface that results from substrate fractionation. The idea here is that not the classical surface of the terrestrial ecosystem, but its fractal surface, i. e., the real contact interface of soils with water and air, should be considered. This radically inverts our current view that the exchange surface between the atmosphere and oceans is higher than the one with the terrestrial component. As microorganisms represent the widest biota fraction in soils, both in terms of biomass and number of organisms, and as they are tightly associated with this tremendous fractal surface, they play a key role in biogeochemical cycles including those of climate-relevant gases. The importance of this role is even reinforced when considering the carbon flux driven by so called chemolithotroph bacteria that mobilize important quantities of CO_2 from the atmosphere during their attack on rocks. As the time scale at which such processes operate is very high, they are to be considered as a driving force of geomorphological processes. The consequences of wear down are therefore much broader than the sole contribution to soil edification. It influences the geology and the climate (see Chap. 3).

2.2

Importance of Soil Texture

In the soil matrix, the solid phase of soils, the skeleton and the fine earth correspond to particle fractions with an equivalent diameter higher and lower than 2 mm, respectively. The fine earth is split into three particle

size fractions, the sand fraction with an equivalent diameter of 50 or 63–2000 μm , the silt fraction (2–50 or 63 μm) and the already mentioned clay fraction ($< 2 \mu\text{m}$). The proportion of each fraction of the fine earth defines the soil texture which is a crucial property as it determines at two levels the volume available for the two other soil phases, the gaseous (soil–air) and the aqueous ones (soil–water or soil solution). Sandy soils not only have a higher total available volume for water and air, they warrant a better water percolation and evaporation, resulting in rapid shifts of soil moisture versus soil aeration. In contrast, clay soils have numerous capillary pores that retain water and lower aeration and water circulation. These properties are determinant for microorganisms themselves, as they influence the balance between oxidative and reductive biological processes which drive biogeochemical cycles in soils (see Chaps. 7–9). Soil texture and soil pore size are also important as they rule the distribution of soil organisms. The classification of organisms used by soil biologists refers to the dimension of soil particles and soil pores (Fig. 1).

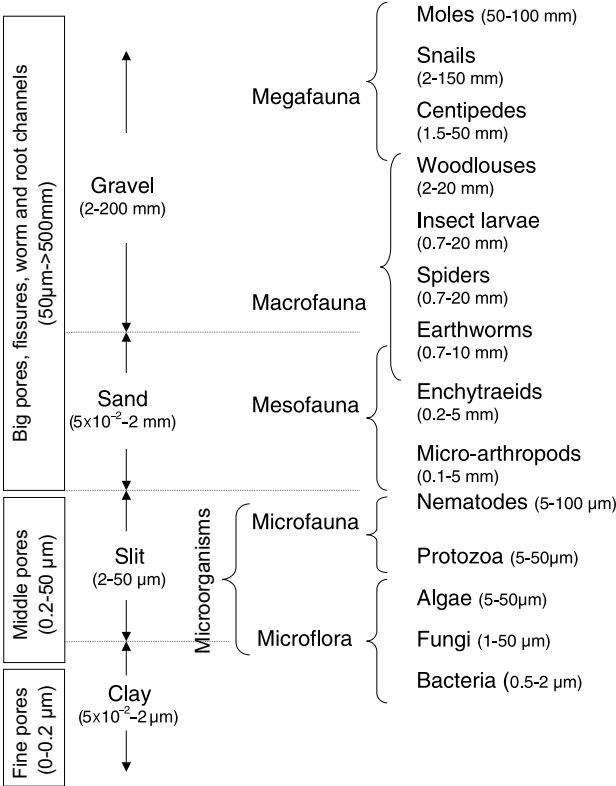


Fig. 1. Classification of soil biota in relation to size of pores and particle in soils used in soil biology. (Adapted from Gisi et al. 1997)

2.3

Input of Organic Matter into Soils and Aggregation

After the wear down or weathering of the initial substrate that results in producing a matrix with a huge reactive surface and determines complex niches for the soil organisms, the second important event in soil genesis is the input and transformation of organic matter. This organic matter originates from the organisms that establish themselves on and within soils. Here, two mechanisms are balanced that are detailed in Chap. 4. On the one hand, organic matter may be mineralized, resulting in production of CO₂, phosphate, sulfate, nitrate, etc. that may be remobilized by the soil biota, undergo further microbial transformation through oxidation or reduction, or eventually leave soils as gas or by transfer into the groundwater (for details, see Chaps. 6–9). On the other hand, it may only be partially decomposed into more or less complex organic radicals that polymerize and form humus, a very stable complex component of soils. Both the mineralization and humification processes are driven by soil bacteria and fungi and involve a broad set of enzymes with either narrow substrate specificity like cellulases or, on the contrary, the ability to attack a diversity of substrates. This is the case for oxidative exo-enzymes such as laccases (Luis et al. 2004). Although humus rarely represents more than several percent of the soil matrix, it confers many properties to soils. Due to its colloidal structure, it increases the soil water holding capacity and participates in the formation of aggregates with soil minerals, contributing to building what is called the soil structure. Like clay, humus particles are loaded negatively and bind and exchange cations. Therefore, this fraction influences soil fertility, especially in many soils of the tropics, where the clay fraction is less stable than in temperate region.

In addition to an indirect role in aggregation and soil structure via their contribution to humification, soil microorganisms also act directly. Bacteria and fungi exude colloidal polysaccharides that can glue soil particles. Soil fungi, for example, produce glomalin, which has been demonstrated to represent a high proportion of soil organic matter promoting aggregate formation (Rillig et al. 2002). The mechanical role of microorganisms is also considerable, given their biomass of 40–200 g m⁻² and their hyphal structure (Dighton and Kooistra 1993; Thorn 1997) that contributes to anchoring soil components to each other. To pay tribute to this phenomenon, Chap. 5 is devoted to the role of microorganisms in soil aggregation.

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