FIELD TECHNIQUES: SOIL SYSTEMS

P. Blaser
Swiss Federal Institute for Forest, Snow and Landscape Research CH - 8903 Birmensdorf, Switzerland

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Contents

Summary

This article deals with the principles of soil formation and shows the problems to recognize and visualize the many effects of man made stress in soils. Soils are transformation products of minerals and organic matter with a defined organization, morphology and structure. They are closely related to site factors and for this, the soil properties vary considerably in time and space. Due to many buffer reactions, the time needed to produce visible changes in a soil is, on a human time scale, usually very long. Nevertheless, a careless treatment of soils by inappropriate techniques and the impact of excessive deposition of chemical compounds have an adverse effect on soil properties and functions. The article highlights the effects of deposition with nitrogen, acidifying substances, inorganic trace elements and organic pollutants on the soils. It also discusses the role of soils in global changes. Special attention is given to the fact that most of the elements considered as pollutants appear as natural weathering products in soils. The same is true for the acidification which is a natural process in soils of cool-humid climates where the amount of precipitation exceeds the amount of evapotranspiration. To detect pollutants in soils, usually laboratory analyses are needed. Appropriate sampling strategies and tools, which are discussed in this section, are a prerequisite to find a correct answer.

1. Introduction

Soils are part of the uppermost earth crust extending from the parent rock to the soil surface. They belong to the pedosphere and are affected by the lithosphere, the atmosphere, the hydrosphere and the biosphere. Soils are open, porous systems containing solids, liquids and gases in which an exchange of matter and energy with their surrounding spheres takes place. Soil formation results from an interplay of the soil forming factors parent material, climate, organisms and topography that act through time by a number of soil forming processes like weathering, translocation, neoformation of minerals and humic substances as well as the formation of soil structure. A soil is therefore a transformation product of mineral and organic matter with a defined organization, morphology and structure. With increasing time of soil formation the initial state of the parent material is subject to change through the action of the pedogenic processes. The pedogenesis leads to a vertical differentiation of the soil body in layers with distinct properties and is closely related to the site conditions. According to the enormous variation of the soil forming conditions, soils comprise a large continuum of properties that vary in space and time. Soils can therefore be understood as four dimensional space-time dependent open systems.

While single soil properties can exhibit a small scale spacial variability, the soil body as a whole generally varies only over greater distances or with drastic changes of the soil forming conditions (e.g. bedrock, topography). Over short distances the change of the soil properties may be very small and hardly detectable. However, over greater distances or with drastic changes of the soil forming conditions (e.g. bedrock, topography) completely different soils can develop. For the sake of soil description and classification soils of the same stage of development with similar horizons and properties are grouped according to soil types.

The time needed to produce visible changes in a soil varies among the different soil horizons. Most sensitive for change is the humus layer which is closely related to the vegetation whereas changes in deeper mineral horizons need much greater time spans.

In contrast to the slowly changing visible soil properties, governed by the soil forming processes, other processes such as cation exchange, result in rapid changes of chemical and physical parameters. Most of them are not detectable in the field and have to be studied by appropriate analytical methods.

A soil represents a precious natural resource which needs a very long time to develop. On a human time scale soils are not renewable. Soils are the habitat of plants. They are the rooting medium and the storage compartment for nutrients and water. Together with other environmental conditions, soils contribute substantially to the fertility of a site. Beside these functions, soils act as a filter for manure, for slurries and pollutants, some of them with hazardous character and soils restrict their transport to groundwater. Moreover, soils have a tremendous buffer capacity for pH changes and for the effects of toxic substances. Soils are the medium where ecologically important transformation processes take place. Through the action of soil organisms, organic litter is transformed to stable soil humus and finally it is mineralized to the corresponding elements. On the other hand, weathering products are reorganized to new soil components such as clay minerals which are thermodynamically more stable than the pre-cursor primary minerals. Despite its large ability to buffer natural and anthropogenic influences, soils suffer from chemical and mechanical stresses that can have detrimental effects on the soil quantity, its quality, and on the soil functions.

2. Field techniques to study soil formation and soil classification

Pedological fieldwork depends on the objectives of the investigator as well as on the nature of the soils. Principally, pedological field work implies a reconstruction of pedological processes from observed soil properties based on known soil forming conditions. Since soil development and many soil properties depend on site conditions, site selection and site description is most often the first step in pedological field work. *Topography*, synonymous with relief, can be described in the field. It strongly affects soil formation and the spatial distribution of the various soil types in the landscape. It mainly controls the water movement within the profile as well as the erosion. Furthermore it modifies climatic parameters due to altitude, exposition and inclination and consequently it affects the type of vegetation. From the *organisms* that live in or on the surface of a soil, most often the vegetation is considered only because the macro- and mesofauna together with the microorganisms are difficult to recognize in the field.

Where *bedrock* cannot be observed in the field, geological maps can be helpful for the characterization of the parent material. A simple field test to distinguish between calcareous and non calcareous parent material, a geochemical parameter which is equally important for the soil development as for the soil ecology, can be performed with a 10% HCl solution. For the characterization of the *climate* that governs primarily the rate and type of soil formation, information on long term mean annual values, primarily temperature and precipitation regime, are needed. If no data for a given site are available they have to be interpolated from published figures or climatic maps established at comparable sites in the vicinity.

In most cases the first step for the examination of a soil is to establish a vertical section through the soil, called a soil profile. Such a profile provides a two dimensional insight into a body that varies in three dimensions.

The description of the soil profile starts with an annotation of the soil depth down to the barely weathered parent material and with a differentiation of visibly different horizontal layers, called soil horizons. Main horizons are designated with a number of defined upper case letters whereas lower case letters are used to describe some specific properties of these horizons. Although the "International Society of Soil Science" published a proposal for a uniform system of soil horizon designation, different methods are used in various countries.

Further examination is then performed by horizon. Soil properties which can be studied in the field are the thickness and boundaries of the soil horizons, their color, texture, structure, consistence, density and the root distribution. Together with the examination of the humus type these properties provide information on the mineral and organic components of a soil, on the transformation and translocation processes as well as on the biological activity which governs litter decomposition and humification. The most important biological processes that take place in a soil is the decomposition of fresh organic litter and its transformation to soil humus. These two processes are closely related to the release and turn-over of nutrients and thus affect soil fertility. The decomposition of organic matter and the formation of humic substances includes several biological and biochemical steps, involving myriades of soil organisms. Litter decomposition and humification are governed by all factors which influence the biological activity in a soil, primarily by temperature and humidity. A careful examination of the humus type thus provides information on the site conditions which determine the humification and the turnover rate of organic matter.

To analyze the influence of a given soil forming factor, several soil profiles have to be studied that are located in a sequence according to the variable soil forming factor with the other soil factors kept as constant as possible. The influence of topography on soil formation can be evaluated along a catena, which is similar to toposequence. Climatic sequences are established along a changing climatic gradient to study the corresponding influence and chrono-sequences which give information on the influence of time on soil formation. It has to be emphasized, however, that a strict separation of the soil forming factors is hardly possible because frequently several factors change simultaneously.

Many results of the field examination deliver only relative values but a visual examination of the soil profiles is imperative for understanding soil formation and for soil classification. However, for quantification and for the sake of a sound interpretation, most of the information needed requires additional laboratory work.

Soil classification

Because of the large variety of soil types there is a considerable need for grouping them into soil classes. Soil classification simplifies the communication among soil scientists and allows soil mapping. Until today there is no international agreement on nomenclature and soil classification. Basically, three fundamentally different approaches are used to classify soils according to pedogenetic criteria. They are based either on soil forming *factors, on processes, or on soil properties*. Since the soils are classified according to diagnostic soil horizons, the recognition and characterization of such horizons is crucial. The classification on soil forming *factors* leads to a grouping according to climate and vegetation (zonal soils), or to the parent material and topography (intrazonal soils). This approach was widely applied in the beginning of soil classification, mainly in Russia and in North America. It is a relatively simple approach but of little value with respect to the interpretation of the soil genesis and soil development.

The classification established on *soil properties* is entirely based on field and analytical data. It was first proposed in the U.S.A. in 1960 (”Soil Taxonomy”) and it is the most common system up today. This system uses precisely defined diagnostic horizons and other soil properties which have to be present or absent for an association to a given soil class. It contains several soil orders, suborders, great groups, subgroups, families and series.

This system requires a large amount of field and analytical data. It is well defined but it is not very helpful for pedogenetic interpretations. In contrast, the morphogenetic classification combines soil forming processes that cause morphological diagnostic criteria. The simultaneous consideration of site factors and soil forming processes that lead to the development of soil properties needs an advanced understanding of soil formation. This system is used in various European countries often with national adaptations and modifications. It contains four divisions with a variable number of soil types and subtypes. Another widely used combined classification system is the FAO-UNESCO approach which was developed for world wide application and which provides a legend for the Soil Map of the World. The classification of the soils is based on diagnostic properties, on soil processes and on site factors. It contains 26 main classes and 106 soil units. It is important to note that a final classification is not always possible in the field because sometimes a large number of chemical parameters are needed.

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Biographical Sketch

Peter Blaser is soil scientist at the Swiss Federal Institute for Forest, Snow and Landscape Research where he directs the division soil ecology and site sciences. His research interests are in the field of soil formation and soil chemistry with special emphasis on the soil solution chemistry, trace metal complexation, and soil acidification. He earned his PhD at the Swiss Federal Institut of Technology (ETH) in Zurich.