

3 Soil Conditions

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3.1 Introduction

The process of drainage takes place by water flowing over the land surface and through the soil. Obviously, therefore, the properties of the soil to conduct water both horizontally and vertically are of major importance for drainage. Drainage, however, is only one of the possible crop-improvement practices and should not be considered in isolation. Other aspects of soil, such as water retention, workability, and fertility, strongly affect plant productivity, and need to be assessed or studied in conjunction with drainage.

Soils provide a 'foothold' for plants, supply them with water, oxygen, and nutrients, and form an environment for many kinds of fauna. Section 3.2 discusses the influence of soil-forming factors and the various physical, chemical, and biological processes taking place in the parent material of soils, leading to the transformation and translocation of constituents in the developing soil. The resulting heterogeneity of soil characteristics and properties is treated in Section 3.3. Section 3.4 discusses the basic characteristics of soils and their related properties. Changes in the hydrological conditions affect land use by removing or adding constraints to crop growth. Anyone considering drainage applications will benefit from an understanding of soil genesis, and of general and specific soil conditions; a soil survey is therefore a prerequisite for planning and designing land-improvement projects (Section 3.5). Two widely applied soil classification systems are presented in Section 3.6. Section 3.7 looks into a number of soils with particular water-management problems, and briefly discusses the role of the soil scientist and drainage engineer in drainage surveys.

This chapter can only briefly deal with various aspects of soil that are important for drainage purposes. For a more extensive treatise of various subjects the reader is referred to textbooks and other documents mentioned in the reference list (e.g. Ahn 1993; Brady 1990; FAO 1979, 1985; FitzPatrick 1986; Jury et al. 1991; Klute et al. 1986).

3.2 Soil Formation

The word 'soil' means different things to people with different backgrounds, interests, or disciplines. To illustrate this point, three simplified views of soils will be given: from the angles of agronomy, drainage engineering, and soil science (or pedology):

- In agronomy, soil is the medium in which plant roots anchor and from which they extract water and nutrients;
- In drainage engineering, soil is a matrix with particular characteristics of water entry and permeability;

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- In pedology, soil is that part of the earth's crust where soil has formed as a result of various interactive processes. This section discusses the pedological base of soil formation.

Soils are formed in the upper part of the earth's crust from 'parent material' that consists of rock, sediment, or peat. Soil formation is more than the weathering of rocks and minerals, because the interactions between the soil-forming factors are manifold. FitzPatrick (1986) gives a highly readable account of soil formation.

Table 3.1 presents an overview of the factors and processes by which soils are formed, the basic soil characteristics and properties, and the related agricultural qualities of land and soil.

3.2.1 Soil-Forming Factors

To a large extent, the soil-forming factors in Table 3.1 are interdependent, influencing one another in different ways. This explains the occurrence of a wide variety of soils. For example, the organisms (vegetation and fauna) are strongly influenced by the climate, and topography is influenced by parent material and time.

Climate

Climate has a major influence on soil formation, the two main factors being temperature and precipitation.

In warm moist climates, the rate of soil formation is high, because of rapid chemical weathering and because such conditions are conducive to biological agents that produce and transform organic matter. This rapid soil formation in warm moist climates often leads to deep, strongly weathered soils.

In cold dry climates, the rate of soil development is low, because chemical weathering is slow, and because biological agents do not thrive in cold or dry environments.

In warm dry environments, soils develop because of physical weathering through the heating and cooling that breaks up rocks.

In cold moist climates, soils develop through the physical effects of freezing and thawing on rocks and soil constituents. Soils formed under cold conditions are generally thin and only slightly weathered.

Parent Material

Soils develop in a certain climate, within a particular landform, and on a particular parent material or parent rock. The nature of the underlying parent rock from which the soil develops greatly determines the intermediate or final product of the pedogenetic (= soil-forming) process. For example, a sandstone develops into a sand; acid rock develops into a poor acid soil. Because the parent material is so important for soil formation, the rock type is often chosen as a criterion for subdividing or grouping soils (Section 3.6).

Topography

Soil forms within a topography that can be flat, nearly flat, slightly sloping, moderately sloping, or steeply sloping. Each landform is characterized by a particular slope or

Table 3.1 Soil forming factors and processes, basic soil characteristics and properties, and the agricultural qualities of soil and land (after Van Beers 1979)

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|---|------------|--|
| Soil forming factors (Section 3.2.2) | | Parent material Topography Climate Organisms (flora and fauna) Time Human activity |
| Soil forming processes (Section 3.2.3) | | Physical Chemical Biological |
| Vertical and horizontal differentiation (Section 3.3) | | Soil profile Heterogeneity |
| Basic soil characteristics (Section 3.4.1) | | Texture Mineral composition Physico-chemical characteristics of clay Organic matter |
| Soil properties (Section 3.4.2) | | Physical, chemical and biological properties of the solid, liquid and gaseous phase |
| Agricultural qualities | Land | Climate Topography, slope Hydrology Soil pattern Accessibility, trafficability |
| | Whole soil | Nutrient availability or fertility: - Cation exchange capacity - Acidity Salinity and sodicity Water retention Groundwater depth & quality Vertical variation in texture |
| | Topsoil | Infiltration Structure stability Workability Erodibility |
| | Subsoil | Depth Water transmission |

sequence of slopes, and also by a particular parent material. Soil formation is related to the geomorphology (or landform), mainly because the movement of water and solids is affected by the slope of the land. The hydrological conditions play an important role in soil formation. These conditions alter when irrigation or artificial drainage is introduced. Thus, human interference will in time lead to changes in soil properties.

Organisms

The organisms that influence soil formation can conveniently be subdivided into higher plants (natural vegetation or crops), micro-organisms (moulds and other fungi), vertebrates (burrowing animals like moles), and meso-fauna (earthworms, ants, termites). These organisms mix the soil matrix and lead to the formation of organic matter. Moist conditions and high soil temperatures have a favourable effect on biological activity. Organisms are partly responsible for transforming and translocating organic matter and other soil constituents. They also improve aeration and permeability by the holes and channels they form.

Time

Time is a passive factor in the process of soil formation. In slightly sloping areas in humid tropical regions, where high rainfall and high temperatures cause intensive weathering and leaching, time is a predominant soil-forming factor. In other circumstances, the influence of time is less pronounced, but exists nonetheless.

Human Activities

From a pedological point of view, human activities do not have a major impact on soils, since they have taken place only over a relatively short time. From an agricultural point of view, however, they have a great impact, since soil properties are often seriously changed by human intervention. Hence, human activities are mentioned here as a separate factor. Examples of the results of human activities are:

- A changed soil-water regime with the introduction of irrigation or drainage;
- The mixing of horizons with different properties by ploughing;
- A changed nutrient status by fertilization or exhaustion;
- Salinization by unbalanced water management;
- Soil erosion due to the cultivation of sloping lands.

3.2.2 Soil-Forming Processes

Physical, chemical, and biological processes of soil formation are highly interactive. The physical processes involve changes in properties such as water content, volume, consistency, and structure. The chemical processes involve changes in the chemical and physico-chemical compounds of the soil. The biological processes involve changes influenced by the organisms living in the soil.

The major processes are summarized below. More details are given in the discussion on soil profiles (Section 3.3) and the characteristics and properties of soils (Section 3.4).

Physical Processes

The main physical processes of soil formation are:

- The translocation of water and dissolved salts, or of suspended clay particles;
- The formation of aggregates, which is a major cause of soil-structure development;
- Expansion and contraction as a result of wetting and drying of clay particles with a 2:1 type mineral (Section 3.3);