

PEDOGENESIS AND SOIL FORMING FACTORS

Antonie Veldkamp

*Wageningen Agricultural University, Department of Environmental Sciences,
Wageningen, The Netherlands*

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Summary

The main soil forming processes and soil forming factors based on the properties and land use limitations of the major soils groups are reviewed with reference to their effect on land use. Subsequently, their process impact on use options is discussed.

In general, it can be concluded that some soil properties, in particular those strongly related to parent material, soil depth and soil age, cannot be changed without the input of high level technologies. Other soil properties and related processes can be partly modified with specific management such as textural differentiation, podzolic, andic and ferrallitic properties and salt accumulation in subsoils. Therefore, these pedogenetic properties have a somewhat less dominating effect on land use. In a similar way this also applies for factors like flooding frequency and slope. Dikes and terraces are well-known tools to deal with these factors.

The best manageable soil properties are organic matter content of top soils and hydromorphy. Land drainage can quickly improve soil productivity of arable land and grassland. But the most used and most effective process to manage soils in order to maintain long term productivity is to increase organic matter content of the top soil.

A quick overview of the effects of land use intensification and conversion on soil properties is given. There is an overall tendency towards the decline of the favorable soil properties needed for high and sustainable productivity. The most obvious trend is a decrease in organic matter content, and because this can be a rather quick process this very vulnerable soil property requires constant attention.

1. Pedogenesis and Soil Forming Factors

Soil properties and processes can strongly affect land use options. Not all land uses are possible on all soils, and when certain uses do they often require specific management strategies. Because of this, biophysical land evaluation has always strongly emphasized on soil properties combined with climate conditions. Both are difficult to change and especially low input agriculture has to work with climate and soil conditions as given. Notwithstanding, modern technologies allow land managers to overcome a good number of basic constraints, with irrigation being a clear example to alleviate water limitations.

Soils, soil properties and soil formation are affected by: climate, parent material, vegetation, fauna and man, topography and time. The nature and importance of each of these soil forming factors vary, and most soils are still in the process of change as shown in pedogenetic profile differentiations and weathering. The terminology used in this paper refers to the terms of the World Reference Base for Soil Resources (WRB) and the FAO-UNESCO Soil Classification System (see **Soil Geography and Classification**).

The nature of a soil, its profile build-up and specific properties are the direct result of several pedogenetic processes linked to the soil forming factors mentioned above. The most important of these processes are shortly reviewed below.

1.1. Organic Surface Horizon

Organic matter (OM) accumulates in the soil as litter at the surface, and as decaying roots and microbial biomass (microbes, fungi, etc.). This is the result of the balance of production, decomposition and mixing of organic substances and soil material. Decomposition and mixing of OM are mainly due to the soil micro- and meso-fauna and are enhanced by oxygen and nutrient availability, high temperature and low amounts of Fe^{3+} and Al^{3+} bound to the organic matter. If one or more of these factors are not optimal in the soil, OM decay and mixing are hampered and this leads to organic matter accumulation. In terms of land use the nature of the top soil is essential as it contains most nutrients, and therefore land use types leading to a decline of OM in the soil deteriorate quickly.

1.2. Hydromorphism

Prolonged water saturation and seasonal alternating water logging and drainage have a pronounced affect on chemical and morphological soil properties. Changes in the degree of water saturation affect the supply of O_2 to the soil and roots, which in turn influence the oxidation state of iron and manganese and pH. Under waterlogged conditions reduction prevails, and this leads in the presence of sufficient organic matter to the dissolution of Fe^{2+} and Mn^{3+} or Mn^{4+} and to the development of typical grayish reduction colors. Upon aeration, oxygen enters the system and iron and manganese crystallize into Fe^{3+} and Mn^{3+} oxides and hydroxides, leading to the development of typical reddish colors. Under reduced conditions the pH is between 6 and 7, but it can decrease considerably under oxidizing conditions.

In strongly leached soils an alternation of oxidation and reduction can lead to a breakdown of clay minerals; this phenomenon is called *ferrolysis*. This process can help to enhance abrupt textural changes on top of a dense subsoil horizon, as can be observed in Planosols (*see below: Planosols*).

Soils affected by hydromorphism are usually not suitable as arable land because of the unfavorable rooting conditions and increased acidity after drainage.

1.3. Textural Differentiation

Textural differentiation between parent material, topsoil and subsoil are common in soils under all climatic conditions. It affects root development and internal hydrologic properties of the soil, in particular permeability and water retention capacity. Abrupt textural changes can also lead to local hydromorphism at levels with important porosity changes.

There are at least eight different reasons for a textural differentiation in the profile: (1) physical and chemical weathering; (2) vertical transport of fine soil particles through

biological activity; (3) eluviation and illuviation of clay suspended in the soil water; (4) superficial removal of fine soil particles by erosion; (5) superficial removal of clay due to tillage in wetland rice agriculture; (6) clay formation in the subsoil; (7) weathering of primary minerals in some subsurface horizons; and (8) vertical movement of soil matrix material.

1.4. Calcic, Gypsiferous and Saline Properties

Many soils in low rainfall areas accumulate relatively soluble minerals that affect both their own properties and the plants and crops that grow on them. Calcite, gypsum, chlorides and sulfates are commonly accumulating salts. The depth of accumulation is a function of the precipitation and evaporation balance. The more soluble salts only accumulate under real arid conditions.

Plant growth is usually not much hampered by calcium and magnesium carbonates, and to a lesser extent by gypsum (calcium sulfate). More soluble salts, however, cause problems with plant growth and create so-called saline soils. In sodium-dominated (or alkaline) soils, clays become unstable and may cause severe structural degradation (*See below: Solonetz*). Arable farming in saline soils is therefore only possible when irrigated, and with a good drainage system for leaching the harmful salts.

1.5. Vertic Properties

Soils dominated by swelling clay minerals and affected by a contrasting seasonal climate often develop vertic properties. These are expressed by a combination of (1) deep cracks when dry; (2) intersecting slickensides in the subsoil; (3) the presence of wedge-shaped structural aggregates in depth; (4) and the occurrence of a 'nutty' surface structure.

The strong cracking and self mulching makes these soils not very suitable for perennial crops. Moreover, the presence of a micro-undulating micro-relief (gilgai) requires additional planning measures in irrigation projects.

1.6. Podzolization

Podzolization occurs through transport of organic matter, iron and aluminum in a soluble form and under acid conditions from the surface to deeper horizons. The process consists of a phase of mobilization followed by an immobilization of these compounds. Unsaturated organic acids dissolve Fe and Al. The immobilization is either caused by saturation of the organic acid complex by these metals or by microbial breakdown of the carrier.

Podzols develop under conditions where the production of soluble organic acids is not neutralized by divalent cations. This occurs mainly in sandy parent materials holding few weatherable minerals. Low temperature and high rainfall during the growing seasons also stimulate podzolization. Other contributing factors are unpalatable litter, as produced by conifers, heather etc. and impeded biological mixing due to poor fertility, periodic water stagnation and/or cold climate.

The low nutrient content and low pH conditions of soils with podzol characteristics are not favorable for agricultural use.

1.7. Andic Properties

The formation of amorphous aluminum silicates and/or Al-bound organic matter gives rise to so-called andic properties. The key factor governing this process is the rapid weathering of easily weatherable materials (often volcanic glass). The Al-Si gel (allophane) has a considerable potential anion exchange capacity leading to phosphate retention in these soils. Allophane has strong aggregation, which increases upon drying, high water retention and high pore volume with non-rigid pores.

Andic properties are not unfavorable for agricultural use, though phosphate retention can become a problem.

1.8. Ferralitization

Typical for this process is the removal of silica from primary minerals. This leads to a residual accumulation of (hydr)oxides of iron (Fe), manganese (Mn) and aluminum (Al). Ferralitic weathering involves a strong depletion of basic cations and a low pH. The soil is dominated by low activity clays and hydr(oxides). As a result the chemical status is poor, and soils have a pH-dependent exchange capacity. Given the low pH these soils typically have an anion exchange capacity leading to phosphate retention. Ferralitization causes inherent poor soils with unfavorable chemical properties for agricultural use.

1.9. Chronosequences

Pedogenesis progresses in time and the longer it acts the better a logical evolution in soil development can be observed, from young to older and more mature soils in time. This is reflected in so-called chronosequence studies, like on river terraces where all conditions are assumed to be equal except time. A good example of such a study was made by Jongmans *et al.* (1991) in the Allier basin in France where a shift was observed from recent soils with only an organic surface soil development, towards a textural differentiation in a later phase, and leading in time to temporary water stagnation and hydromorphic conditions; ultimately, it involved further leaching, texture differentiation and finally podzolization. As a result, the agricultural soil potential also changed in time. As these soil property changes are much more gradual than land use change we will not look further into soil profile evolution.

It should also be noted that the present-day properties of many soils are due to long term development under changing conditions. For example, deep tropical red soils can be found in NW Europe (Vogelsberg Germany) as a result of a past climate. Consequently many soils are not always in equilibrium with current conditions. Likewise, highly weathered tropical soils are nowadays found also in semiarid environments, being an indication of much wetter conditions in the past.

In the next paragraph an overview is given of the major world soils as grouped in the WRB and FAO-UNESCO classification systems (*see: Soil Geography and Classification*), their properties and their use limitations.

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Biographical Sketch

Antonie Veldkamp is a professor and a chairperson in the Soil Inventory and Land Evaluation Department of Environmental Sciences at Wageningen University (The Netherlands). He has been active for twenty years in teaching and research in quaternary geology, geomorphology, soil science and land use changes. In all those fields he combines fieldwork with quantitative analysis and process modeling. He developed several models and wrote over 100 international peer reviewed papers. He is a member of the SSC of LUCC (Land Use/Cover Change Project) and the GLP Global Land Project (IGBP and IHDP).

His current research focuses is on the characterization and modeling of integrated soil, landscape and land use systems. The emphasis is on system feedbacks in coupled human-ecological systems. <http://www.lad.wur.nl/>