SOILS AND GENERAL AGRONOMY

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Contents

Summary

Plants, and crops in particular, grow and develop through the uptake of water and

nutrients by the root system in soils and their transformation into biomass through processes governed by photosynthesis. The quality and amount of products harvested from this biomass depend largely on the intrinsic properties of the soil, i.e. the moisture and nutrients made available for uptake by the roots.

This chapter describes in a synthetic form the impact of the most important soil properties on general agronomy, crop production, cultivation methods, and yields, including the specific management aspects which take away some production constraints. Changes in general agronomy as a result of plant breeding, climatic change and competition between newly introduced crops are discussed. The paper refers also to other chapters in this Encyclopedia where some of these aspects have been discussed in more detail.

1. Introduction

The soil is the upper part of the earth's crust and the support basis for plants and crops. Soil science is the discipline associated with describing, classifying, mapping and interpreting soils and soil properties for various uses like agriculture and crop production, road and infrastructure building, water management, etc. Over the past few years the soil has also become a focal point in environmental sciences and ecological land management. Soil health and soil quality are also primary conditions for various forms of sustainable land use. Soil science in its broad context deals with many sub-disciplines like soil fertility, soil physics, soil microbiology, soil chemistry, crop management, tillage, soil and water conservation, contamination, remediation and so forth.
Plants grow and develop through the uptake of water and nutrients from the root system and carbon dioxide from the air, and the transformation of these components into biomass through photosynthesis. The nutritious and economic parts of biomass are useful in the form of grains, fruits, nuts, or leaf vegetables. The quality and quantity of these products depend largely on the intrinsic properties of the soil and climate at a given location, the type and amount of nutrients supplied, and the conditions under which those nutrients are available; a deficiency of any one of these essential nutrients reduces plant growth. The overall status of these conditions is referred to as soil fertility.

Water supply, including moisture available in the root zone in low rainfall periods, and aeration also affect crop production. Water supply is governed by specific soil properties, in particular soil texture, structure and related soil physical characteristics. The role of (micro) biological activities, from earthworms to bacteria, in the creation of optimal soil physical and chemical (fertility) conditions is crucial.

This chapter describes soils and soil properties in their relation to agricultural use, plant growth and crop production, and overall land management. In domains where more detailed information on the subject can be obtained, reference is made to chapters in the Encyclopedia where such additional data are supplied.

2. Perception of Soils

Soils have been described and studied since times immemorial. The original concept of a soil up to the mid-19th century was that it was a “closed box filled with dirt to which water and nutrients should be added for plant growth and crop production”. The dirt was a weathering product derived from the underlying geological parent rock, modified under the influence of a number of external factors like climate, water, biological activity, etc. It was in the first place considered a foothold for plants and a static storage bin for nutrients and water that could be used by plants for development and biomass (crop) production.

Two major events changed this original static concept. The first was the publication (in 1840) of J. Liebig’s “*Chemistry as a Supplement to Farming and Plant Physiology*” which learned about mineral solubility and nutrient uptake. The second was the development (in 1875) of genetic soil science by Dokouchaev and his scholars. In this new perspective soils were considered dynamic and independent natural bodies with a unique morphology resulting from the location-specific combination of climate, living matter, parent rock materials, relief and time (see also*: History, Philosophy and Sociology of Soil Science*).

Through this new perception, soils were no longer considered an outcome of the geological nature of rocks only, but as an integrated expression of different, individual though interlinked factors, expressed in the morphology of the profile. In short, soils were taken away from the umbrella of geology, and soil science developed as an independent and interdisciplinary field in its own right. Over the past decades this concept has gradually been broadened and adapted to the perspectives of the various users.

Nowadays the perception of a soil depends upon the perspective of the person who looks at it**.** A farmer looks at soil differently than an engineer, a geologist differently than a soil scientist. For this reason there is no single, uniform definition of soil. A quick look at some sample definitions helps to demonstrate the differences as follows (see also*: A Brief History of Soil Science*):

- For the engineer soil involves all un-consolidated materials above the bedrock; for him/her the soil is either inert physical building material, or a ground mass that may swell and shrink and, thus, affect the physical stability of constructions.

- For the geologist the soil represents the weathering product of the underlying rock; he/she looks at the soil as coarse rock fragments which are broken down into smaller pieces through weathering.

- For the agronomist the soil corresponds to the natural medium for the growth of plants and crops. In his/her concept the focus is on the fine soil material that retains and releases water and nutrients.

- For the soil scientist soil is a superposition of natural layers related to geomorphologic features or formed *in situ* by complex biochemical and physical weathering processes that contain living matter and are capable of supporting plant life (Philips and Lorz, 2008). He/she views the soil in terms of soil profiles made up of various superposed horizons with different pedogenetic properties.

All these definitions are for the same name, yet they differ considerably because each group approaches soil from a different perspective. In this chapter the focus is on the soil scientist's view with the objective to meet the agronomist's goals.

2.1. Soil Defined

Soil in its traditional agro-pedologic meaning is the natural medium for the growth of (land) plants, whether or not with discernable soil horizons. In a more detailed pedogenetic sense it is a dynamic three-dimensional piece of landscape that supports plants, and that has a unique combination of both internal and external properties. Each pedon, being the smallest volume of soil to identify an individual kind of soil, has a modal set of these characteristics. These can be learned through observation and research in the field and in the laboratory.

In the field the soil is usually described from a profile pit, one by one meter long and large, and 1.20 to 2m deep, considered representative for the surrounding soils area. The lower limit of the pedon is arbitrarily defined by the depth to which plant roots (and biological activity in general) develop, except when there is a clear break with the underlying rock at less than 1.20m. This depth is fixed at 2m (lowest part of the control section) for classification purposes in Soil Taxonomy. The solum may however reach several meters in deeply weathered soils in the tropics (Figure 1).

Figure 1. Giant podzol soil in Malaysia

Soils can be described in several ways, from the most simple single-factor component (e.g. soil color, texture, dry or wet, deep or shallow) or a combination of these, as is the case in most ethno-pedologic studies (see also: *Ethnopedology and Folk Soil Terminology*), to a complex system of criteria along universally agreed standards. These standards enable scientists anywhere in the world to prepare descriptions that can be read and interpreted by competent scientists. The format of these standards evolved, and has gradually been improved during the last century. Today, two major guidelines are currently used: the USDA Soil Survey Manual (USDA, 1951, revised in 1962 and 1993;

Schoeneberger *et al*., 2002) and the FAO Field Guide for Soil Descriptions (FAO, 1990). The two systems are quite comparable and are compatible with each other. These detailed field guides provide standard terms, definitions and symbols to facilitate consistency and (electronic) recording of both soil and landscape information.

A profile description starts with an overview of the surface conditions around the profile site (landform, position, vegetation, erosion hazards, etc.). This is followed by an identification and designation of the various master horizons (A, B and C horizons) and sub-horizons, and their characterization in terms of thickness and boundary distinction, soil matrix color (Munsell Soil Color Chart), texture, structure and consistency, and other specific features. Soil horizon designation is done by symbols of one or two capital letters for the master horizon and lower case letter suffixes for subordinate distinctions, with or without a figure suffix. There are five formal master horizons (O, E, A, B, and C) and two informal (R and D) master horizons (Schaetzel and Anderson, 2005). The master horizons and their subdivisions represent layers which show evidence of pedogenetic and morphological change (see also: *Soil Survey as a Basis for Land Evaluation*).

A number of selected morphological criteria and their classes commonly used in soil profile descriptions is displayed in Table 1. These class limits have often practical meanings. In the case of soil depth, for example, the classes define the areas suitable for grass (10-30cm), cereal (30-50 and 50-100cm) and tree growth (more than 100cm), respectively. Likewise, slope classes make a distinction between areas which are suitable or unsuitable for mechanical farming (critical limit between 6 and 13%, depending on the type of machine). The same holds true for texture (not represented in Table 1) where the different class groupings are not fortuitous, but reflect pragmatic situations. Hence, the sand and loamy sand classes group soils with a too high infiltration rate and therefore not suitable for gravity irrigation. The 18% clay limit between “coarse and fine silty clay” and “coarse and fine loam” were established to correlate the agronomic and engineering interpretations, as at that (appropriate) limit there is a change from plastic to non-plastic conditions, and this is considered by the engineers a very important criterion.

Criteria	**Class**					
Soil depth (cm)	<10	10-30	30-50	50-100	100-150	>150
Slope (%)	0-2	2-6	6-13	13-25	25-55	>55
Drainage	Very poor	Poor	Imperfect	Well drained	Slightly excessive	Excessive
Surface gravel (%)	0-2	2-5	5-15	15-40	40-80	>80
Rock outcrops (%)	<2	2-5	5-15	15-40	40-80	>80
Flooding frequency	None	<1 in 10 years	1 every 5-10 years	1 every 2-4 years	Monthly	Weekly
Flooding duration (in	<1	1-15	15-30	30-90	90-180	>180

days)						
Depth of flooding (cm)	0-25	25-50	50-100	100-150	>150	
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Table 1. Some selected criteria for soil description and their class limits. (adapted from FAO, 1990).

Though field descriptions might in first instance well characterize the most important soil properties, they should be complemented by laboratory analyses for refinement of description and classification of soils (inherent properties), but also to calculate more accurately production recommendations in terms of fertilizer and irrigation/drainage requirements (derived properties). Basically, there are two kinds of laboratory analyses: one that characterizes the more static properties (texture, cation exchange complex), another that analyzes nutrient levels (pH, N, P_2O_5, K_2O, S) and other features (micronutrients) that can be manipulated by soil management practices. Those fertility-related measurements are most frequently confined to the surface layers, to which fertilizers and lime are added. These measurements are usually made annually in order to provide fertilizer recommendations for the specific crops to be grown.

Table 2 (a and b) gives an example of a laboratory data set for current soil analysis of a lowland soil in the tropics. From the data in these tables the following interesting information can be derived (see also: *Land Use Management*):

- This is most probably a natural undisturbed profile as can be seen from the gradual increase of the clay content and decrease of organic carbon (O.C.) content with depth.

- On the basis of soil texture the moisture storage in the root zone (upper 50 cm of soil) can be evaluated at approximately 100mm (Table 3, below), while the internal drainage will be slow. If the water consumption use of the crop is known (for example 5 mm/day) both the irrigation needs and frequency of irrigation can fairly well be calculated.

- The relatively low cation exchange capacity (CE) is typical for a kaolinite-dominated soil. The conversion of the CE over 100g clay in the B horizon (where the impact of OC can almost be neglected) indicates that kaolinite is the dominant clay mineral in the soil. Hence, the nutrient retention capacity is relatively small.

- The sum of bases (Σ bases) and base saturation are relatively high for a soil in the tropics, indicating an ample supply of Ca, Mg and K, a condition also reflected by the pH values. This can be explained by the geomorphologic position of the soil in a lowland, which collects runoff material and mineral nutrients from the surrounding upland areas.

- The concentration of exchangeable sodium (Na^+) is above normal, and the fact that it increases with depth (reaching 13-14% of total CE in the lower layers) indicates that there is an obvious risk for alkalinization by capillary rise from Na^+ rich groundwater.

- The natural nutrient reserve (NPK and Ca) in the root zone can be derived from the figures of N, P_2O_5, K^+ and Ca^{2+} by converting the percentage (for N), ppm (for P_2O_5) or cmol/kg (Ca^{2+} and K^+) soil data from the lab into kg of mineral component, using an assumed bulk density of 1.3 g/cm^3.

- The analysis of exchangeable aluminum is not required when the soil pH is above 4.8 – 5.2 (depending on the analytical method used). When it drops below this critical limit aluminum might reach a toxicity level, and that is generally hazardous to many crops.

Horizon and depth (cm)	**Texture (%)**					**Text. class**	**O.C .%**	**N%**	**C/N**	**pH (H_2O)**
	0-2 µ	**2-20 µ**	**20-50 µ**	**50-250 µ**	**250 µ -2mm**					
A1 : 0-20cm	42.0	34.1	7.2	16.0	0.7	siClay	1.34	0.102	13	6.2
A3: 20-35cm	51.0	21.0	20.3	7.5	0.2	siClay	0.47	0.042	11	5.9
B1: 35- 50cm	57.0	17.5	16.8	8.4	0.3	Clay	0.26	0.029	9	5.9
B2: 50-90cm	64.7	12.3	13.5	9.0	0.5	Clay	0.15	-	-	6.0

Table 2a. Physicochemical data of a lowland soil in the tropics.

Horizon and depth (cm)	**Cation exchange complex (cmol/kg soil)**							**Base satur. (%)**	**P_2O_5 (ppm)**
	CE	**Ca^{2+}**	**Mg^{2+}**	**K^+**	**Na^+**	**Al^{3-}**	**Σ Bases**		
A1 : 0-20cm	12.36	6.95	3.36	0.26	0.60	-	11.41	90	4.13
A3 : 20-35cm	9.31	4.85	2.11	0.16	0.69	-	7.75	83	1.30
B1 : 35-50cm	6.13	2.35	1.39	0.12	0.80	-	4.66	76	0.76
B2 : 50-90cm	6.03	2.02	089	0.09	0.85	-	3.85	64	-

Table 2b. Chemical data of a lowland soil in the tropics.

With present day strong focus on sustainable production systems, soil quality and soil health should be taken into consideration as well. Soil quality is the capacity of a soil to function, within ecosystem and land use boundaries, to sustain biological productivity, maintain environmental quality and promote plant and animal health. Soil quality serves also as an environmental buffer in the formation and destruction of environmentally hazardous components.

Soil quality is closely associated with soil health, and the latter is largely determined by the soil organic system because of the profound influence it has on soil physical, chemical, and biological properties. Therefore, many steps taken to improve soil health deal with increasing the soil organic matter status and the vitality of the soil organic system (see also: *Soil Health and Productivity*). Some techniques to improve soil health include: reduced tillage, use of green manure, application of animal manures, crop rotations, strip cropping, use of cover crops, application of sludge or biosolids, and other additions of organic materials and nutrients. These management techniques enhance the activity of both the micro- and macro-biological soil organic system, and improve favorably other crop-related properties such as soil aggregation, infiltration and water holding capacity, bulk density and aeration, root penetration resistance, runoff and soil erosion, and cation exchange capacity.

Management for soil health can also lead to reduced need for agrochemicals and tillage, reduced fuel consumption by farm equipment, and increased sequestration of carbon dioxide in the soil, all of which benefit the environment. Many of these management aspects have been described in *Conservation Agriculture* and *Land Rehabilitation*.

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Biographical Sketch

Willy Verheye is a former, now retired Research Director at the National Science Foundation, Flanders, and a Professor in the Geography Department, University of Ghent, Belgium. He holds a M.Sc. in physical geography (1961), a PhD. in soil science (1970) and a Post-Doctoral Degree in soil science and land use planning (1980).He has been active for more than thirty-five years both in the academic world, as a professor/ research director in soil science, land evaluation, and land use planning, and as a technical and scientific advisor for rural development projects, especially in developing countries. His research has mainly focused on the field characterization of soils and soil potentials, and on the integration of socio-economic and environmental aspects in rural land use planning. He was a technical and scientific advisor in more than 100 development projects for international (UNDP, FAO, World Bank, African and Asian Development Banks, etc.) and national agencies, as well as for development companies and NGOs active in inter-tropical regions.W. Verheye is the author or co-author of more than 100 peer reviewed papers published in national and international journals, chapters in books and contributions to the Encyclopedia of Life Support Systems (EOLSS). He is Honorary Editor for the EOLSS, Themes on: Soil Sciences, Land Use and Land Cover, and : Crops and Soil Sciences.