Soil Acidity and Alkalinity

Acidity is a general term that refers to the amount of hydrogen ions in the soil solution. Acidity is indicated by the pH, which is the negative logarithm of the H-ion concentration. A neutral solution has a pH = 7, an acid solution a pH < 7, and an alkaline solution a pH > 7. The pH of the soil strongly affects the availability of nutrients to plants. Near neutrality (6 < pH < 7.5), there are seldom problems. At pH < 4.5 and at pH > 8.5, there are always problems with the availability of some nutrients and/or with the toxicity of other elements.

The pH is generally measured in the laboratory, although instruments are now available that allow it to be measured in the field. There are also kits that allow an estimate of the pH by the addition of fluids, but these procedures are not always reliable.

The acidity or alkalinity of a soil cannot generally be observed in the field. Extremely alkaline conditions in so-called black alkali soils, however, can sometimes be inferred from the presence of hygroscopic sodium salts. Very acid conditions can be inferred during field observations from the presence of bleak brown jarosite colours in acid sulphate soils.

Low pH values are associated with strong leaching in a wet environment, whereas high pH values are associated with the absence of leaching and, in arid environments, with the presence of sodium ions.

Fertility

Soil fertility is a compound characteristic of a soil. The fertility of a soil, i.e. the ability to supply the nutrients needed by plants for agricultural production (Ahn 1992), depends on characteristics like clay and organic matter content, cation exchange capacity, base saturation, soil acidity and amount of weatherable minerals, but aspects like workability and tilth, may also also be included. It should be emphasized also that an evaluation of fertility depends on the socio-economic setting. In an environment where fertilizers are relatively expensive, the chemical aspects of fertility play a more prominent role than the physical aspects. Where fertilizers are cheap, good physical soil conditions are more highly valued than the chemical ones.

3.5 Soil Surveys

This section discusses the role played in soil surveys by field observations, field measurements, and laboratory analyses. It should be emphasized that, to be useful for drainage purposes, a soil map requires additional information. The information embodied in such a soil map should include:

- The topography;
- The soil texture of topsoil, subsoil, and sublayer, preferably to a depth of several metres;
- The occurrence of any layers that would disturb the flow of soil water and rooting;
- Historical watertable fluctuations (hydromorphic properties);
- Hydraulic conductivity;
- Soil-water retention;

- Salinity and sodicity status;
- Soil-mechanical properties.

When combined with geohydrological information, this soil map provides integrated information on the natural conditions in the project area. Chapter 18 elaborates on the procedures to be followed in drainage surveys.

3.5.1 Soil Data Collection

During a first field visit, observations can be made on land use, vegetation, crop performance, micro-relief, surface ponding, and the natural drainage conditions. In soil pits excavated at representative sites, the soil characteristics and properties discussed in Section 3.4 can be studied. Horizontal or vertical differences in these properties are of particular importance.

Other features of the soil or the land cannot be observed directly, but data can be obtained from field measurements. Examples are surface infiltration, permeability (hydraulic conductivity), salinity (electrical conductivity/EC), acidity (pH), crop yield, and topography.

Still other data need to be obtained from laboratory analyses. Depending on the analyses required, disturbed samples can be taken from soil pits or by auger. If needed, undisturbed samples can be taken, usually in special sampling cylinders. The disturbed samples can be used to analyze the particle-size distribution (texture), CEC, electrical conductivity of the saturation extract or other soil-water mix ratios, pH, organic-matter content, nutrients, and micro-nutrients. Undisturbed soil samples are usually analyzed for bulk density, soil-water retention, porosity, saturated and unsaturated hydraulic conductivity. Methods of soil analysis are extensively described by Klute et al. (1986).

Some properties can be measured both in the field and in the laboratory. In general, the results of laboratory analyses are more accurate, but cost more to obtain. In cases where laboratory measurements are preferred, a combination of a large number of field measurements, complemented by a few laboratory measurements, could be the right approach. Hydraulic conductivity measurements obtained from small samples often show a wide scatter due to the heterogeneity of the soil. The large-scale field methods that will be discussed in Chapter 12, however, can incorporate the effect of soil heterogeneity.

Though many visual observations yield only a qualitative picture, this picture can be highly relevant. Quite often, lengthy and costly measurements can be omitted if, prior to the start of a measuring and sampling programme, some field observations are made. These can be done quickly and at low cost. Even so, the possibilities and advantages of visual observations often seem to be overlooked. It is emphasized that these three procedures (i.e. the collection of qualitative information during field visits, the collection of data from field measurement programmes, and the collection of data from laboratory analyses) are complementary. Hence, in making proper assessments from soil surveys conducted for drainage purposes, each of these techniques should be used to its full advantage.

3.5.2 Existing Soil Information

When a tract of land has a drainage problem and consideration is being given to improving that situation, a proper inventory and description of the existing drainage conditions first has to be made. One has to understand the way in which these conditions are affecting the present land use. Subsequently, the factors that are causing the deficient drainage conditions have to be identified. Only when the problem has been properly diagnosed can a remedy be devised.

Possible sources of information that may already be available in the area are aerial photographs and satellite imagery, topographic maps, soil maps, vegetation or land-use maps, and farmers' experiences.

The existence and pattern of a natural drainage system in the area can be inferred from aerial photographs, satellite images, and topographic maps.

Soil maps often provide information on drainage conditions, and if they are available, they should always be consulted. In The Netherlands, the soil maps provided by the Soil Survey Institute indicate the soil texture and also the groundwater-fluctuation class. Other soil maps may give no explicit information on drainage conditions, depending, of course, on the purpose for which the soil maps were made. Nevertheless, many soil maps do contain information that refers implicitly to the drainage conditions. If the map includes a descriptive legend of the soil-mapping units, more information on drainage can be retrieved. If the legend is based on a soil classification system, a soil scientist can assist in fully interpreting the map.

Vegetation and land-use maps can provide a good impression of the extent of areas with particular drainage problems. The natural vegetation of well-drained soils is characterized by different species than the natural vegetation of poorly-drained soils. Differences in the morphology and physiognomy (appearance) of the vegetation also indicate differences in drainage conditions. Similarly, arable crops are generally cultivated on well-drained soils, while poorly-drained soils are often used for grazing or for meadow grassland. Vegetation does not, however, give direct information on the feasibility of improving drainage.

Farmers and other residents who have often lived all their lives in or around the area of interest can provide the drainage engineer with useful information. Farmers try to use all kinds of land and are therefore generally able to provide information that will assist the engineer in assessing the technical or financial feasibility of particular drainage improvements. Farmers can provide historical data on floods, on trials and experiences with different forms of land use, and on attempts to improve the drainage conditions of waterlogged soils.

3.5.3 Information to be Collected

After interpreting the information collected from the sources discussed above, one can establish a measurement program to collect the required additional data. What one basically has to obtain is a good insight into all those environmental aspects that one needs to judge the feasibility and the design of an improved drainage situation. A comprehensive list of the relevant soil and land features is presented in Tables 3.5A, 3.5B and 3.6.

Table 3.5A Soil features relevant to subsurface drainage (after Van Beers 1979)

Main aspects	Mechanism to be characterized or predicted	Depth being considered (m)	Some soil charateristics and properties, and other data to be interpreted
Intake at the land surface	Surface infiltration	0 - 0.3 Upper root zone mainly	Infiltration rate Soil texture Swelling of clays Organic matter content Presence of free carbonates Soil structure Structure stability Soil crusts Soil pH Soil colour Soil consistency Visible pores and cracks Root density
Vertical flow through the soil profile	Percolation to the groundwater	0.3 - 1.2 Lower root zone	In addition to the items mentioned above; Rooting depth and root development Particular layers impeding vertical flow
	Capillary rise from the groundwater		Seasonal fluctuations of the watertable Height of capillary rise Unsaturated hydraulic conductivity Electrical conductivity and chemical composition of the groundwater
Horizontal flow mainly	Flow to drains	1.2 - 5.0 Shallow substratum	Soil texture of substrata Depth and thickness of impervious layer(s) Depth and thickness of pervious layer(s) Hydraulic conductivity of permeable and impermeable layers Transmissivity (KD value) Groundwater depth Chemical composition of the groundwater Soil structure and structure stability
	Groundwater flow	> 5.0 Deep substratum	Transmissivity Groundwater quality Sources of salinity

Artificial drainage is implemented to prevent or alleviate waterlogging and subsequent salinization of irrigated areas in arid and semi-arid regions, and to prevent or alleviate waterlogging in the humid tropical and the temperate regions. Although the principles of drainage in both cases are the same, differences in the nature of soils and the processes prevailing in these soils warrant a different approach in soil surveys and other investigations. In semi-arid and arid climates, for example, one has to assess the capillary-rise flux of saline water, whereas, in humid tropical and temperate areas, this process is often less relevant.

As will be shown in the subsequent chapters of this book, the nature of the drainage

Table 3.5B Soil features relevant to surface drainage (after Van Beers 1979)

Main aspects	Mechanisms to be characterized or predicted	Depth being considered	Some soil characteristics and properties, and other data to be interpreted
Horizontal flow	Overland flow Surface channel flow Soil erosion	Land surface only	Slope (degree and length) Vegetation cover (herb, shrub and tree layer) Natural stream channels (distribution, size, depth, gradient) Channel obstructions Roads and culverts Micro-topography or surface irregularity
Water storage or soil water retention	Drainable pore space Storage capacity Land use Cultivation practice Antecedent water conditions	Both the land surface and the root zone	Soil water profiles during high and low groundwater levels Soil water retention curves Soil texture Soil structure

problem and other conditions determine which of the data presented in Tables 3.5 and 3.6 have to be considered for further observation and measurements. The essential task is to assess the water movement and a water balance of the area (Chapter 16), both under the present conditions and after possible improvements.

3.5.4 Soil Survey and Mapping

The availability of a topographic base, preferably in the form of a topographic map with contour lines, is the first requirement for a soil survey. The topographic base serves for choosing observation sites, for plotting observations and drawing boundaries, and for checking the correctness of soil boundaries. If a topographic base is not available, some of the topographic information needed can be derived from recent aerial photographs or satellite pictures.

When soil changes are associated with transitions at the soil surface or in the vegetation cover, and these form a pattern, one speaks of a 'soil association'. When these changes are unpredictable and cannot be mapped, – sometimes because the surveyor has been unable to identify the components through lack of time –, one speaks of a 'soil complex' (e.g. a valley complex).

In practice, the topography is often a very good aid in locating changes in soils. Conversely, it is common practice to compare the soil pattern with the topography. Wherever a soil boundary and a contour line are approximately perpendicular to each other, one has reason to make a careful check whether the soil boundaries are correct. Similarly, the quality of a soil map is doubtful if it shows no signs of a broad relation between soils and topography.

A recent development in The Netherlands is to use soil-survey data to improve the assessment of the soil-hydrological properties of land areas (Wösten et al. 1985, 1988).

Table 3.6 Soil and land features relevant to changes in soil properties as a result of drainage practices

Main aspects	Mechanisms to be characterized or predicted	Depth being considered (m)	Some soil characteristics and properties, and other data to be interpreted
Soil physical properties	Subsidence	0 - 5.0	Presence of mud and peat deposits (thickness, water content, organic matter content, soil texture) Drainage base (field drainage system, main drainage system, and outlet)
	Soil ripening	0 - 2.0	Crack and biopore development Aeration mottles Irreversible water losses Hydraulic conductivity
Soil chemical properties	Oxidation of pyrites	0 - 1.2	Presence of pyrites
	(De)salinization and (de)sodification		Electrical conductivity and chemical composition of soil water extracts Sodium adsorption ratio Exchangeable sodium percentage Structure stability

The methodology relates these soil-hydrological properties (i.e. the relation between soil-water content and matric head, and the unsaturated hydraulic conductivity) with other soil properties (e.g. the clay, silt, and organic-matter content, the median particle size of the sand fraction, and the bulk density). The relationships are established for soil horizons, but not for soil profiles or soil mapping units. Based on these relationships, soil maps can be translated into maps of particular soil-hydrological constants.

3.6 Soil Classification

3.6.1 Introduction

This section will briefly explain how the most widely-used soil classification systems work and will indicate what useful information the drainage engineer can obtain from soil classifications.

Unfortunately, unlike the taxonomy of flora and fauna for which the Linnean system is universally accepted, no system of soil classification can yet claim worldwide acceptance. Most countries had already developed a national soil-classification system prior to the formulation of the FAO- UNESCO 'Legend to the Soil Map of the World', which – although not officially called a classification system – is at present the only taxonomic system with a truly worldwide outlook (FAO-UNESCO 1974; FAO 1988). Another system of near-worldwide application is the Soil Taxonomy System of USDA Soil Conservation Service (Soil Survey

Staff 1975) (Section 3.6.3). Both systems are updated regularly. For a broader spectrum of review, see for instance Young (1976).

3.6.2 The FAO-UNESCO Classification System

FAO has attempted to integrate the useful aspects of various national classification systems into a universal system (FAO-UNESCO 1974; FAO 1988).

The revised legend of the FAO-UNESCO Soil Map of the World (FAO 1988) distinguishes two taxonomic levels: 'major soil groupings' and 'soil units'. There are 28 major soil groupings. The system works by distinguishing groupings and units of soils with characteristics deviant from the other soils. The classification is based on an elimination system: if a soil to be classified does not qualify for the first grouping, the second grouping is checked; if it does not qualify for the second grouping, the third is checked, and so on.

Each major soil grouping is composed of a number of units ranging from 2 to 9. This yields a total of 153 units. The name of a unit consists of an adjective ending in '-ic' and the noun signifying a major grouping (e.g. 'Thionic Fluvisols', which are alluvial soils with a high sulphur content, also known as acid sulphate soils). The FAO-UNESCO Classification System uses 40 different adjectives. For an explanation of the meaning of the names of the major soil groupings and the unit name adjectives, see FAO (1988).

The major soil groupings and soil units are identified with a key, which uses the following differentiating criteria: 7 master horizons, 16 diagnostic horizons, and 28 diagnostic properties. The master horizons were presented in Section 3.3.2. Some diagnostic properties which explicitly refer to the drainage conditions of soils are presented in Section 3.6.5.

Finally, soil units can be subdivided into soil phases. This division at the third level is made in view of soil management, and is based on rooting depth, groundwater depth, hydraulic conductivity, layers of high salinity, etc.

3.6.3 The USDA/SCS Classification System

In contrast to the FAO Legend, the USDA/SCS Soil Taxonomy (Soil Survey Staff 1975; 1992) distinguishes four taxonomic levels: 'orders', 'suborders', 'great groups', and 'subgroups'. The Soil Taxonomy naming system makes use of root suffixes for the orders, prefixes for the suborders, prefixes for the great groups, and adjectives for the subgroups. The system uses lengthy criteria for separation at each of the four levels. It has a total of nearly 2000 subgroups. The Thionic Fluvisol used as an example for the FAO/UNESCO System would, in this classification, be:

- Order: ENTisol (soils with only limited profile development);
- Suborder AQUENT (wet entisols);
- Great group SULFAQUENT (wet entisols with sulphidic (= acid sulphate) properties in the profile);
- And two subgroups:
  - The haplic Sulfaquent with a good bearing capacity; and
  - The typic Sulfaquent with a poor bearing capacity.

3.6.4 Discussion

The major soil groupings identified in the FAO legend are to a large extent genetic types (i.e. they are related to the formation of the soil). Though the system of classification is artificial, it leads to more or less natural groupings, many of which have been recognized in earlier soil classification systems. Moreover, the groupings are in general identifiable in the field, and most groupings exhibit particular characteristics that are relevant for agricultural use.

The USDA Classification is a morphometric system, which means that all properties used to describe the soils can be measured in the field or in the laboratory. The great detail of the USDA Classification makes it a classification to be used only by, and for, soil specialists. For more general purposes, the FAO-UNESCO System deserves preference. Young (1976) and FitzPatrick (1986) discuss the differences between the two classification systems.

The FAO-UNESCO Classification System combines the first- and second-level separation of soil groups and soil units in one key, whereas the USDA/SCS Soil Taxonomy uses a key for each level of separation. The key for first-level separation in the USDA/SCS System has no relation to the drainage conditions of the soil.

3.6.5 Soil Classification and Drainage

The soils described in this section are major soil groupings and units from the FAO/UNESCO Classification System. These are soils that often pose problems for drainage (Section 3.7). The characteristics mentioned below may also be identified at soil-unit level (i.e. when a soil is classified into another major soil grouping).

Histosols are all organic soils or peat soils with an organic layer at least 0.40 m thick.

Vertisols are heavy, often dark, clay soils (more than 30% clay), which develop large and deep cracks. Intensive alternating shrinkage and swelling result in a typical micro-relief of mounds (gilgai) and slickensides at some depth. In the topsoil of Vertisols, the common structure sequence shows granular structure elements on top of prismatic elements.

Fluvisols are young soils developed on recent alluvial deposits in river valleys and deltas, former lakes, and coastal regions (fluvial, lacustrine, and marine deposits, respectively). Most Fluvisols consist of stratified layers with different textures. *Thionic Fluvisols*, known as acid sulphate soils, have a sulphuric horizon or sulphidic material, or both, at less than 1.25 m depth.

Solonchaks are saline soils with a high content of soluble salts, mainly chlorides and sulphates. Saline soils are defined by the electrical conductivity of the saturation extract (Chapter 15).

Gleysols are soils dominated by hydromorphic properties in the upper 0.50 m of the profile (i.e. soils with a shallow watertable). (For a description of gleyic properties, see below.)

Planosols are soils with a heavily leached surface soil (E-horizon) over a clayey impermeable pan that is often an argillic or natric B-horizon. The surface layer shows stagnic properties (see below). Planosols have a structureless surface layer on top of prismatic structure elements.

Solonetz are soils with a natric B-horizon, which is an argillic horizon (accumulation of alluvial clay) with an Exchangeable Sodium Percentage ESP > 15% (Chapter 15). Solonetz or sodic soils have granular structure elements on top of columnar structure elements.

Plinthosols are soils containing plinthite (i.e. a clayey soil material with intense red mottles, rich in iron and poor in organic matter). Plinthite irreversibly hardens if it dries out, and is then called ironstone. Ironstone often occurs as a hardpan.

The worldwide occurrence of these major groupings can be appreciated from the 1:5 000 000 FAO-UNESCO Soil Map of the World (FAO-UNESCO 1974) and the more recent World Soil Resources Map at scale 1:25 000 000 (FAO 1991).

Soil units that have deficient drainage are those with gleyic or stagnic properties. Gleyic properties are bluish grey colours caused by conditions of semi-permanent reduction, present within 1.00 m of the surface. Stagnic properties are brown mottles caused by temporary reduction or alternating wetting and drying, present within 0.50 m of the surface.

Apart from gleyic and stagnic properties, other properties may refer implicitly to the drainage conditions (e.g. abrupt textural changes, or shallow soils).

3.7 Agricultural Use and Problem Soils for Drainage

3.7.1 Introduction

Many soils throughout the world are unsuitable, or only marginally suitable, for agricultural use. Apart from limitations related to climate, the major soil-related problems are low fertility, excessive salinity and sodicity, limited depth or excessive stoniness, and deficient drainage conditions. Limited soil fertility is, on a worldwide scale, probably the greatest problem, and is often associated with excess acidity. Many tropical soils of limited fertility are only suitable for the cultivation of flooded rice.

Attempts were made to describe the suitability of soils for specific types of land use by land capability classifications (Klingebiel and Montgomery 1961) and land evaluation (FAO 1976, 1985). These techniques, however, are only qualitative and depend strongly on the (often intuitive) judgement of the expert. Present developments are towards computerized quantified techniques with simulation of crop production for different scenarios (Feddes et al. 1978; Driessen and Konijn 1992). These techniques, however, form only an approximation since it is virtually impossible to describe the complete interactive soil-water-crop-atmosphere system with mathematical correctness. Moreover, the data required for such a description are never available on a project scale. Even so, these techniques do enable long-term performance evaluation of agricultural interventions and a reasonable cost-benefit analysis.

The soils that most often pose problems for drainage, or create problems when artificial drainage is introduced, are peat soils, Vertisols, fine-textured alluvial soils, acid sulphate soils, saline soils, sodic soils, and Planosols. Beek et al. (1980) extensively discuss the properties of these soils, and their potentials for improvement. The effects of their soil characteristics and properties on drainage are given in Table 3.6.

Peat Soils
Peat soils, organic soils, or Histosols vary widely in their physical and chemical properties. The high porosity of peat soils creates problems if peats that are almost saturated with water are reclaimed for the cultivation of dry-land crops. Considerable subsidence can be expected when peat soils and soils with peat layers are drained (Chapter 13). The water regime induced by an artificial drainage system may affect the hydraulic properties of the peat, requiring an adjustment of the drainage system after some years of operation. In addition, increased aeration may adversely affect other physical properties of peat.

Vertisols
Vertisols, also known as black cotton soils, owe their specific properties to the dominance of swelling clay minerals, mainly montmorillonite. In the dry season, these soils develop wide and deep cracks, which close when the clay swells after the first rains. Dry Vertisols may have a high infiltration rate, but, when wetted, they become almost impermeable. Most Vertisols are subject to surface-water stagnation at some period of the year. Under these poor drainage conditions, leaching of soluble components is severely restricted. The optimum soil-water range for tillage is narrow.

Fine-Textured Alluvial Soils
Soil conditions in river plains, deltas, and coastal areas are highly variable because of the type and pattern of sedimentation of the parent material. Lacustrine deposits are more uniform. In general, most Fluvisols with fine-textured layers are deficient in drainage. Loosely-packed muds are found where fine sediments are deposited under permanently submerged conditions. When they are drained, a specific type of initial soil formation takes place, called 'soil ripening'. Soil ripening involves the change of a reduced mud into a normal oxidized soil, and has physical, chemical, and biological aspects (Chapter 13; Pons and Zonneveld 1965).

Acid Sulphate Soils
Acid sulphate soils are formed in marine or brackish sediments. During sedimentation, sulphate (SO_4^{2-}) from sea water is reduced in the presence of organic matter to form pyrite (FeS_2). Further sedimentation gradually changes the environment into a swamp forest, which is waterlogged for most of the year because of poor drainage. Under these conditions, the mineral soil is often covered by a peat layer.

Upon exposure to the air, the pyrite in the soil profile oxidizes to form sulphuric acid, rendering the soil unsuitable for agricultural use. Important characteristics of acid sulphate soils are a pH below 4 and a high clay content. The main problem with potential acid sulphate soils is that they are waterlogged and unripe. If these soils are to be used for agriculture, some drainage has to take place. In this reclamation, great care has to be taken because excessive drainage – often in combination with burning (which destroys the peat layer) – can have a strongly negative impact. Dent (1986) gives a detailed description of the physical and chemical processes that take place in acid sulphate soils, and presents alternative management strategies for different physical environments. Such strategies aim at preventing acidification of these soils, through a combination of careful water management, a proper choice of crops, liming, and fertilization.

Saline and Sodic Soils
Saline soils and sodic soils, the latter formerly called 'alkali soils', are most widespread in irrigated areas in arid and semi-arid regions, but also occur in the more humid climates, especially in coastal areas. The salts or exchangeable sodium in saline and sodic soils hinder crop growth. For efficient crop production, these salts must be leached from the rootzone. This procedure itself is often problematic because, in most regions where these soils occur, irrigation water is scarce. In addition, many sodic soils have a poor structure and a very low hydraulic conductivity. The physical behaviour of salt-affected soils and techniques for their reclamation are dealt with in Chapter 15.

Planosols
Planosols typically have lower clay contents in their surface horizons than in their slowly-permeable deeper horizons. Planosols are deficient in drainage. Seasonal waterlogging, which hampers plant growth, alternates with drought conditions, whose severity depends on local climatic conditions. Many Planosols have a low natural fertility.

3.7.2 Discussion

The deficiencies of these soils for drainage vary enormously in magnitude, depending, among other things, on the degree of soil development. The scope for improvement can also vary greatly. Well-developed Planosols and Solonetz have poor to very poor drainage characteristics that can hardly be improved. As a consequence, the reclamation of these soils is scarcely worthwhile. On the other hand, fine-textured Fluvisols and Vertisols are often agriculturally usable without drainage measures, and certain Fluvisols and Gleysols can be improved by artificial drainage. In general, for many fine-textured soils, especially those with a high content of montmorillonite clay, the permeability and other properties related to the texture cannot be improved. Under special conditions, however, reclamation may lead to the development of a good and stable porosity and good drainage conditions. The reclaimed parts of Lake IJssel in The Netherlands are proof of this.

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