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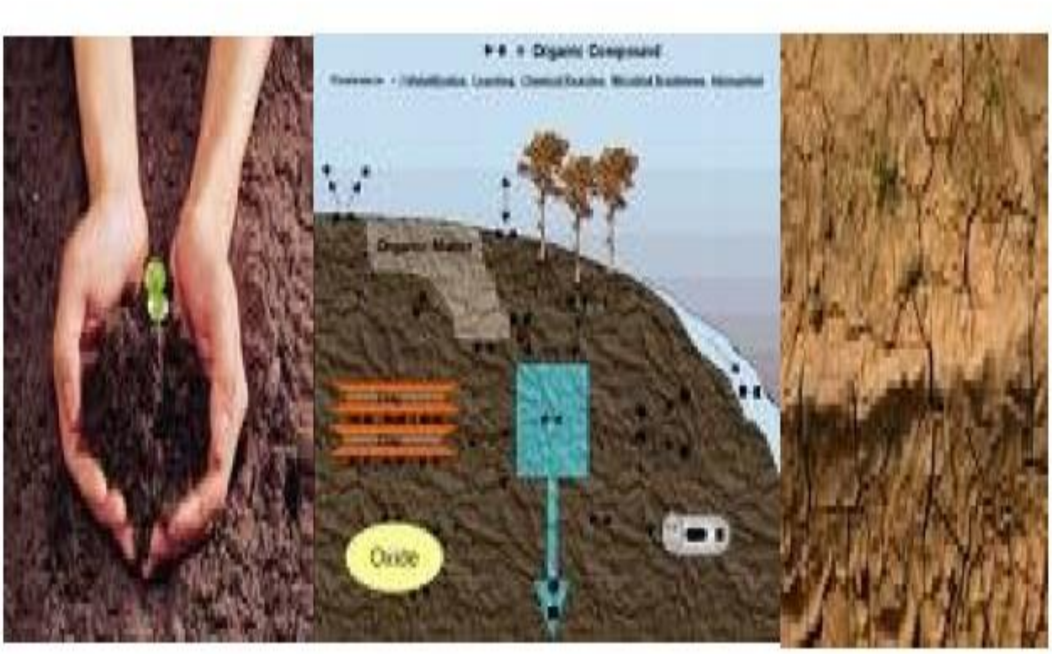
SOIL POLLUTION



CHAPTER FIVE

SOIL DEGRADATION

For Post graduate Students 2020\2021
Faculty of Engineering
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1. *Soil Degradation and Soil Quality*

Soil degradation is defined as the decline in soil quality caused through its misuse by human activity (Barrow 1991). The term soil quality itself may be further defined as، "The capacity or capability of a soil to produce safe and nutritious crops in a sustained manner over a long term, and to enhance human and animal health, without impairing the natural resource base or adversely affecting the environment" (Parr et al. 1992).

Degradation or decline of soil quality may occur due to physical or chemical processes triggered off by natural phenomena, or induced by humans through misuse of land resources. Processes such as soil erosion, nutrient run-off, water logging, desertification or compaction, may give examples of physical degradation processes, while acidification, organic matter loss, salinization, nutrient depletion by leaching, or toxicants accumulation, are all processes that can be classified as being agents and indicators of chemical degradation of soil.

Indicators of soil quality are numerous. They may be biological indicators, assessed by interpreting the figures indicating density of microorganisms' populations, or through measuring some of the basic biological activities, such as respiration or intensity of biogeochemical reactions. They may also be physical indicators measured by investigating some of the fundamental physical characteristics of soil, such as bulk density, water infiltration or field water holding capacity. Chemical indicators of soil are normally assessed through pH-values or the concentration of certain ions such as nitrates. Indicators of soil quality may also be just visual indicators, obtained from observation or photographic interpretation, as for example exposure of subsoil, change in soil colour, ephemeral gullies or blowing soil. Visual indicators can deliver very important indications for the change of soil quality.

1.1. Biological Indicators of Soil Quality – Soil Respiration Rates

The main indicator of biological activities in soil is the soil respiration rate, which can be assessed through measuring the carbon dioxide evolution resulting from the decomposition of organic matter. In other words, it is closely related to the efficiency of biological processes taking place within the soil. Biological processes in soils depend on several factors, among which moisture, temperature, oxygen, partial pressure, and availability of organic matter are of central importance. We find that soil pores filled with moisture up to 60% will provide the most optimum conditions for organic activities، because pores, which are more saturated with water (>60%), cannot provide sufficient oxygen concentration for the flourishing of aerobic decomposers, which carry out most of the work in organic matter decomposition. A similar pattern of behavior is also displayed by temperature, as it is observed that biological activities double for every increase of 18 °F in temperature; yet this trend ends at a certain maximum (specific for different groups) after which they decline once more until they reach a minimum. Adding organic matter of low C/N-ratio to the soil (e.g. manure, leguminous cover crops) may increase soil respiration rates since these substances are easily decomposed.

The addition of pesticides or similar agricultural chemicals may impair or directly kill soil organisms, eventually leading to lower soil respiration rates and diminished soil quality. Table 5.1 shows a ranking of soils according to their soil respiration rates (Woods End Research 1997; Evanylo and McGuinn 2000).

Table 5.1 Class ratings of soils according to their respiration rates (Woods End Research 1997)

Soil respiration (CO_2-lb ac^{-1} day^{-1})	Class	Soil condition
0	No soil activity	Soil has no biological activity – virtually sterile
<9.5	Very low soil activity	Very depleted of organic matter; little activity
9.5 – 16	Moderately low activity	Some what depleted; low biological activity
16 – 32	Medium soil activity	Approaching or declining from an ideal activity
32 – 64	Ideal soil activity	Ideal state of activity
>64	High soil activity	Very high level of microbial activity

1.2. Physical Indicators of Soil Quality

The availability of oxygen and the mobility of water, into or through the soil, are all attributes very closely related to physical properties, as for example texture, structure، density and porosity. Some of these properties (e.g. texture) are immutable, i.e. they cannot be modified by technical efforts. Others, such as density or water holding capacity، may be improved using appropriate soil management techniques. In the following، a short account of these properties and their use as indicators for soil quality will be considered.

Soil Bulk Density

Soil bulk density is defined as the mass of soil per unit volume in its natural field state، including air space and mineral matter, plus organic substance. High values of bulk density may restrict the movement of surface waters through the soil, leading to a loss of nutrients by leaching. It may also increase erosion rates. Continuous tilling may increase the bulk density of soils, yet continuous cropping, adding of organic conditioners and trafficking on wet soil may largely reduce it.

Bulk density measurements are very important for assessing soil quality, since root growth and penetration of soil، together with the ease of soil aeration, are largely controlled by this factor. Table 5.2 (Arshad et al. 1996) shows some values of bulk densities for several textural classes, together with an assessment of their observed effect on root growth.

Table 5.2 General relationship between soil bulk density and soil quality based on soil texture (Arshad et al. 1996)

Soil texture	Ideal bulk densities ($g\ cm^{-3}$)	Bulk densities that may affect root growth ($g\ cm^{-3}$)	Bulk densities that restrict root growth (g/cm^3)
Sands, loamy sands	<1.60	1.69	>1.80
Sandy loams, loams	<1.40	1.63	>1.80
Sandy clay loams	<1.40	1.60	>1.75
Silts, silt loams	<1.30	1.60	>1.75
Silt loams, silty clay loams	<1.40	1.55	>1.65
Sandy clays, silty clays, some clay loams (35-45% clay)	<1.10	1.49	>1.58

Water Infiltration

Infiltration is defined as the process by which water enters the soil. Its rate depends on soil type, soil structure and soil water content (Lowery et al. 1996). Infiltration is important for reducing run-off and consequent erosion. Increased soil compaction and loss of surface structure (reduced aggregation) are the main factors in reducing water infiltration rates in soils. Such rates are normally dependent upon the occurrence of large pores occupying the upper surfaces of the soil; therefore they depend on soil texture in the first place. Table 5.3 (Hillel

1982) shows the steady infiltration rates in inch per hour for some soil textural groups.

Table 5.3 Steady infiltration rates for different soil texture groups in very deeply wetted soils (Hillel 1982)

Soil type	Steady infiltration rate (in h^{-1})
Sands	>0.8
Sandy and silty soils	0.4 – 0.8
Loams	0.2 – 0.4
Clayey soils	0.04 – 0.2
Sodic clayey soils	<0.04

2. Physical Soil Degradation

2.1. Soil Erosion

Soil erosion occurs when the rate of soil removal by water and/or wind exceeds the rate of soil formation. Soil formation is generally a very slow process with rates ranging around 1 cm/100–400 years; this makes about 0.1–1.3 t ha^{-1}. In areas with intensive land use or deforestation, erosion may be enhanced by human activities, yet we should bear in mind that erosion in general is a natural process that has always been taking place on Earth's surface. To differentiate between natural erosion and erosion induced by human activities, we call the former background erosion. It is almost in equilibrium with soil formation (<1.0 t ha^{-1}) in plain areas and a little bit higher in mountain regions. The harm caused by human induced erosion is that it seriously disturbs this balance.

Detachment of soil material may occur because of running water or winds, whereby، in both cases, the severity of erosion will depend upon the capacity of the eroding agent to transport it. Following factors generally determine the intensity of erosion.

- **Soil erodiblity**. This is a measure of the soil resistance to detachment and transport. It depends particularly on soil texture, organic content, structure, and permeability. Generally, soils with low contents of clay and organic matter are more readily eroded than soils with a higher content of the same. The rule shown in Fig. 5.3 holds for most soil types.

  This relation supports the idea that clay content may provide a measure for soil erodibility (Evans 1980), since clods formed by clay minerals together with organic matter stabilize the soil and make it more resistant to erosion. Soils with a high content of base minerals are generally more stable as these contribute to the chemical bonding of the aggregates (Morgan 1995). Resistance of soils to wind erosion will depend more on the moisture content of the soil, wet soil being less erodible than dry soil; yet all other factors remain as in the case of water erosion.

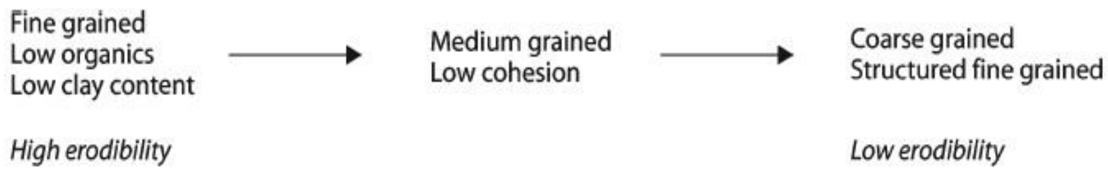


Fig. 5.3 Soil erodibility

- **Erosivity**. This is a measure of the potential of the eroding agent to erode and is commonly expressed in kinetic energy (Morgan 1995). With regards to rainfall, this will be related to the intensity of the rainfall as well as to the size of raindrops. The most widely used index is the one known as EI30. This is a compound index of kinetic energy and the maximum 30 minutes rainfall intensity. Wind erosivity indices are based largely on the velocity and duration of the wind. Erosion induced by human activities depends upon various factors such as land use, overgrazing in pasturelands and deforestation. In the developing world, however, socio-economic factors add to the reasons of enhanced erosion.

2.1.1. Measuring Soil Erosion

Field methods may be designed to collect data on soil loss from relatively small representative plots (erosion plots), or to carry out serial investigations and measurements on wide areas, as for example a drainage basin. The so-called field reconnaissance methods, which are normally used to get first approximation of the amount of erosion in a given situation, are very popular among soil conservation workers. These are cheap methods and can be carried out by semi-skilled staff and need little maintenance. Reconnaissance methods may be classified into two main types: measuring change of surface levels and volumetric measurements.

Measuring of Surface Levels

For sites of intensive erosion such as on steep slopes and areas of extensive run-off، the direct measurement of level changes may provide an appropriate method of predicting soil loss amounts. Changes in soil level may be determined by:

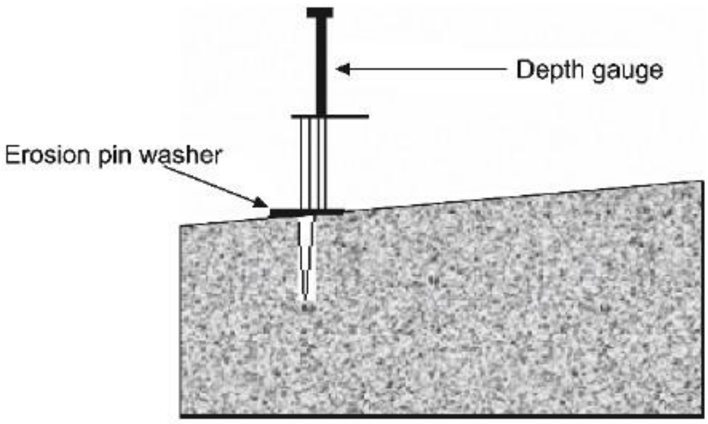
- Point measurements to determine the level change in a single dimension.
- Profile and cross section measurements in two dimensions.
- Volumetric measurements in three dimensions

Point Measurements

Several methods have been designed for measuring soil level in single points, and, since these methods are mostly inexpensive, a great number of measuring stations are usually used to collect a large volume of data. Of these methods the following are most popular:

Erosion pins. In this method a pin is driven into the soil. The top of the pin gives a datum from which change in the soil level can be determined. The pins (also known as pegs, spikes, stakes or rods) may be made of wood, or any other material, which will not rot or decay (see Fig. 5.4). As seen in Fig. 5.4, the pin has a moving metal washer sliding over the whole pin and providing better hold for measurement up to the pin top. A typical length of pins is 300 mm, which allows a firm and sufficient penetration into the soil. Readers interested in more details on this method, together with an illustration of its use، may refer to Takei et al. (1981).

Fig. 5.4 Erosion pin to measure surface level (Hudson 1993)



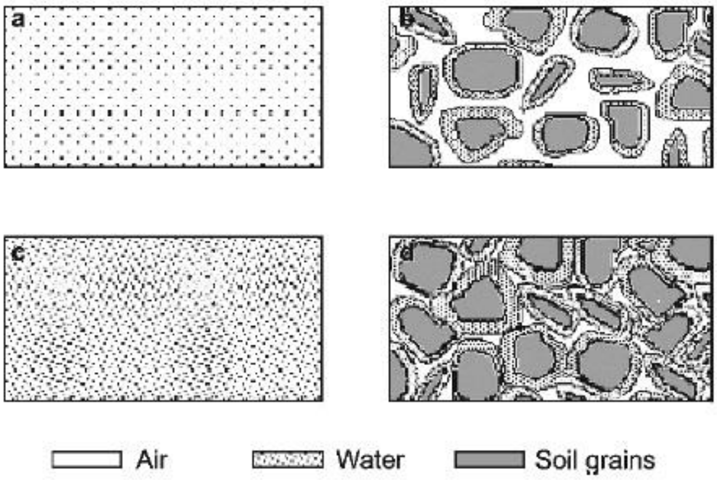
Paint collars. In locations of high erosion rates such as a stream bed or gully floor، change of soil level may be made visible by painting a collar just above soil level around rocks, fence posts or anything stable. Erosion reveals an unpainted band below the paint line.

Bottle tops. This is a very simple way of making changes in soil level visible and thus available to measurement. Pressing bottle tops into the soil surface provides a protection for the initial soil level at the beginning of the measurement process. The depth of subsequent erosion is shown by the height of the pedestals where the soil is protected by the bottle tops.

2.1.3.Soil Compaction

Compaction is the mass reduction of soil and is generally expressed in dry bulk density, porosity, and resistance to penetration. Compacted soils are normally of a higher bulk density than comparable non-compacted ones (>1.5 g cm^{-3} compared to 1- 1.5 g cm^{-3} in non-compacted soils). The resulting reduction of pore space lends the soil a compact dense character (see Fig. 5.6). This leads to a reduction of both water infiltration and drainage from the compacted layer. Aeration problems may also arise due to the reduction of the proportional volume of air in the interstitial space (Fig. 5.6d).

Fig. 5.6 a Non-compacted soil; **b** close up from (a) – observe the proportional volume of soil air; **c** compacted soil; **d** close up from (c) – observe the increase of the proportional volume of water-filled pores at the cost of soil air. The legend directly under the figure is applicable only for (b) and (d)



Physical changes arising from compaction may have far reaching consequences for biological and chemical conditions prevailing in the soil. The reduction of the rate of decomposition of organic matter and consequent reduction of nutrients may provide an example. This occurs when the proportion of water-filled pore space is increased due to the total reduction of interstitial pore size (Fig. 5.6d), which in turn causes a temperature drop reducing the activity of soil organisms.

Compaction, being a result of high vertical pressures, is controlled by many factors pertaining to soil properties, such as texture clay content and clay mineralogy. Clays، due to their sheet structures, are highly susceptible to volume reduction. This leads، in clay rich soils (on application of vertical high pressures), to the formation of highly compacted horizons at shallow depths (20–30 cm). These horizons, known as cultivation pans, impede drainage and hamper the formation of plant root networks. They also delay germination and may even completely stop it.

Causes of Soil Compaction

Soil compaction may occur as a result of various human induced factors as well as natural causes, however, the steady increase of machinery used in farming, as well as the increase in weight of field equipment, makes human induced compaction a matter of growing concern in many countries today. Some of the factors causing soil compaction are briefly discussed in the following:

Tillage and other farming operations. Compacted layers (also known as tillage pans) may occur as a result of continuous ploughing at the same depth. Tillage pans (2.5-5 cm thick) may be easily alleviated by varying the depth of ploughing over time.

Wheel traffic. As a matter of fact, this is the major human induced cause of soil compaction. Farm machines are continuously becoming bigger and heavier to meet the increase in farm size. This increases the danger of compaction for farm soils؛ especially in spring planting, which is often done before the soil is dry enough to support the heavy weight of farm machines (up to 20 tons).

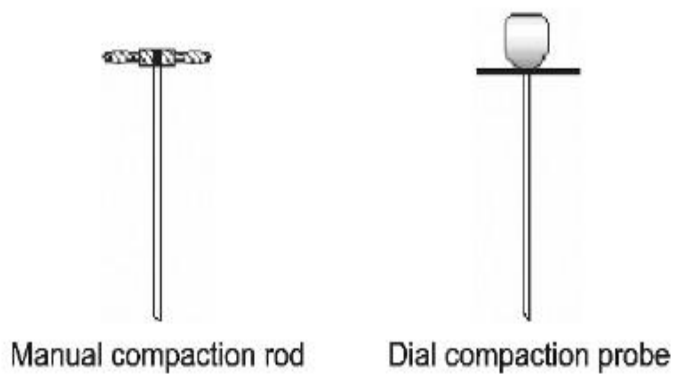
Minimal crop rotation. Crop rotation, if practiced frequently, helps break subsoil compaction due to variation in rooting systems of the different crops, and makes it essential to carry out frequent tilling operations, which may reduce the probability of compaction.

Raindrop impact. This is the major natural cause of soil compaction. It aids the formation of crusts on the soil surface (~1.5 cm thick). Such crusts may prevent germination and cause the same harms mentioned above.

Testing for Soil Compaction

Soil compaction may not be easy to locate, due to the fact that it mostly occurs at the subsurface. Compaction testers such as manual rods (Fig. 5.7a) or dial probes (Fig. 5.7b) may provide the best help to deal with this task. Compaction testers pushed into the soil with steady, even pressure, to a depth of 90–125 cm, will indicate compaction، if they are met with a resistance at any depth within this range.

Fig. 5.7 Compaction testing tools; **a** manual compaction rod; **b** dial compaction probe



Manual rods provide evidence of compaction, yet they provide no concrete measurement of strength or degree of compaction. For this, dial probes and digital recording compaction meters may be used. Many companies are now offering digital compaction meters (penetrometers) with integrated data loggers that can work together with GPS-tools, at relatively low prices.

Alleviating Soil Compaction

One of the best methods for remediation of soil compaction is the technique known as subsoiling or chiselling. This is done by breaking the compacted subsoil, without inverting it, with a special knifelike instrument (chisel), which is pulled through the soil usually at a depth of 30–60 cm and a spacing of 60–150 cm. Drilling holes under the drip line of trees and back filling with mulch or compost adds organic matter to the soil and preserves soil moisture. This reduces the adverse effects of compaction، since soils rich in organic matter are less susceptible to compaction than mineral ones. Most important in the avoidance of compaction, however, is limiting traffic in areas in the field with a compaction problem and reducing the pressure exerted by agricultural machines through inflating their tyres to the least permissible psi, while using tyre types that lessen the negative effects of wheel traffic.

2.2.3.Soil Crusting and Sealing

Crusting is the name given to the phenomenon of thin crust formation on soil surfaces، whereby wet crusts are collectively known as seals; this is the reason why crusts and seals are sometimes treated as being one and the same object. Crusts are sometimes known as cappings and are generally formed on exposed soil in brittle and semibrittle)seasonably dry) environments.

Chen et al. (1980) classify crusts into two main types according to their mode of formation. These are:

- Structural crusts, which are developed in place (in situ crusts).

- Crusts, which have been transported from their original place of formation.

To these we may also add salty crusts, which are thin layers of salt formed at soil surfaces. Short descriptions of these types may be given as follows:

Structural Crusts

These are crusts formed in place by raindrop impact. They evolve through gradual coalescing of aggregates under the impact of raindrops and may form broken clods that lie above the surface (slaking crusts: Valentin 1991), or may be formed in several (generally 3) well-sorted layers. The uppermost layer is normally composed of loose، coarse sand, the middle one is formed of fine densely packed grains, and the lower one is almost totally made of fine particles with reduced porosity (sieving crusts: Casenave and Valentin 1989 and 1992).

Depositional (Sedimentary) Crusts

These are crusts that are caused by the transport and deposition of particles, due to water flows. Micro-aggregates are washed away by such flows, to be deposited at low lying topographic parts of the soil, resulting in the spreading of thin sheets that may later coalesce to form seals or crusts. Sources of fine aggregates are various, they may be derived from flood and furrow irrigation water, from raindrop impact splash of loose soil particles, or from run-off and sheet erosion.

Some authors classify crusts according to their nature into physical/chemical and biological crusts. In this respect we may consider salty crusts as chemical ones، whereas biological crusts may be widely varying, both in composition and mode of formation.

Biological Crusts

Biological crusts (also known as cryptogamic, microbiotic, cryptobiotic or microphytic crusts) are, as the name says, crusts formed through biological activities of plants and algae. Different assemblages of blue green algae, diatoms, golden brown algae, lichens، mosses and few xerophytes (salt loving plants) that can flourish in presence of limited water supply may form such crusts. Their effect on soils is not entirely agreed upon. Some authors consider them useful for soil quality development due to their role in helping to fix nitrogen (blue green algae) and offering protection against erosion. Other authors, however, consider their role in soil protection against erosion as being minimal، due to their fragility. Generally, though, biological crusts may hamper germination and affect soil cultivation.

Mechanisms of Crust Formation

Crust formation results from four main processes that work hand in hand and complement each other (Agassi et al. 1981; Morin et al. 1981). These are:

- physical dispersion of soil grains followed by compaction due to raindrop impact؛
- chemical dispersion of clay particles؛
- formation of continuous dense layers of clay particles by interface suction forces(Morin et al. 1981)؛
- increases in soil acidity making soil more susceptible to crust formation.

Whatever the mechanisms and processes involved in crust formation are, the results are very harmful to soil, for crust formation markedly reduces the micro-porosity of the soil surface layer. The results can be devastating for the soil, since water infiltration varies as the fourth power of the diameter of the pores. Avoidance and Alleviation of Crust Formation.

Soil crusting is mostly induced on soils of higher acidity and those having a high content of fine clay material. On such soils, raindrop impact destroys the structure of the surface layer. Accordingly, alleviation and avoidance of crusting may include the reducing of sodicity and acidification, as well as finding ways to induce flocculation of fine materials. This may partially be achieved by adding gypsum to the soil. Gypsum increases the flocculation of fine mineral and organic matter, reduces the amount of shrinkage and swelling of clays, by moderating change of water content, and increases the activity of soil organisms through adding calcium to the soil. Using soil conditioners such as polyacrylamide (PAM) mixed with gypsum was found to be very effective in decreasing crust formation, run-off and erosion (Tang et al. 2006).

The addition of gypsum is more effective in volcanic soils rather than in alluvial ones. The best results are achieved in soils with a high clay content (30% or more) and exchangeable sodium of more than 5%. Sometimes accumulation of litter on the surface would also lead to sealing and crusting, since broadleaf litter (especially if the leaves lie horizontally) reduces infiltration. Accordingly, removal of leaf litter is considered as one of the measures to avoid crust formation.

The Impact of Acidity on Soil Quality

Soil acidity has an impact on many essential properties that determine soil quality. Most important in this respect is its effect on the availability of nutrients. Nutrients such as phosphorus, potassium, magnesium and calcium decrease through acidity، whereas the availability of metallic micronutrients increases. This applies for metallic ions such as zinc, manganese, copper, and iron. Mobilisation of aluminium, zinc and manganese may result in toxicity to plant roots. The following problems may arise:

- Aluminium and/or manganese toxicity
- Deficiency of phosphorus, due to its tying up by iron and aluminium
- Calcium and magnesium deficiency

In addition to problems related to nutrient availability, the prevalence of lower pH values may affect the environmental conditions required for bacterial growth, thus hampering the evolution of organic matter in the soil and lowering its biological activity.