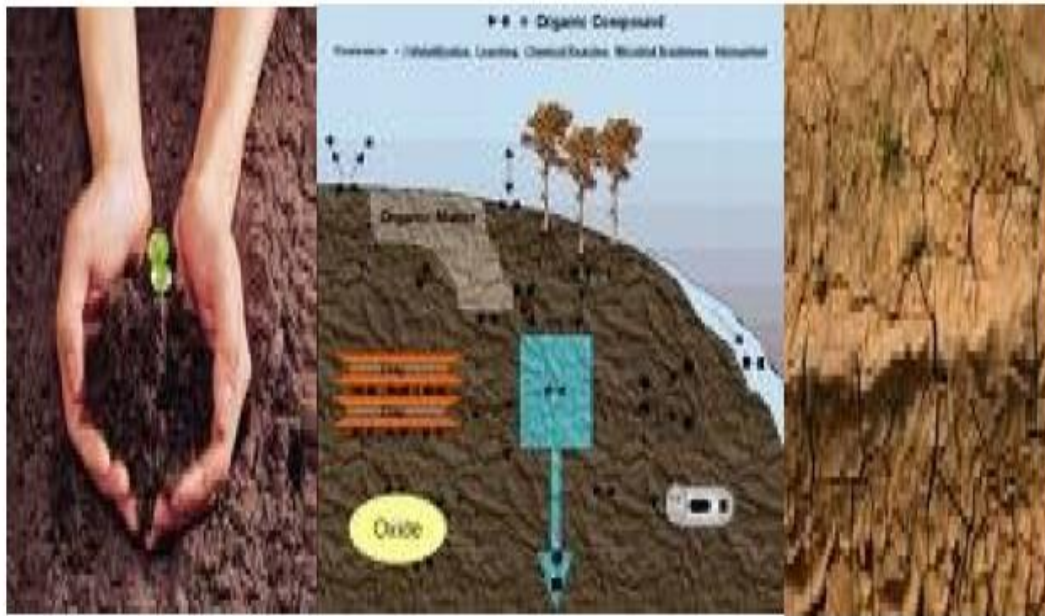




# SOIL POLLUTION



## ***CHAPTER THREE*** ***SOIL PROPERTIES***

For Post graduate Students 2020\2021  
Faculty of Engineering  
Mustansiriyah University  
Environmental Engineering Department

## **1. Physical Properties**

### **1.1. Colour**

Colour is the most obvious trait in a soil profile. It may in many cases be indicative of soil composition. Red and yellow colour is generally indicative of enrichment in ferric iron, while grey hues may result of higher concentrations of aluminium oxides and silicates. Black colours are generally caused by an abundance of organic material. However, under warm temperate conditions, soils containing less than 3% of humus may have deep black colours.

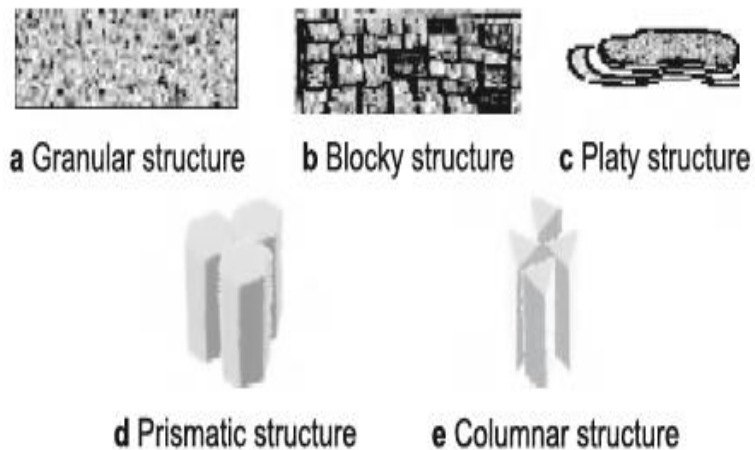
### **1.2. Texture**

Texture is the term referring to the size and organization of the soil particles. particles known as soil separates, may be described, according to their grain size, as soil components (less than 2 mm in diameter), or simply as cobbles, pebbles or gravel, if they are larger than this. Soils may be classified according to their textures in different classes depending on the ratio of sand: clay: silt (Fig. 3.1). A hypothetical soil made of equal parts of these 3 components is termed loam. A loam can be described more specifically as sandy, clay, or silty loam according to the dominant component.

### **1.3. Structure**

Soil structure refers to the aggregation or arrangement of primary soil particles. Structure is important because it can partially modify or overcome aspects of soil texture. The term ped (as it was mentioned before) describes an individual unit of soil aggregates; it is a natural lump or cluster, with clay and humus holding the particles together. Peds separate from each other along zones of weakness, creating voids that are important for moisture storage and drainage. Spherical peds have more pore space and greater permeability. They are therefore more productive for plant growth than coarse, blocky, prismatic, or platy peds, despite comparable fertility (see Fig. 3.2).

Fig. 3.2 Essential types of soil structure



#### 1.4. Consistence

Cohesive properties of a soil, such as resistance to mechanical stress and manipulation under varying moisture conditions, are grouped under the heading consistence. Wet soils are variably sticky. Plasticity is roughly measured by rolling a piece of soil between the fingers and thumb to see whether it rolls into a thin strand. Moist soil implies that it is filled to about half of field capacity, and its consistence grades from loose (non-coherent), to friable (easily pulverized), to firm (not crushable between thumb and forefinger). Finally, a dry soil is typically brittle and rigid, with consistence ranging from loose, to soft, to hard, to extremely hard. The segmentation that occurs in various soil horizons is a function of consistence and is usually described as continuous or discontinuous. Soils are variously noted as weakly or strongly cemented, or indurate (hardened). Calcium carbonate, silica, and oxides, or salts of iron and aluminium, can all serve as cementing agents.

#### 1.5. Porosity

Grain size and pore volume are the most important factors controlling the percolation of water and ventilation within the soil. Porosity, as a measure of the

percentage of volume of pore space with respect to the total volume, can be indirectly calculated using the following equation:

$$\text{Porosity} = 1 - \frac{(\text{Bulk}) \text{ density}}{(\text{Particle}) \text{ density}} \times 100 \quad (3.1)$$

Porosity can also be directly determined by the volume of water contained in a saturated undisturbed soil core of a given volume. The weight of the saturation water is determined through the difference between the wet and dry volume of the core. Porosity in this case will be calculated as follows:

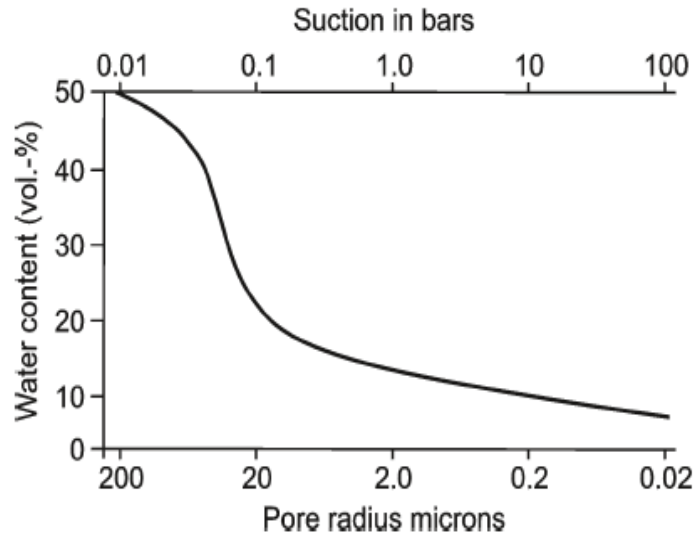
$$\text{Porosity (\%)} = 1 - \frac{W_s - W_d}{V} \times 100 \quad (3.2)$$

Where  $W_s$  stands for the weight of the water-saturated core,  $W_d$  for the weight of the dry core, and  $V$  represents the volume of the same. Intrinsic to porosity is the pore size distribution; a very important physical parameter, it stands in direct relation to water retention and related properties such as drainage and aeration of a given soil, and hence to its agricultural productivity. Pore size distribution can be determined from the so-called moisture retention curves (see Fig. 3.3).

Moisture retention curves are established by determining the volumetric water content at various points over a range of tensions or suctions applied to an undisturbed soil core (Hall et al. 1977). This depends on the fact that the volume of water removed from an undisturbed soil core, at a given tension, is directly proportional to the pore size. According to Fig. 3.3, the total porosity of the core

under investigation is 50% and of this, 27% of pores are  $>20\ \mu\text{m}$  in diameter, 15% are  $2.0\text{--}20\ \mu\text{m}$  and 10% are  $<0.2\ \mu\text{m}$ .

Fig. 3.3 A characteristic moisture retention curve (drawn after Ellis and Mellor 1995)



## 2. Chemical Properties

Based on their chemical composition and the degree of agricultural exploitation, soils may display certain chemical properties, which are not only diagnostic for their origin and environmental parameters, but also very sensitive indicators of their land use value. The most prominent of these are the degree of soil acidity (pH), together with ion exchange and cation adsorption capacities, which are very important factors for plant nutrition potentials of the soil. In fact, these properties are closely related to one another as we may see by looking at them.

### 2.1. Soil Acidity (pH)

Soil-pH is usually measured in a standard suspension of 1:2.5 (weight to volume) of soil in distilled water, or in dilute solution of calcium chloride (0.01

M). Besides being closely related to the ion exchange properties of soil (see below), soil acidity is related to other properties, such as organic content and clay mineralogy of the soil. It also has a direct relationship to the availability of metals as it affects their solubility and their capacity to form chelates in the soil. In this sense, Al<sup>3+</sup> ions play an important role in controlling the concentration of hydrogen ions in soil waters, and hence the level of soil acidity (pH). This effect is brought about by hydrolysis when H<sup>+</sup> ions would be generated through the following reaction:



Positively charged hydroxy-aluminium species may undergo further hydrolysis to produce additional H<sup>+</sup> ions, leading to higher soil acidity.



Thus, aluminium hydrolysis in readily acidic soils will promote further acidity. Such a phenomenon is characteristic for humid, clay rich soils. Soils of acidic character are generally rich in calcium and/or magnesium, because calcium and magnesium may precipitate as carbonate, increasing the buffering capacity of the solution.



As the above reaction demonstrates, sodium does not show the same property as calcium and magnesium and that is why alkaline soils will have a higher sodium presence than that of the latter two. This dependence of soil pH-value on the availability and nature of the base cations makes it transient, i.e. changing in short term as well as in long spans of time, according to the availability and saturation of the base cations  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ ,  $\text{Na}^{+}$ , and  $\text{K}^{+}$ . The input of these bases by atmospheric agents (precipitation), geochemical conditions (weathering), or agronomic activities (fertilisers) would eventually lead to fluctuations in the pH-value.

A general pattern, however, is that water dominated soils (soils of humid regions) have low pH-values, because their content of organic and carbonic acids is often subject to replenishing and recharge by rain fall. Under these conditions, the acids, in the way mentioned above for alumino-silicates, attack minerals, producing more acidity.

Under arid conditions, however, minerals which are salts of weak acids and strong bases would dominate the system, producing higher levels of alkalinity and causing the soil pH to raise to values between 9 and 10 or even more. Desert soils, having such elevated values of pH, are referred to as rock dominated soils. One should however be careful in dealing with soil pH-values above 10, since these may indicate contamination with strong bases such as Na, OH, or  $\text{Ca}(\text{OH})_2$ . Though in some cases, like in some regions of north-western Egypt, this extreme elevation might be due to the dissolution of such minerals as nahcolite ( $\text{NaHCO}_3$ ) or natron ( $\text{Na}_2\text{CO}_3 \cdot 10\text{H}_2\text{O}$ ).

## 2.2. Ion Exchange

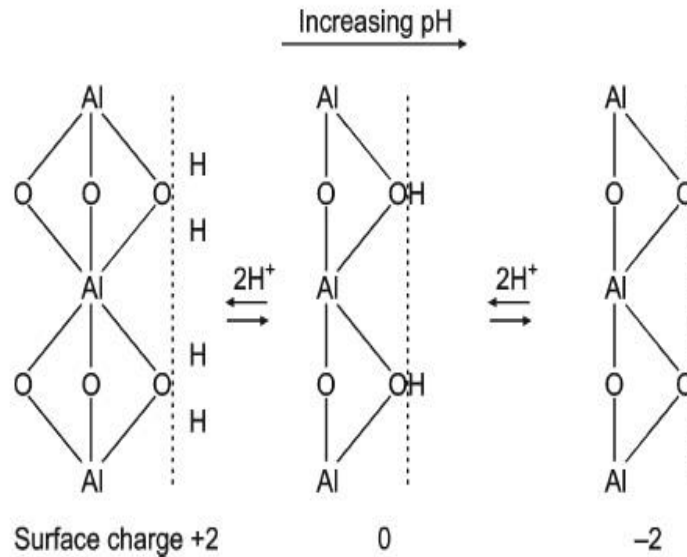
Exchangeable cations are those held between the layers of clay minerals as well as those held on the surfaces of clays and organic particles (clayhumus complex or exchangeable complex) by virtue of the high surface energy resulting from the immense surface area of these finely divided substances. In the case of clay minerals, cations occupying interlayer positions possess permanent positive charges that satisfy structural conditions of the crystal lattice. They may be replaced by other cations of similar size but of lower valency giving rise to isomorphous substitution, which is not directly dependent on the soil pH. In the case of the clay humus complex in general, surface charges are not governed solely by structural considerations. They result largely from surface reactions such as reversible dissociation of surface groups or functional groups of organic compounds, and since these reactions are pH dependent, the charges would vary according to the prevailing pH. This can be illustrated by the reaction of aluminium “oxyacids” under different conditions of Acidity. Two of these compounds are known to occur in soils –  $\text{Al}(\text{OH})_3$  (gibbsite – sometimes called simply aluminium hydroxide) and its anhydride  $\text{HAlO}_2$ .

As illustrated by Fig. 3.4, the anhydride, which is amphoteric, produces different species according to whether it reacts under acidic or alkaline conditions. Under acidic conditions, the edge hydroxyl groups may take up  $\text{H}^+$  ions to produce the positively charged hydroxy aluminium with a charge of +2, while removal of  $\text{H}^+$  from these groups under alkaline conditions produces a negatively charged species with a charge of -2. Such negatively charged colloidal particles are known as micelles. They act like giant anions that attract cations to their surfaces resulting in the formation of an electrical double layer (made of the negatively charged layer on the micelle and the positively charged layer of adsorbed cations) around each of them. Cations closer to the negatively

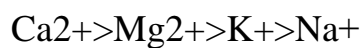


charged layer will be more strongly attracted than those at a greater distance, and that is why cations with a smaller radius of hydration will be preferentially adsorbed and less readily replaced.

Fig. 3.4 Influence of pH on surface charge in aluminium oxide (White 1997)



Another factor controlling adsorption and replacement is the valency. Cations with a high valency have a high energy of adsorption and are therefore adsorbed in preference to cations with a lower valency. The following sequence is generally accepted for preferential adsorption of base cations:  $\text{Ca}^{2+} > \text{Mg}^{2+} > \text{K}^+ > \text{Na}^+$ . These cations will be less readily replaced and that is why they are represented in soil composition by a similar sequence of concentration:



$\% \text{ } \backslash \text{ } \wedge \text{ } \% \text{ } \circ \text{ } \% \wedge \text{ } \bullet$

In addition to this, anion adsorption and replacement may occur. It is, under certain conditions, even more common.

### 2.3. Cation Exchange Capacity (CEC)

The cation exchange capacity of soils is generally measured by the cation yield of the soil through extraction with an ammonium acetate solution. It is also a measure of the surface negative charge, as well as the potential for cation adsorption. CEC is generally expressed in meq per 100 g of soil. Its value depends largely on the organic and clay content of the soil as well as the acidity and clay mineralogy of the same.

Another quantitative attribute of cation exchange in soils is the property known as the percentage base saturation, which is simply a measure of the proportion of exchangeable bases on the soil exchange complex. It can be calculated from the following equation:

$$\text{Base saturation (\%)} = \frac{\text{Ca}^{2+} + \text{Mg}^{2+} + \text{K}^{+} + \text{Na}^{+}}{\text{CEC}} \times 100$$

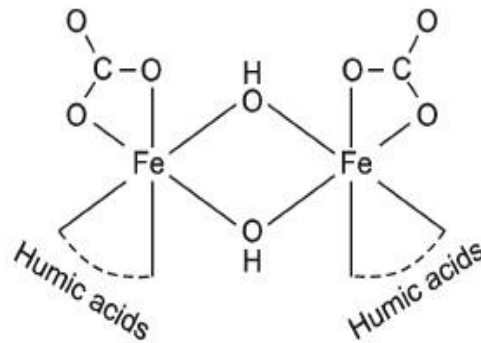
The difference between CEC and total exchangeable base content provides a measure of exchangeable hydrogen content. (For further information consult Rowell (1994)).

$$\text{Exchangeable H}^{+} = \text{CEC} - (\text{Ca}^{2+} + \text{Mg}^{2+} + \text{K}^{+} + \text{Na}^{+}) \quad (3.7)$$

Metal binding by small organic molecules, which are largely composed of polymeric weak acids of the type of humic and fulvic acids, takes place through the formation of outer sphere complexes by binding the metal to the carboxylic or phenolic groups see Fig. 3.5.

The CEC of organic soil is largely due to organic matter, and its contribution to the CEC of mineral soil may be >200 meq/100 g of organic matter (Bloom 1981).

Fig. 3.5 Bonding of metals on humic substances by chelation (from Mirsal 1995)



### **3.4. The Interaction of Organic Soil Matter with Mineral Components**

Chemical changes of sediments at environments near the Earth's surface (at normal temperatures and pressure levels) are generally known in sedimentology under the collective term diagenesis. The most important early diagenetic changes of soil organic matter include oxidation, reduction and carbon-carbon coupling. In considering these changes and their varieties, one is immediately struck by the ubiquitous involvement of metals and their derivatives.

Reactions involving metals with organic matter may range from simple salt formation with organic acids, to catalysis of complex formation by metals lending them-selves as templates, or even indirectly by metals facilitating the work of enzymes. In the following, some of the well known reactions of metals with soil organic matter will be used to illustrate this.

## **Physical and Chemical Adsorption on Clay Minerals**

**Adsorption** caused by Van der Waal's forces. According to Stevenson (1994), adsorption of organic materials on the surfaces of clay flakes by the weak Van der Waal's forces can play a considerable role in attaching organic matter to the surfaces of clay minerals. This is valid for polar as well as for non-polar molecules. Figure 3.6 taken from Jerzy Weber (2005), after Stevenson (1994), shows a model of how Van der Waal's forces may be distributed on clay surfaces.

**Adsorption** on interlamellar spaces of clay minerals. Schnitzer and Kodama (1977) have shown that fulvic acid may be adsorbed on surfaces at the interlamellar spaces of montmorillonite. Theng (1979) and Theng et al. (1986) confirmed the same opinion. Many recent works have now shown that this mechanism is one of the most important for the retention of proteins and charged organic compounds by expandable layer silicates (see under clay minerals).

**Bonding by cation bridging.** Clay surfaces are negatively charged – a fact that will cause repulsion of negatively charged organic anions. Polyvalent cations like  $\text{Ca}^{2+}$ ,  $\text{Fe}^{2+}$ , and  $\text{Al}^{3+}$  are capable of forming a bridge between such anions and the surfaces of clay, so that they may be attracted to each other, forming clay organic complexes as shown in Fig. 3.7 (Fotyma and Mercik 1992).

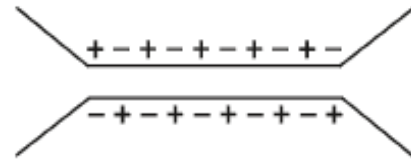
**Hydrogen bonding.** The attachment of organic molecules on clay surfaces, may occur by hydrogen bonding between polar groups of the organic molecules and adsorbed water molecules, or silicate oxygen. A model of such bonding is shown in Fig. 3.8 according to Fotyma and Mercik (1992).

**Adsorption** by coatings of hydrous oxides of iron and aluminium on clay surfaces. Coatings of hydrous oxides of iron and aluminium on the surfaces of clay minerals are capable of adsorbing humic substances, where these may be attached by simple coulombic attraction. Figure 3.9 shows a model of how such complexes may be formed.

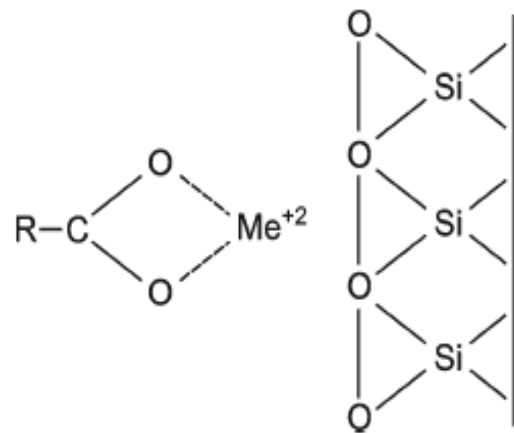
### **3.5. Oxidation-Reduction Status**

The redox potential (Eh), or oxidation-reduction status, is an indicator of the degree of soil aeration or the amount of oxygen present in the soil atmosphere. It can be directly measured by inserting an appropriate electrode in the soil. In aerobic soils, electrons produced during respiration, combine with oxygen. Under anaerobic conditions, however, oxygen is unavailable, and other chemical compounds must act as electron receptors. Ferric iron compounds often take on this role, undergoing reduction to ferrous iron compounds.

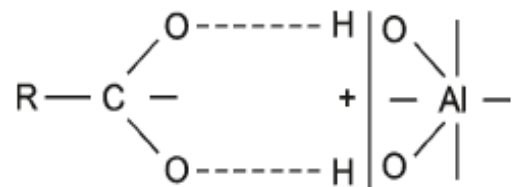
**Fig. 3.6** Van der Waal's forces on clays (Stevenson 1994)



**Fig. 3.7** Formation of organic clay complexes by cation bridging according to Fotyma and Mercik (1992)



**Fig. 3.8** Formation of organic clay complexes by hydrogen bonding (Fotyma and Mercik 1992)



**Fig. 3.9** Formation of clay organic complexes with the help of hydrous oxides (Fotyma and Mercik 1992)

