CHAPTER I

INTRODUCTION

Jenny (1941) identified and described five main soil-forming factors which are responsible for soil development. These are parent materials, climate, topography, biological action and time. They all interact with and influence each other.

The mineral materials from which a soil is formed are called the ***parent materials***. Rock, whether its origin is igneous, sedimentary, or metamorphic, is the source of all soil mineral materials and the origin of all plant nutrients with exception of nitrogen, hydrogen and carbon. As the parent material is chemically and physically weathered, transported, deposited and precipitated, it is transformed into a soil. Metamorphic rocks change dense solids into porous unconsolidated materials that differ markedly in terms of chemical composition and structure from the parent rocks ***(Bohn et al., 2001)***. Typical soil mineral materials are Quartz (SiO_2), Feldspar ($KAl\ Si_3 O_8$), Calcite ($CaCO_3$), Mica or Biotite ($K\ Mg,\ Fe_3\ Al\ Si_3U_5\ (OH)_2$).

The mineral fraction ranges from 0% to 50%, clay and organic matter are between 20% and 30% ***(Donahue et al., 1977).***

Generally, the average soil contains 45% mineral, 5% organic material, 25% air and 25 % water.

Climate interferes in rock weathering both by its temperature variation (and its influence of internal pressure) and in the amount of water that is available in the rock or soil to dissolve mineral components. The physical processes related to erosion, freezing and thawing, heating and cooling break rocks apart. The biggest change comes, however, from a number of chemical reactions related to the exposure to water, oxygen, CO_2 and organic compounds. These chemical processes depend mainly on the amount of water available. A major result of such processes is the formation of basic cations or acidic species according to the nature of the parent rock (basic like basalt or acidic like granite), degree of water availability and leaching of these species. Clay minerals are negatively charged due to substitution phenomena, the negative charges usually naturalize with the positive charges (cations) in soil solution. Therefore, equilibrium should always exist between the negative charges of the soil components and the cations in solution.

Topography affects soil formation primarily in that it modifies the water and temperature in the profile. Soils on steep hills have much less water moving down the profile than in loud locked depressions that receive runoff water surrounding higher areas. Oxygen deficiency in water-logged soils results in an accumulation of large amounts of organic materials. In a rid climate, where moisture is limiting, cooler soil temperature and less evaporation are conductive to deeper soils in north slopes. The opposite is true in the southern hemisphere. The physical and chemical interactions of the soil with the atmosphere and the percolating water affect the composition of atmosphere and the ground water. These reactions are important for cleaning the environment after natural and human-induced pollution. Given sufficient time, a soil will evolve into a soil profile which consists of two or more layers; it is referred to as soil horizons that differ in one or more properties such as their texture, structure, density, porosity, consistency, temperature, color and reactivity. The biological influences on soil properties are strongest near the surface, while the geochemical influences on soil properties are strongest at greater depths.

Biota (living plants and animals) and their organic wastes and residues have a marked influence on soil development. They release acids in the soil, and form holes and corridors for water and air penetration. Moreover, decaying organic materials from humus that improves soil structure, such as earthworms, ants, termites, nematodes, gophers and other burrowing animals are important in soil formation when they exist in large numbers. Soils with low organic matter content (<3%) are often termed mineral soils, while soils with organic matter content (>15%) are often called organic soils.

Time has an intensifying effect in the sense that, the longer a process can be active, the more impact it will have on the changes which it creates in the environment.

Jenny (1941) described the weathering rate as related to the five factors (F) by the relation:

$$\frac{\Delta \text{Weathering}}{\Delta \text{Time}} = \text{F (climate, topography, parent material, time, biosphere)}$$

The relative importance of each factor in the above equation varies with local and regional conditions. Converting this equation into a quantitative equation is not possible at present because none of the five factors has been described numerically.

Under favorable conditions, a recognizable soil profile may develop within 200 years, but under less favorable conditions the time may be extended to thousands of years.

Parent materials, climate, topography, biota and time interact to produce natural soils. As human population has grown, they have directly or indirectly created soils on a small scale and affected soil properties. For example, the regular additions of organic matter have produced soils with increased phosphorous content.

I.1. Physical Properties of Soil

(a) Soil texture (soil profile):

It reflects the coarse or finesse of the soil and the particle size distribution in the soil. Soil particles are classified into sand, silt (loam) and clay. Sand has the largest particle size thus allowing for more air and water to move in. Clayey soils are heavy and hold a lot of water, while loamy soils are intermediate between sandy and clayey ones. Soil texture is determined by the relative properties of the three kinds of soil particles, called soil "separates". Large soil structures called "peds" are created from the separates when iron oxides, carbonates, clay and silica with the organic constituent humus coat particles and cause them to adhere into large relatively stable secondary structures. Soil texture affects soil behavior in particular its retention capacity for nutrients and water ***(Brown et al., 2003).***The physical properties may vary through the depth of a soil profile ***(Kellogg et al., 1957)***.

(b) Soil density:

Soil density, particularly, dry bulk density, is a measure of soil compaction which contains air and water, i.e., the volume of solid particles and spaces or pores between them.

Soil particles density (true density) is the density of solid particles of the soil without spaces. Accordingly, the soil density can be calculated using the following relations:

$$\text{Bulk density} = \frac{\text{Soil bulk volume}}{\text{Mass of dry soil}}$$

$$\text{True density} = \frac{\text{Mass of dry soil}}{\text{Soil true volume}}$$

Soil true density is larger than soil bulk density. Soils have densities between 1 and 2 g/cm^3 ***(Saxton et al., 1986).*** Both particle density and the density of the whole soil (dry bulk density) have to be determined in order to calculate porosity.

(c) Soil porosity:

Soil porosity consists of the part of the soil volume occupied by gases and water. It is of a vital importance in the ability of soils to support plant, animal and microbial life. Organic matter and the associated biological activity in soils play an important role in maintaining soil porosity.

Porosity values range from macro pore space > 50 micron to meso pore space (0.1 – 50 micron) till micro pore space < 0.1 micron. The spaces hold water, allow drainage, allow entry of O_2 and removal of CO_2 from the soil, allow roots to penetrate, and are indirectly responsible for modifying the mechanical properties of soils. Soil porosity can be determined from the following relation:

Total porosity (%) = (total pore volume ÷ container volume) x 100.

I.2. Chemical Properties of Soil:

(a) Soil acidity and alkalinity and soil pH.

Soil pH refers to soil's acidity or alkalinity and is the measure of hydrogen ions **[**H^+**]** in the soil. A high amount of **[**H^+**]** corresponds to a low pH value and vice versa. When the term neutral (normally pH=7) is applied to soils, it is given a slightly different meaning being a range from about pH 6.5 to7. Soil acidity or alkalinity involves more than just the pH of the soil solution.

The effect of pH on soil is to remove from the soil, or to make available, certain ions. Soils with high acidity tend to have toxic amounts of aluminum and manganese, while soil organisms are hindered by high acidity. Most agricultural crops do best with mineral soils of pH 6.5 and organic soils of pH 5.5 ***(Donahue et al., 1977)***.

Soil pH controls many chemical processes that take place during plant growth. It specifically affects plant nutrients availability by controlling the chemical forms of the nutrients. Different plants have different soil pH requirements. The optimum pH range for most plants is between 5.5 and 7.0 ***(Leonard and Perry, 2012)***.

Generally, soils become acidic as a result of atmospheric inputs of hydrogen ions or compounds which produce hydrogen ions. On reaction with soil minerals, the amounts of exchangeable hydrogen and aluminum ions are increased, and soluble products are lost by leaching. The pH change depends on the magnitude of the external and internal inputs and the extent to which hydrogen ions react with the soil and the products are leached. The resistance of soil to change of pH is known as the buffer capacity ***(Rowell, D.L., 1994).***

Measurements of soil pH are normally made in a suspension of soil in water such that the value obtained is primarily related to the solution pH. However, hydrogen ions are also present on cation exchange sites and have an effect on the measurements**.**

(b) Cation exchange capacity (CEC).

It is the quantity of negative charges per kg of soil expressed in milli equivalents per 50g. Cation exchange between colloids and soil water moderates soil pH, prevents nutrients from leaching away from roots, alters soil structure and purifies percolating water by adsorbing cations of all types, both useful and harmful ***(Donahue et al., 1977)***.

(c) Anion exchange capacity (AEC).

It is the soil ability to remove anions from the soil water solution, sequester those for later exchange as the plant roots and release carbonate anions to the soil solution. Levels of AEC are much lower than for CEC. Phosphates tend to be held at anion exchange sites. AEC decreases with increasing pH (alkalinity) ***(Donahue et al., 1977)***.

(d) Electrical conductivity (EC).

Electrical conductivity is the ability of a material to transmit (conduct) an electrical current and is commonly expressed in units of millisimiens per meter (ms/m). E.C. of a soil is a measurement that correlates with soil properties which affect crop productivity including soil texture, cation exchange capacity, organic matter level and salinity ***(Eshami et al., 2012)***. E.C. of soils varies depending on the amount of moisture held by soil particles. Sands have a low conductivity, silts have a medium conductivity and clays have a high conductivity. Consequently, E.C. correlates strongly to soil particle size and texture ***(Mark and Holshouser, 2005).***

(*e*) *Soil fertility.*

Studying soil chemistry and soil fertility has been the main interest of people studying plant growth and agricultural production. The ability of soils to sustain increased production depends largely on the way in which their properties are altered as a result of cultivation. There are 16 known elements that are essential for plant growth as will be mentioned later. Plants require nutrients that are not created through photosynthesis. Removals of nutrients from soils by crops have to be balanced by inputs, either by natural processes or through the use of manures and fertilizers. Nutrient availability can be improved relatively easily by applying fertilizers.

Fertilizers add nutrients in forms which are already present naturally. They change nutrients concentrations in the soil and may increase production. Plants get hydrogen, oxygen and carbon from air and water, in addition to nitrogen, phosphorus and potassium in high amounts as macronutrients. Plants require other nutrients like calcium, magnesium and sulfur but in lesser amounts. Also, other micronutrients essential for plant life, in their order of importance to plant needs , include iron, manganese, zinc, copper, boron, chlorine and molybdenum .They are required in very small amounts but they are essential in that most are necessary parts of enzyme system which speeds up plants metabolisms. They are generally available in the mineral component of the soil, but the heavy application of phosphates can cause deficiency in zinc and iron by the formation of insoluble zinc and iron phosphates. Iron deficiency may also result from excessive amounts of heavy metals or calcium minerals (lime) in the soil. Excess amounts of soluble boron, molybdenum and chloride ions are toxic ***(Donahue et al., 1977)***.

Barabasz et al. (2002) reported that mineral fertilization of arable land positively affects the increase of the biological productivity of various ecosystems as well as the microbial activity in soil. From the three elements N, P and K^{-}used for fertilization – nitrogen is one of the most important factors affecting soil fertility and productivity as well as the growth and development of cultivated plants. However, the chemical studies show that high N rates of fertilization result in the formation of carcinogenic nitrosamines in soil environments. The use of mineral N resulted in significant changes in microorganisms under investigated ecological conditions.

Sarwar et al. (2008) found that crop productivity of soils of Pakistan has become stagnant in the last decade. One of the major constraints is organic matter status that has reached to bare minimum. On the basis of experimental results, a recommendation for the farmers can be formulated that they should compost the crop residues and apply in their soils for the increased sustainable crop production. In this way, the soil fertility can be improved with a net improvement in land productivity.

Dragan et al. (2015) found that nitrogen fertilization is the most influential in terms of increasing crop production. Mineral nitrogen, in addition to increasing the content of nitrate in soil, leads to changes in soil pH and many other soil properties. Long-term mineral nitrogen addition experiments (over 40 years) give valuable information about how those changes occur and point out the trends of the changes. The results show significant increases in N content, humus and soil CEC.

Growth factors are expressed as the needs for plant growth and successive production such as light, water, temperature and essential plant nutrients. Omission of these elements will result in abnormal growth because they cannot be replaced or substituted ***(Arnon and Stout, 1939).*** Nearly all plant nutrients are taken up in ionic forms from the soil solution as cations or as anions. Plants release bicarbonate $(HCO3)^-$ and hydroxyl $(OH)^-$ anions from their roots to allow absorption of nutrient anions or hydrogen cations in exchange for cation forms of nutrients. As a result, nutrient ions freed from sequestration on colloids are released into soil solution. Through ion exchange, elements such as calcium and potassium are released from this state of electrostatic adsorption on colloidal surface and escape into the soil solution.

(f) Heavy metals in soil environments.

The environmental problems with heavy metals are that they, as elements, are undestroyable and the most of them have toxic effects on living organisms when exceeding a certain concentration. Furthermore, some heavy metals are being subjected to bioaccumulation and may pose a risk to human health when transferred to the food chain. Soils, whether in urban or agricultural areas represent a major sink for metals released into the environment from a wide variety of anthropogenic source ***(Niragu et al., 1992)*****.**

In most soil environments sorption is the dominating speciation process, and thus the largest fraction of heavy metal in a soil is associated with the solid phase of that soil. Pollution problems arise when heavy metals are mobilized into the soil solution and taken up by plants or transported to the surface/ ground water . The properties of the soil are thus very important in the attenuation of heavy metals in the environment.

I.3. Fertilization

(a) Fertilizers.

A **fertilizer** is any material of natural or synthetic origin (other than liming materials) that is applied to soils or to plant tissues (usually leaves) to supply one or more plant nutrients essential to the growth of plant. Fertilizers are kingpin in enhancing crop production**.** The proper use of fertilizers on soils of low natural fertility makes it possible to grow a wider variety of crops.

Generally, the effects of fertilizers on plants are as follows.

Nitrogen : leaf growth.

Phosphorus: development of roots, flowers, seeds and fruits.

Potassium: strong stem growth, movement of water in plants, promotion

of flowering and fruiting.

The relatively low costs of fertilizers as compared with the cost of other farm inputs, such as land, wages and farm machinery have contributed towards increasing fertilizer consumption.

Balanced fertilization means application of essential plant nutrients, particularly the major nutrients, N, P and K in optimum quantity through correct method and time of application in right proportion. It is essential to encourage the use of nitrogenous, phosphatic and potassic fertilizers, so as to achieve the desirable consumption ratio of 4:2:1 to maintain the soil health and to sustain the crop productivity.

A fertilizer is said to be complete when it contains the major nutrients, nitrogen, phosphorus and potassium. An excessive use of fertilizer which is not utilized for crop production can pollute the environment.

Fertilizer-bags are labeled with at least three numbers. These numbers list the percentage of nitrogen (N), available phosphate (as P_2O_5) and soluble potash (as K_2O). These numbers represent nitrogen, phosphorous and potassium, commonly referred to as N-P-K. However, these elements are symbolically represented as N-P_2O_5-K_2O. For example, if we have a 100 pound-bag of fertilizer labeled 10-10-10, it contains 10 pounds of N, 10 pounds of P_2O_5, and 10 pounds of K_2O. The other 70 pounds are a filler or a carrier which is important to help spread the fertilizer evenly and avoid burning plants with too much fertilizer. Fillers may be clay, saw dust, etc. Other parts of the nutrient carrier may be other elements associated with the nitrogen, phosphorous and potassium such as hydrogen, oxygen, calcium and chloride. When a fertilizer is applied to a soil, nearby water begins to move very gradually toward the area where the fertilizer has been applied. Fertilizer salts begin to diffuse or move away from the place where they were applied. This dilutes the fertilizer and distributes it throughout a much larger area. Liquid fertilizer formulations include complete formulas and special types offer just one or two nutrients, all must be diluted with water.

(b) Plant nutrition.

Plant nutrition involves biological, physical and chemical processes. Water and nutrients provide the mechanical support to plants consisting of weathered materials, decaying organic matter and air. Generally, plant roots can readily absorb all of the nutrients from the soil solution provided. There is enough oxygen gas in the soil to support root metabolism. With the exception of carbon, hydrogen and oxygen, which are supplied by carbon dioxide and water, the nutrients are derived originally from the mineral components of the soil. Although minerals are the origin of those nutrients, the organic component is the reservoir of the majority of readily available plant nutrients. Sixteen nutrients are essential for plant growth and reproduction. They are carbon, hydrogen, oxygen, nitrogen, phosphorus, potassium, sulfur, calcium, magnesium, iron, boron, manganese, copper, zinc, molybdenum and chlorine .The application of finally ground minerals, feldspar and apatite to soil does not provide the necessary amount of potassium and phosphorus for good plant growth ***(Onwudiwe et al., 2014)*.**

Nutrients which enhance the health but whose deficiency does not stop the life cycle of plants, including cobalt, strontium, vanadium, silicon and nickel, may be added to the list of essential plant nutrients.

Plants obtain their carbon from atmospheric carbon dioxide. A plant's weight is forty-five percent carbon. Plant residues have a carbon to nitrogen ratio (C/N) of 50: 1. As the soil organic material