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FERTILITY EVALUATION OF SOIL FOR CEREAL PRODUCTION

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ABSTRACT

Fundamental needs of human beings food, clothes and shelter are fulfilled through the medium of soil. Soil is an important part of our agriculture. Global cultivation of crops and other vegetation is directly dependent on soil quality. An understanding of physical and chemical condition of any soil is essential for proper implementation of the other management practices. Therefore, the study of physicochemical properties of soil is very important because both physical and chemical properties are the once that affect the soil productivity. This review on physicochemical study of soil is based on various parameters like pH, electrical conductivity, texture, moisture, temperature, soil organic matter, available nitrogen, phosphorus and potassium. This knowledge will create awareness among the farmers about economic productivity of Ethiopian soils.

Keywords: Fertility, Soil composition, physicochemical properties, Soil pollution

Introduction

Soil fertility includes both chemical and physical fertility of the soil. A soil which contains adequate amounts of the various substances required for plant nutrition, in available forms, and which is not excessively acidic or alkaline and is free of toxic agents, possess chemical fertility. However, the overall suitability of a soil as a medium for plant growth depends not only up on the presence and quantity of chemical nutrients, and on the absence of toxicity, but up on the state and mobility of water and air and upon the mechanical attributes of the soil and its thermal regime. The soil must be loose and sufficiently soft and friable to permit germination and root development without mechanical obstruction, this refers to physical fertility.

Both physical and chemical fertility limits soil productivity (Hillel, 1980). The study of soil fertility involves examining the forms in which plant nutrients occur in the soil, how these become available to the plant, and factors that influence their uptake (Martin 1993). This in turn leads to a study of the measures that can be taken to improve soil fertility and crop yield by applying nutrient to the soil- plant system. This is usually done by adding fertilizers, manure and amendments to the soil but sometimes by supplying nutrients directly to the plant parts by means of sprays.

A mineral element is considered essential to plant growth and development if the element is involved in plant metabolic functions and plant cannot complete its life cycle without the element. Usually the plant exhibits a visual symptom indicating a deficiency in specific nutrient, which normally can be corrected or prevented by supplying that nutrient (Tisdale *et al.*, 1995). However, visual nutrient symptoms can be caused by many other plant stress factors. Therefore, caution should be taken when diagnosing deficiency symptoms. Plants feed mainly by taking essential elements through their roots, but also nutrients can be absorbed by the leaves and the other plant parts particularly through leaf stomata (Martin, 1993).

The importance of soil fertility and plant nutrition to health and survival of all life cannot be understated as human population continues to increase, human disturbance of earth's ecosystem to produce food and fiber will place greater demand on the supply of essential nutrients. Therefore, it is critical that we increase our understanding of the chemical, biological and physical properties and relationships in the soil- plant-atmosphere continuum that control nutrient availability (Tisdale *et al*., 1995).

As with many innovators, the initial use of fertilizers was treated with some suspicion, and they were considered inferior to natural manures. Today, doubts about the increasing use of agricultural chemicals in general, fueled by occasional mistakes, appear to be on the increase in some circles, though, not among most practicing agronomists. Two facts should be born in mind. The first is that a nutrient ion, such as ammonium, $NH4^+$, is exactly the same whether it is obtained from the decomposition of cow dung manure or applied in a bag labeled sulfate of ammonia, 21%N. If a crop plant cannot distinguish between the two sources, then why should we? Secondly, the current levels of food production, involving as they do the annual consumption of millions of tons of fertilizers (Martin, 1993). Thus, if we wish to go back to the nineteenth century methods of food production we have also somehow to reduce the world's population to a fraction of its present number. The answer is not to try to ignore or do without chemical fertilizers, but to study their use and effects with more care, so that their uses become more efficient and effective and mistakes and wastes are progressively eliminated (Martin, 1993).

The evidence is clear that the soils native ability to supply sufficient nutrients has decreased with the plant productivity levels with increased human demand for food. One of the greatest challenges for our generation will be to develop and implement soil, water and nutrient management technologies that enhance the quality of soil, water and air. If we do not improve and/ or sustain the productive capacity of our fragile soil, we cannot continue to support the food and fiber demand of our growing population (Tisdale *et al.*, 1995).

Soil Productivity as a Factor of Soil Fertility

At present, the issue of soil productivity has become a global concern. According to Brady and Weil (2002), the two major interactive worldwide problems are widespread hunger and malnutrition, and the deterioration of quality of the environment resulting from injudicious attempts made to alleviate hunger and malnutrition. The quality, management and conservation of the world's soils are critical elements in the rectification of the sated problems.

The evidence is clear that the soils' natural ability to supply sufficient nutrients has decreased with the higher plant productivity levels associated with increased human demand for food (Tisdale *et al.,* 1993). Cognizant of these very fact, Heluf (1995) stated that the challenge to Agricultural scientists and farmers today is how and where to produce enough food crop to feed the alarmingly growing world population. The quest for increased and sustainable productivity to match with population growth has been a central issue in agriculture for as long as crops have been grown. Its stark significance is seen today in areas of Africa that are suffering from frequent drought and the consequent famine. In countries with a capacity for excess food production, maintenance of soil fertility is a requirement for both economic and environmental viability of their farming system, with production matched to national needs and export demands (Rowell, 1994).

Soil fertility decline has been described as the single most important constraint to food security in Sub-Saharan Africa (SSA). Soil fertility is not just a problem of nutrient deficiency. It is a problem of soil physicochemical and biological degradation. The problem relates the linkage between poverty and land degradation, often perverse national and global policies with respect to incentives and institutional failures (Verchot *et al.,* 2007).

The secret of ensuring food security for the ever-increasing world population is strongly linked to the productivity of soils. Soil, one of the most precious resources of land, plays critical and irreplaceable role in determining man's standard of living. This implies that the overall productivity and sustainability of a given agricultural sector is heavily dependent on the fertility and productivity of soil resources (Wakene, 2001). Soil fertility depletion is the fundamental biophysical root cause for declining per capita food production in the SSA countries in general (Sanchez *et al*., 1997) and in Ethiopia in particular.

Most of the tropical soils are acid, infertile and, hence, cannot support sustainable crop production without external inputs of inorganic or organic fertilizers. Even some soils which were once fertile have become devoid of nutrients and can no longer sustain crop production

(Mafongoya *et al.,* 1998). The loss of soil fertility from continual nutrient mining by crop removal without adequate replenishment, combined with imbalanced plant nutrition practices, has posed a serious threat to agricultural production (FAO, 2006a). In Ethiopia, declining soil fertility presents a major challenge to bring about increased and sustainable productivity in order to feed the ever-increasing population of the country. As a result, millions are suffering from poverty and malnutrition. Eyasu (2002) indicated that under increasing demographic pressure, cultivation becomes permanent. According to same author, the conventional hypothesis is that the traditional farming systems in SSA lead to the mining of the natural soil fertility when cultivation becomes more permanent due to increasing population pressure. In many cases, removal of vegetation cover, depletion of soil nutrients and organic matter (OM), and accelerated soil erosion have all led to the drastic decline in soil productivity. The turning point to solve the problem is systematic application of scientific methods to assess the fertility status of soils through their physical, chemical and biological properties. Research results have shown that the success in soil management to maintain soil quality depends on understanding of the properties of a given soil. This is a requisite for designing appropriate management strategies and thereby solving many challenges that the Ethiopians are facing in the crop and livestock production sectors and in their efforts towards natural resource management for sustainable development (Wakene, 2001). Soil fertility is a function of its physical, chemical and biological properties on which we have to have not only qualitative but also quantitative information to formulate the appropriate fertility management programs. According to Mesfin (1980), extensive research is required on the physical, chemical and biological properties of Ethiopian soils.

Empirical solutions such as simply adding major plant nutrients to the soil and/or literature based research findings will not suffice. Soil fertility is the most valuable asset. Therefore, to maintain where it is high and to improve where it is low, assessment is a prerequisite to rate soils on the basis of their fertility status. In Ethiopia, the information presently available on soil fertility status is not adequate to meet the requirement of agricultural development programs, and rational fertilizer promotions and recommendations based on actual limiting nutrients for a given crop. The prevailing blanket fertilizer rate recommendation throughout the country justifies the existence of little information on the fertility status of Ethiopia's soils.

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Periodic assessment of important soil properties and their responses to changes in land management is necessary in order to improve and maintain the fertility and productivity of soils (Wakene and Heluf, 2003). Mapping the spatial variability of soil fertility by applying geographic information system (GIS) is also the order of the day to avail information for present and future uses. The soil fertility mapping can be used for delineating soil fertility status, studying soil fertility changing due to land use dynamics and determining nutrient requirement for the deficient areas.

Soil Fertility Management

Soil fertility is not static, hence, undergoes considerable change with time in either direction (build up and depletion of nutrients) depending on management practices. Crop yield is related to the available nutrient content in the soil. For instance, the problem of soil fertility in maize production is well understood by the farmers and they try to tackle this problem through different technique mainly manuring, changing crops on field and using commercial fertilizers. Commercial fertilizers are used by only small proportions of the farmers. In Ethiopia, where maize grown, farmers often do not apply adequate amounts of fertilizers. Even when applied, the application, which is crucial from the production point of view, is missed. Not only the fertilizer dose but its management is very important for increasing the productivity and fertilizer use efficiency. About 30 to 70% of the applied nitrogen may be lost as ammonia within 7 to 10 days after application. Improved management can substantially reduce these losses. Nitrogen and phosphorus are considered to be the most limiting nutrients. The easiest way to increase soil nitrogen and phosphorus is the addition of inorganic nutrients such as Urea and DAP to the soil for immediate crop growth requirement in the same season (Kelsa *et al*., 1992).

The low nutrient levels in the soil are caused by removal of surface soil by erosion, crop removal of nutrients from the soil, little or no fertilizer application, and total removal of crop residues from the farmland and burning, and lack of a proper crop rotation program. Ethiopia’s geomorphic features tend to cause serious soil erosion problems. Farmers do not practice appropriate soil conservation practices until the surface fertile soil is washed away and the land becomes unproductive (Tolessa *et al*, 2001)

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Inter relation of Important Growth Factors in crop Production

Growth factors for plants are those interdependent factors, which predominantly are imposed by external environment where the plant grows and affects its growth and development. They are resources for which the plant has to compete in the process of growth. Though there are more than fifty factors (both genetic and environmental) influencing crop growth and yield (Tisdale *et al.*, 1993) the major ones are ***temperature, moisture and light (that establish the upper limit of the potential yield of crops), nutrients, soil factors and management aspect.***

Soil fertility level has influence in supplying various essential nutrients to plants and thereby affects accumulation and distribution of dry matter to various organs. Yield can often be reduced 10-30% by deficiencies of major nutrients before any clear symptoms of deficiency are observed in the field (Lafitte, 1994). Calcium, magnesium and sulfur are taken by plants in fairly small quantities and are referred to, as secondary elements and the rest are micronutrients. ***Many factors among which are total nitrogen supply, soil moisture, soil physical and chemical properties, soil temperature, soil aeration, etc influence availability of these nutrient resources (Olson and Sander, 1992).***

Crop management practices are deliberately undertaken for the good of the crop, either by Protecting and/or by creating favorable conditions so that there is an optimum growth conditions for the crop. Soil management practices by farmers enhance nutrient availability from the soil for the crop and this follows more dry matter accumulation in crops (Olson and Sander, 1992).

In permanent agricultural systems, soil fertility is maintained through applications of manure, other organic materials, inorganic fertilizers, lime and the inclusion of legumes in the cropping systems, or a combination of these. In many parts of the world the availability, use and profitability of inorganic fertilizers have been low whereas there has been intensification of land-use and expansion of crop cultivation to marginal soils. As a result, soil fertility has declined and it is perceived to be widespread, particularly in sub-Saharan Africa including Ethiopia (Pieri, C. 1989; Smaling, E.M.A., 1993). Similarly, low soil fertility is recognized as an important constraint to increased food production and farm incomes in many parts of sub- Saharan Africa.

Soil fertility decline is considered as an important cause for low productivity of many soils. It has not received the same amount of research attention as soil erosion; possibly as soil fertility decline is less visible and less spectacular and more difficult to assess. Assessing soil fertility status is difficult because most soil chemical properties either change very slowly or have large seasonal fluctuations; in both cases, it requires long-term research commitment.

Growing agricultural crops implies that nutrients (N, P, K, etc.) are removed from the soil through the agricultural produce (food, fiber, wood) and crop residues. Nutrient removal results in a decline soil fertility when replenishment with inorganic or organic nutrient inputs is inadequate.

About 85% of Ethiopian population are engaged in agricultural production and contribute significantly to the total export value. Previous studies of the tropical soils revealed that nitrogen and phosphorus are low and hence limiting crop production (Asgelil Dibabe, 2000). Little information is currently available to farmers and extension workers on soil fertility status and nutrient management. Although, Folmer *et al.*1998 employed some mathematical model based on land units and land system in order to predict potential nutrient problems, this has not presented the clear picture about the nutrient status.

In this respect the main objective of the Fertility evaluation of the soil should focus on assessing fertility status of the soils using indigenous local indicators of soil fertility and soil laboratory analytical data. This information and data would thus assist in developing appropriate soil fertility management strategies and options for soil fertility pattern in a given area. Here are described soil Physical and chemical properties as limiting factors of soil fertility for crop production. However, the following summary criteria should be regarded as a general one and its main use is to evaluate the natural fertility of soils and to indicate potential excess and deficiency problems in soils.

SOIL PHYSICAL PROPERTIES

Adaptability to cultivation and the level of biological activity that can be supported by the soil are determined by the physical properties of the soils. Soil physical properties also largely determine the soil's water and air supplying capacity to plants. Many soil physical properties change with changes in land use system and its management such as intensity of cultivation, the instrument used and the nature of the land under cultivation, rendering the soil less permeable and more susceptible to runoff and erosion losses (Sanchez, 1976). Some of the soil physical properties are discussed below.

i. Soil texture

A number of physical and chemical properties of soils determine soil texture. It affects the infiltration and retention of water, soil aeration, absorption of nutrients, microbial activities, tillage and irrigation practices (Foth, 1990; Gupta, 2004). It is also an indicator of some other related soil features such as type of parent material, homogeneity and heterogeneity within the profile, migration of clay and intensity of weathering of soil material or age of soil (Miller and Donahue,1995; Lilienfein *et al*., 2000).

Soil texture is one of the inherent soil physical properties less affected by management. The rate of increase in stickiness or ability to mould as the moisture content increases depend on the content of silt and clay, the degree to which the clay particles are bound together instable granules and the OM content of the soil (White, 1997). Over a very long period of time, pedogenic processes such as erosion, deposition, eluviations and weathering can change the textures of various soil horizons (Forth, 1990; Brady and Weil, 2002).

ii. Bulk and particle densities

Measurement of soil bulk density (the mass of a unit volume of dry soil) is required for the determination of compactness, as a measure of soil structure, for calculating soil pore space and as indicator of aeration status and water content (Barauah and Barthakulh, 1997). Bulk density also provides information on the environment available to soil microorganisms. White (1997) stated that values of bulk density ranges from < 1 g/cm3 for soils high in OM, 1.0 to 1.4g/cm3 for well- aggregated loamy soils and 1.2 to 1.8 g/cm3 for sands and compacted horizons in clay soils. Bulk density normally decreases as mineral soils become finer in texture. Soils having low and high bulk density exhibit favorable and poor physical conditions, respectively. Bulk densities of soil horizons are inversely related to the amount of pore space and soil OM (Brady and Weil, 2002; Gupta, 2004). Any factor that influences soil pore space will also affect the bulk density. For instance, intensive cultivation increases bulk density resulting in reduction of total porosity.

The study results of Woldeamlak and Stroosnijder (2003) and Mulugeta (2004) revealed that the bulk density of cultivated soils was higher than the bulk density of forest soils. Soil bulk density increased in the 0-10 and 10-20 cm layers relative to the length of time the soils were subjected to cultivation (Mulugeta, 2004). Similarly, Ahmed (2002) reported that soil bulk density under both cultivated and grazing lands increased with increasing soil depth. On the other hand, Wakene (2001) reported that bulk density was higher at the surface than the subsurface horizons in the abandoned and lands left fallow for twelve years. The changes in the physical soil attributes on the farm fields can be attributed to the impacts of frequent tillage and the decline in OM content of the soils.

Particle density is the mass or weight of a unit volume of soil solids. It affects soil porosity, aeration and rate of sedimentation of particles. The mean particle density of most mineral soils is about 2.60 to 2.75 g/cm3, but the presence of iron oxide and heavy minerals increases the average value of particle density and the presence of OM lowers it (Hillel, 1980). According to Ahmed (2002), the surface soil layer had lower particle density value than the subsoil horizons and the higher particle density (2.93 g/cm3) was obtained at the subsoil horizons in different land use systems at different elevation. This is attributed to the lower OM content in the subsoil than in the surface horizons.

iii. Total porosity

The total porosity of soils usually lies between 30% and 70%. In soils with the same particle density, the lower the bulk density, the higher is the percent total porosity. As soil particles vary in size and shape, pore spaces also vary in size, shape and direction (Foth, 1990). Coarse textured soils tend to be less porous than fine texture soils, although the mean size of individual pores is larger in the former than in the latter. There is close relationship between relative compaction and the larger (macropores) of soils (Ike and Aremu, 1992). According to the same authors, tillage reduces the macropore spaces and produces a discontinuity in pore space between the cultivated surface and the subsurface soils. Generally, intensive cultivation causes soil compaction and degradation of soil properties including porosity. Macropores can occur as the spaces between individual sand grains in coarse textural soils. Thus, although a sand soil has relatively low total porosity, the movement of air and water through such soil is surprisingly rapid because of the dominance of macropores. Fertile soils with ideal conditions for most agricultural crops have sufficient pore space, more or less equally divided between large (macro) and small (micro) pores. The decreasing OM and increasing in clay that occur with depth in many soil profiles are associated with a shift from macro-pores to micro-pores (Brady and Weil, 2002). Micropores are water field; and they are too small to permit much air movement. Water movement in micropores is slow, and much of the water retained in these pores is not available to plants. Fine textured soils, especially those without a stable granular structure may have a dominance of micropores, thus allowing relatively slow gas and water movement, despite the relative large volume of total pore space (Landon, 1991). Considering the surface soils, Wakene (2001) stated that the lowest total porosity (36.2%) was observed on the abandoned research field, followed by (41.6%) under the land left fallow for twelve years and the highest (56.7%) was recorded on the farmer's field. Along with the increase in soil bulk density, soil total porosity showed marked declines in both soil layers (0-10 and 10-20 cm) with increasing period under cultivation (Mulugeta, 2004). The lowest total porosity was the reflections of the low OM content.

iv. Soil water content and retention capacity

Soil water enhances various soil physicochemical reactions and supplies essential nutrients for plants and animals including micro and macroorganisms residing in soils in order that they can carry out their own activities (Tisdale *et al.*, 1995; Brady and Weil, 2002). The portion of stored soil water that can readily be absorbed by plants is said to be available water. The plant available soil water is held within a potential between field capacity (FC) and permanent wilting point (PWP). Available soil water content is greatly influenced by soil OM content, texture, mineralogy and soil morphology (Landon, 1991). According to Teklu (1992), soils with high amount of clay have higher amount of water both at -1/3 and -15 bars than soils with low amount of clay content and thus, water retention capacity of a soil is a function of silicate clays and amorphous materials. Water occupies the soil pore spaces and is adsorbed to soil particles.

Soil water content at FC, PWP and available water holding capacity (AWHC) were found to increase with depth for the soil under different management practice (Wakene, 2001; Ahmed, 2002). The increases of these three components of soil moisture with depth were correlated positively with the clay fractions of the soils, which increased with profile depth. Variation in topography, land use and soil attributes all affect the distribution of soil moisture (Ahmed, 2002; Brady and Weil, 2002). Wakene (2001) reported that the highest (526 mm/m) and the lowest (275 mm/m) of soil water content at FC were observed in the deeper subsoil (90-140 cm) layer of the continuously cultivated farmer's field and the surface (0-16 cm) soil layer of the abandoned research field respectively, at Bako area. Similarly, the highest (391 mm/m) and the lowest (174 mm/m) of soil water contents at PWP were recorded for the subsoil (45-80 cm) layer of the land left fallow for fifteen years and surface (0-16 cm) layer of the abandoned research field, respectively.

SOIL CHEMICAL PROPERTIES

Soil chemical properties are the most important among the factors that determine the nutrient supplying power of the soil to the plants and microbes. The chemical reactions that occur in the soil affect processes leading to soil development and soil fertility build up. Minerals inherited from the soil parent materials overtime release chemical elements that undergo various changes and transformations within the soil.

i. Soil reaction (pH) and electrical conductivity

Soil reaction (usually expressed as pH value) is the degree of soil acidity or alkalinity, which is caused by particular chemical, mineralogical and/or biological environment. Soil reaction affects nutrient availability and toxicity, microbial activity, and root growth. Thus, it is one of the most important chemical characteristics of the soil solution because both higher plants and microorganisms respond so markedly to their chemical environment.

Table 1. Soil pH Levels and Associated Conditions

Soil pH	Indications	Associated Conditions
<5.5	Soil is deficient in Calcium(Ca) and/or magnesium(Mg)	Poor crop growth due to low cation exchange capacity and possible Al^{3+} toxicity. Expect P deficiency
5.5-6.5	Soil is lime free, should be closely monitored	Satisfactory for most crops
6.5-7.5	Ideal range for crop	Soil Exchange Capacity is production near 100% base saturation
7.5-8.4	Free lime ($CaCO_3$) exists in Soil	Usually excellent filtration and percolation of water due to high Ca content of clays. Both P and micronutrients are less available.
> 8.4	Invariably indicates sodic soil	Poor physical conditions. Infiltration and percolation of soil water is slow. Possible root deterioration and organic matter dissolution.

Source: Hach Company, USA (1992)

Descriptive terms commonly associated with certain ranges in pH are extremely acidic (pH <4.5), very strongly acidic (pH 4.5-5.0), strongly acidic (pH 5.1-5.5), moderately acidic (pH5.6-6.0), slightly acid (pH 6.1-6.5), neutral (pH 6.6-7.3), slightly alkaline (pH 7.4-7.8), moderately alkaline (pH 7.9-8.4), strongly alkaline (pH 8.5-9.0), and very strongly alkaline (pH > 9.1) (Foth and Ellis, 1997). The degree and nature of soil reaction influenced by different anthropogenic and natural activities including leaching of exchangeable bases, acid rains, decomposition of organic materials**,** application of commercial fertilizers and other farming practices (Rowell, 1994; Miller and Donahue, 1995; Tisdale *et al.*, 1995; Brady and Weil, 2002).

In strongly acidic soils, Al^{3+} becomes soluble and increase soil acidity while in alkaline soils; exchangeable basic cations tend to occupy the exchange sites of the soils by replacing exchangeable H and Al ions (Miller and Donahue, 1995; Eylachew, 1999; Brady and Weil, 2002).

Electrical conductivity (EC) is a measure of salinity. In addition to overcoming some of the ambiguities of total dissolved salts measurements, the EC measurement is quicker and sufficiently accurate for most purposes (Bohn *et al.*, 2001). Excessive accumulation of soluble salts convert soils to salt affected soils and the process leading to accumulation of salts are common in arid and semi-arid regions where rainfall amount is insufficient to leach soluble salts.

ii. Soil organic matter

Soil OM arises from the debris of green plants, animal residues and excreta that are deposited on the surface and mixed to a variable extent with the mineral component (White, 1997). Soil OM is defined as any living or dead plant and animal materials in the soil and it comprises a wide range of organic species such as humic substances, carbohydrates, proteins, and plant residues (Dudal and Decaers, 1993; Foth and Ellis, 1997). Humus is the substance left after soil organisms have modified original organic materials to a rather stable group of decay products as is the colloidal remains of OM (Sopher and Baird, 1982; Millar and Donahue, 1995). Foth (1990) has indicated that the distribution of OM, expressed as organic carbon, is 38% in trees and ground cover, 9% in the forest floor and 53% is in the soil including the roots plus the OM associated with soil particles.

In most tropical environments, the conversion of forest vegetation to agricultural land results in a decline of the soil OM content to a newer, lower equilibrium (Woldeamlak and Stroosnijder, 2003). Most cultivated soils of Ethiopia are poor in OM contents due to low amount of organic materials applied to the soil and complete removal of the biomass from the field (Yihenew, 2002), and due to severe deforestation, steep relief condition, intensive cultivation and excessive erosion hazards (Eylachew, 1999). Biological degradation is frequently equated with the depletion of vegetation cover and OM in the soil, but also denotes the reduction of beneficial soil organisms that is important indicator of soil fertility (Oldman, 1993). Uncultivated soils have higher in soil OM (both on surface and in soil) than those soils cultivated years (Miller and Gardiner, 2001). In the forest, there is a continuous growth of plants and additions to the three pools of OM: standing crop, forest floor and soil. In the grassland ecosystems, much more of the OM is in the soil and much less occurs in the standing plants and grassland floor. Although approximately 50% of the total OM in the forest ecosystems may be in the soil, over 95% may be in the soil where grasses are the dominant vegetation (Foth, 1990). This means land management practices, which reduce soil fertility, will seriously decrease its chemical activity and also its ability to hold plant nutrients (Assefa, 1978). Soluble and exchangeable aluminum in acid soils are substantially reduced by organic amendments (Hoyt and Turner, 1975; Hue and Amien, 1989). Cook and Ellis (1987), Tisdale *et al.* (1995) and Ol hare (1997) reported that some of the functions of OM/humus are:

(a) aids in water management as residues or plants protect the soil surface from rain drop impacts, resist wind action, and thus, greatly aid in erosion control. Furthermore, decomposing OM causes soil aggregation, which aids infiltration and increases pore space in clay soils. Thus, water and oxygen holding capacity is increased, even beyond the absorptive capacity of OM,

(b) increases exchange and buffering capacity since well decomposed OM or humus has a very high CEC that adds to the buffering capacity of the soil

(c) minimizes leaching loss because organic substances have the ability of holding substances other than cations against leaching,

(d) sources of nutrients (N, P, S and most micronutrients) and growth promoting substances, that is, hormones or growth -promoting and regulating substances valuable to plants may be produced by organisms that decompose soil OM,

(e) stabilizes soil structure, and

(f) provides energy for microbial activity.

Gregorich *et al.* (1995) reported that the concentration of organic carbon (OC) in the forest soil decreased with depth by more than 10-fold in the surface 30 cm, from 139 g/kg soil in the 0-15 cm layer to 12 g/kg soil in the 15-30 cm layer. In contrast, the OC concentration under corn was similar for soil layers within the plow layer, ranging between 19 and 21 gram carbon per kg of soil. However, the mass of OC in the surface 10 cm of the forest soil was about three times greater than the soil under corn, but below 10 cm, the quantity of OC in the forest was similar to that of the soils cultivated for corn (Gregorich *et al*., 1995). Thus, the surface layer is most relevant to assess the impact of management practices on soil OM, because surface soils are easily modified directly by cultivation.

The total amount of OC in the soil can be considered as a measure of stored OM. In a sense, stored OM is a mean OM store or standing stock of OM because it reflects the net product or balance between ongoing accumulation and decomposition processes and it is thus greatly influenced by crop management and productivity. Over the past few years, various attempts have been made to obtain both global and regional inventories of soil OM storage based on soil map units. Generally, sample generic soil horizons based on the effects of land use types and/or management practices provide a useful estimate of total soil carbon storage (Carter *et al*., 1997).

iii. Total Nitrogen

Nitrogen (N) is the forth plant nutrient taken up by plants in greatest quantity next to carbon, oxygen and hydrogen, but it is one of the most deficient elements in the tropics for crop production (Sanchez, 1976; Mengel and Kirkby, 1987; Mesfin, 1998). The total N content of a soil is directly associated with its OC content and its amount on cultivated soils is between

0.03% and 0.04% by weight (Mengel and Kirkby, 1987; Tisdale *et al*., 1995). The N content is lower in continuously and intensively cultivated and highly weathered soils of the humid and sub-humid tropics due to leaching and in highly saline and sodic soils of semi-arid and arid regions due to low OM content (Tisdale *et al*., 1995). Wakene (2001) reported that there was a 30% and 76% depletion of total N from agricultural fields cultivated for 40 years and abandoned land, respectively, compared to the virgin land in Bako area, Ethiopia. Average total N increased from cultivated to grazing and forest land soils, which again declined with increasing depth from surface to subsurface soils (Nega, 2006). The considerable reduction of total N in the continuously cultivated fields could be attributed to the rapid turnover (mineralization) of the organic substrates derived from crop residue (root biomass) whenever added following intensive cultivation (McDonagh *et al*., 2001). Moreover, the decline in soil OC and total N, although commonly expected following deforestation and conversion to farm fields, might have been exacerbated by the insufficient inputs of organic substrates from the farming system (Mulugeta, 2004). The same author also stated that the levels of soil OC and total N in the surface soil (0-10 cm) were significantly lower, and declined increasingly with cultivation time in the farm fields, compared to the soil under the natural forest.

iv. Carbon to nitrogen ratio

Carbon (C) to nitrogen (N) ratio (C/N) is an indicator of net N mineralization and accumulation in soils. Organic matter rich in carbon provides a large source of energy to soil microorganisms. Consequently, it brings population expansion of microorganism and higher consumption of mineralized N. Dense populations of microorganisms inhabit the upper soil surface and have an access to the soil N sources. If the ratio of the substrate is high there will be no net mineralization and accumulation of N (Attiwill and Leeper, 1987). They further noted that as decomposition proceeds, carbon is released as CO_2 and the C/N ratio of the substrate falls. Conversion of carbon in crop residue and other organic materials applied to the soil into humus requires nutrients (Lal, 2001).

Plant residues with C/N ratios of 20:1 or narrower have sufficient N to supply the decomposing microorganisms and also to release N for plant use. Residues with C/N ratios of 20:1 to 30:1

supply sufficient N for decomposition but not enough to result in much release of N for plant use the first few weeks after incorporation. Residues with C/N ratios wider than 30:1 decompose slowly because they lack sufficient N for the microorganisms to use for increasing their number, which causes microbes to use N already available in the soil (Miller and Gardiner, 2001). They have further stated that the wider the C/N ratio of organic materials applied, the more is the need for applying N as a fertilizer to convert biomass into humus. Microbial respiration (soil respiration) is defined as oxygen uptake or CO_2 evolution by bacteria, fungi, algae and protozoans, and includes the gas exchange of aerobic and anaerobic metabolism (Anderson *et al.,* 1982). According to the same authors, soil respiration results from the degradation of organic matter (for example mineralization of harvest residues). This soil biological activity consists of numerous individual activities; the formation CO_2 being the last step of carbon mineralization. Conditions that favour growth of microorganisms will favour fast decomposition rates: continuous warm temperature, wetness, clay types of texture, suitable soil pH (slightly acidic), and adequate nutrients and absence of other decomposition inhibitors such as toxic levels of elements (aluminum, manganese, boron, chloride), soluble salts, shade, and organic phytotoxines (Miller and Gardiner, 2001). Foth (1990) suggested that low soil temperature, by decreasing the rate of decomposition, appeared to have had an important effect on OM content of the soil.

v. Available phosphorus

Phosphorus (P) is known as the master key to agriculture because lack of available P in the soils limits the growth of both cultivated and uncultivated plants (Foth and Ellis, 1997). Following N, P has more wide spread influence on both natural and agricultural ecosystems than any other essential elements. In most natural ecosystems, such as forests and grasslands, P uptake by plants is constrained by both the low total quantity of the element in the soil and by very low solubility of the scarce quantity that is present (Brady and Weil, 2002). It is the most commonly plant growth-limiting nutrient in the tropical soils next to water and N. Erosion tends to transport predominantly the clay and OM fractions of the soil, which are relatively rich in P fractions. Thus, compared to the original soil, eroded sediments are often enriched in P by a ratio of two or more (Brady and Weil 2002). According to Foth and Ellis (1997), natural soil will contain from 50 to over 1,000 mg of total P per kilogram of soil. Of this quantity, about 30 to 50% may be in inorganic form in mineral soils (Foth and Ellis, 1997).

The main sources of plant available P are the weathering of soil minerals, the decomposition and mineralization of soil OM and commercial fertilizers. Most of the soils in Ethiopia particularly Nitisols and other acid soils are known to have low P contents, not only due to the inherently low available P content, but also due to the high P fixation capacity of the soils (Murphy, 1968; Eylachew, 1987). Oxisols, Ultisols, Vertisols and Alfisols are generally low in total P while Andosols are generally high in P content.

vi. Cation exchange capacity

The Cation exchange capacity (CEC) of soils is defined as the capacity of soils to adsorb and exchange cations (Brady and Weil, 2002). Cation exchange capacity is an important parameter of soil because it gives an indication of the type of clay minerals present in the soil, its capacity to retain nutrients against leaching and assessing their fertility and environmental behavior. Generally, the chemical activity of the soil depends on its CEC. The CEC of a soil is strongly affected by the amount and type of clay, and amount of OM present in the soil (Curtis and Courson, 1981). Both clay and colloidal OM are negatively charged and therefore can act as anions (Kimmins, 1997)**.** As a result, these two materials, either individually or combined as a clay-humus complex, have the ability to adsorb and hold positively charged ions (cations). Soils with large amounts of clay and OM have higher CEC than sandy soils low in OM. In surface horizons of mineral soils, higher OM and clay content significantly contribute to the CEC, while in the subsoil particularly where Bt horizon exist, more CEC is contributed by the clay fractions than by OM due to the decline of OM with profile depth (Foth, 1990; Brady and Weil, 2002). Soil solutions contain dissolved chemicals, and many of these chemicals carry positive charges (cations) or negative charges (anions) (Fisher and Binkley, 2000). Cation exchange is considered to be of greater importance to soil fertility than anion exchange, because the majority of essential minerals are absorbed by plants as cations (Poritchett and Fisher, 1987).

The nutrients required for plant growth are present in the soil in a variety of forms (Kimmins, 1997). They may be dissolved in the soil solution, from where they can be utilized directly. They may be absorbed onto exchange sites, from where they inter soil solution or be directly exploited by tree roots or microorganisms that come in contact with the exchange site. Alternatively, they may be firmly fixed in clay lattices, immobilized in decomposition resistant OM, or present in insoluble inorganic compounds. An exchangeable cation is one that is held on a negatively charged surface and displaced by another cation. The exchangeable cation is a desirable form of a nutrient being quickly brought into solution and made accessible to roots by the exchange with proton. Although the cation nutrients held on the exchange sites form a readily available pool, they do not represent the cation supplying ability of the soil (Binkley and Sollins, 1990; Binkley *et al*., 1992). Cations removed from the exchange sites often are replenished rapidly from other sources, such as OM decomposition, mineral weathering, or release of ions fixed within the layers of clay minerals. Generally, processes that affect texture (such as clay) and OM due to land use changes also affect CEC of soils. Woldeamlak and Stroosnijder (2003) reported that CEC value was highest in soils under forest land and lowest under cultivated land. Besides, due to intensity of human action, there was a drastic loss of CEC in the surface than in the subsurface layers in soils of Senbat watershed, western Ethiopia (Nega, 2006). Therefore, it is necessary to study and evaluate soil chemical properties to avoid soil nutrient depletion and degradation, and to sustain production.

Table 2 Interpretation of soil test data for some nutrients in soils with medium CEC.

Available (extractable) nutrients				Expected relative yield without fertilizer
Soil Fertility Class	P	K	Mg	
	(mg/Kg Soil)			(%)
Very low	<5	<50	<20	<50
Low	5-9	50-100	20-40	50-80
Medium	10-17	100-175	40-80	80-100
High	18-25	175-300	80-180	100
Very high	>25	>300	>180	100

Source: FAO, 1980

For macronutrients the data are generally classified into categories of supply, e.g.: very low, low, medium, high, and very high. From these categories, the nutrient amounts required level are estimated. For micronutrients, a critical level is generally used to decide whether an application of that nutrient is needed. Table 2 provides a generalized idea of the relation of available nutrient status to expected yields (without external addition) for a soil of medium CEC (10-20 cmol/Kg). The values in the final column of the table indicate the approximate yield level that the existing soil fertility level could support.

In most cases, soil nutrient status is stated as low, medium or high. This needs to be done for each nutrient. For nutrients other than N, P, K, a single critical level is usually designated below which a soil is considered to be deficient in that nutrient, hence requiring its application. These figures represent general norms but can vary widely with the type of soil, crop and methods used. Therefore, only locally developed fertility limits should be used for specific soils and crops, even within a country or region.

On the basis of soil testing, nutrient supply maps can be drawn for farms, larger regions and countries. Such maps provide a useful generalized picture of the soil fertility of an area. However, the extent to which soil fertility maps can be used for planning nutrient management strategies depends on how through, recent and representative the soil sampling has been on which such maps are based. Macro level maps are more useful as an awareness and educational tool rather than for determining out nutrient application strategies.

vii. Exchangeable acidity

Exchangeable hydrogen (H) together with exchangeable aluminum (Al) are known as soil exchangeable acidity. Soil acidity occurs when acidic H+ ion occurs in the soil solution to a greater extent and when an acid soluble Al3+ reacts with water (hydrolysis) and results in the release of H^+ and hydroxyl Al ions into the soil solution (Rowell, 1994; Brady and Weil, 2002).

As soils become strongly acidic, they may develop sufficient Al in the root zone and the amount of exchangeable basic cations decrease, solubility and availability of some toxic plant nutrient increase and the activities of many soil microorganisms are reduced, resulting in accumulation of OM, reduced mineralization and lower availability of some macronutrients like N, S and P and limitation of growth of most crop plants (Rowell, 1994) and ultimately decline in crop yields and productivity (Miller and Donahue, 1995; Tisdale *et al.*, 1995; Foth and Ellis,1997; Brady and Weil, 2002). Foth and Ellis (1997) stated that during soil acidification, protonation increases the mobilization of Al and Al forms serve as a sink for the accumulation of H^+. The concentration of the H+ in soils to cause acidity is pronounced at pH values below 4 while excess concentration of Al^{3+} is observed at pH below 5.5 (Nair and Chamuah, 1993). In strongly acidic conditions of humid regions where rainfall is sufficient to leach exchangeable basic cations, exchangeable Al occupies more than approximately 60% of the effective cation exchange capacity, resulting in a toxic level of aluminum in the soil solution (Buol *et al.,* 1989). Generally, the presence of more than 1 parts per million of Al^{3+} in the soil solution can significantly bring toxicity to plants. Hence, the management of exchangeable Al is a primary concern in acid soils.

viii. Exchangeable potassium and sodium

Soil parent materials contain potassium (K) mainly in feldspars and micas. As these minerals weather, and the K ions released become either exchangeable or exist as adsorbed or as soluble in the solution (Foth and Ellis, 1997). Potassium is the third most important essential element next to N and P that limit plant productivity. Its behavior in the soil is influenced primarily by soil cation exchange properties and mineral weathering rather than by microbiological processes. Unlike N and P, K causes no off-site environmental problems when it leaves the soil system. It is not toxic and does not cause eutrophication in aquatic systems (Brady and Weil, 2002).

Wakene (2001) reported that the variation in the distribution of K depends on the mineral present, particles size distribution, degree of weathering, soil management practices, climatic conditions, degree of soil development, the intensity of cultivation and the parent material from which the soil is formed. The greater the proportion of clay mineral high in K, the greater will be the potential K availability in soils (Tisdale *et al.*, 1995). Soil K is mostly a mineral form and the daily K needs of plants are little affected by organic associated K, except for exchangeable K adsorbed on OM. Alemayehu (1990) described low presence of exchangeable K under acidic soils under intensive cultivation.

Normally, losses of K by leaching appear to be more serious on soils with low activity clays than soils with high- activity clays, and K from fertilizer application move deeply (Foth and Ellis, 1997). Exchangeable sodium (Na) alters soil physical and chemical properties mainly by inducing swelling and dispersion of clay and organic particles resulting in restricting water permeability and air movement and crust formation and nutritional disorders (decrease solubility and availability of calcium (Ca) and magnesium (Mg) ions) (Szabolcs, 1969; Sposito, 1989). Moreover, it also adversely affects the population, composition and activity of beneficial soil microorganisms directly through its toxicity effects and indirectly by adversely affecting soil physical and as well as chemical properties. In general, high exchangeable Na in soils causes soil sodicity which affects soil fertility and productivity.

ix. Exchangeable calcium and magnesium

Soils in areas of moisture scarcity (such as in arid and semi-arid regions) have less potential to be affected by leaching of cations than do soils of humid and humid regions (Jordan, 1993). Soils under continuous cultivation, application of acid forming inorganic fertilizers, high exchangeable and extractable Al and low pH are characterized by low contents of Ca and Mg mineral nutrients resulting in Ca and Mg deficiency due to excessive leaching (Dudal and Decaers, 1993). Exchangeable Mg commonly saturates only 5 to 20% of the effective CEC, as compared to the 60 to 90% typical for Ca in neutral to somewhat acid soils (Brady and Weil, 2002). Research works conducted on Ethiopian soils indicated that exchangeable Ca and Mg cations dominate the exchange sites of most soils and contributed higher to the total percent base saturation particularly in Vertisols (Mesfin, 1998; Eyelachew, 2001). Different crops have different optimum ranges of nutrient requirements. The response to calcium fertilizer is expected form most crops when the exchangeable Ca is less than 0.2 cmol(+)/kg of soils, while 0.5 cmol(+)/kg soil is reported to be the deficiency threshold level for Mg in the tropics (Landon, 1991).

x. Micronutrients (Fe, Mn, Zn and Cu)

The term micronutrients refer to a number of elements that are required by plants in very small quantities. This term usually applies to elements that are contained in plant tissues in amounts less than 100 mg/kg (Foth and Ellis, 1997). According to the same authors, the four essential micronutrients that exist as cations in soils unlike to boron and molybdenum are zinc (Zn), copper (Cu), iron (Fe) and manganese (Mn) (Table 3).

Adsorption of micronutrients, either by soil OM or by clay-size inorganic soil components is an important mechanism of removing micronutrients from the soil solution (Foth and Ellis 1997). Thus, each may be added to the soil's pool of soluble micronutrients by weathering of minerals, by mineralization of OM, or by addition as a soluble salts (Foth and Ellis, 1997). Factors affecting the availability of micronutrients are parent material, soil reaction, soil texture, and soil OM (Brady and Weil, 2002). Tisdale *et al.* (1995) stated that micronutrients have positive relation with the fine mineral fractions like clay and silt while negative relations with coarser sand particles. This is because their high retention of moisture induces the diffusion of these elements (Tisdale *et al.*, 1995). Soil OM content also significantly affects the availability of micronutrients. According to Hodgson (1963), the presence of OM may promote the availability of certain elements by supplying soluble complexing agents that interfere with their fixation. Krauskopf (1972) stated that the main source of micronutrient elements in most soils is the parent material, from which the soil is formed. Iron, Zn, Mn and Cu are somewhat more abundant in basalt. Brady and Weil (2002) indicated that the solubility, availability and plant uptake of micronutrient cations (Cu, Fe, Mn and Zn) are more under acidic conditions (pH of 5.0 to 6.5) (Table 3).

Table 3 below presents some critical data for a range of crops based on various sources. In most cases, these correspond to 90% of maximum yield. These are approximations compiled from various sources. Specific situations require further refinement. For example, critical concentrations in the case of oil-palm are different for young palms and for older palms (Fairhurst and Hardter, 2003). A selection of critical plant nutrient concentrations for any crops has been compiled by the international Fertilizer Industry Association (IFA, 1992) among others.

Table 3. Critical nutrient concentrations for 90% yield for interpretation of plant analysis data

Element	Wheat & rice	Oilseed rape	Sugar cane	Alfalfa (Lucerne)	Grass	Citrus
(%)						
N	3.00	3.50	1.50	3.50	3.00	2.50
P	0.25	0.30	0.20	0.25	0.40	0.15
K	2.50	2.50	1.50	2.00	2.50	1.00
Mg	0.15	0.20	0.12	0.25	0.20	0.20
S	0.15	0.50	0.15	0.30	0.20	0.15
(μg/g)						
Mn	30.0	30.0	20.0	30.0	60.0	25.0
Zn	20.0	20.0	15.0	15.0	50.0	20.0
Cu	5.0	5.0	3.0	5.0	8.0	5.0
B	6.0	25.0	1.5	25.0	6.0	25.0
Mo	0.3	0.3	0.1	0.2	0.3	0.2

Source: FAO, 1980

SUMMARY

Soil properties affect different aspects of crop in agriculture. These are factors that are essential in effective crop production. Soil physical properties play an important part in the growth of plants. Since the soil serves as an anchorage for plant roots, it should possess the favourable physical conditions that promote root growth. That will allow the roots to move easily with in the soil in search for moisture and nutrients. It is necessary for a farmland to have a good soil tilth. A soil with a good soil tilth has a condition with its ease of tillage and penetration for seed emergence and crop root growth. This condition is directly affected by soil texture, porosity, bulk density and water holding capacity.

On the other hand, chemical properties also dictate the fertility of a given land. Soil nutrients except Nitrogen are inherent in the soil. However, due to continuous cropping and cultivation and the natural nutrient depletion process, the natural soil fertility of the farmlands are dramatically declining. The destruction of soil physical properties and depletion of chemical properties, together, has caused the imbalance of the natural soil system resulting in the decrease of produce from the farmlands and favouring the prevalence of pest and diseases.

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