General Concept of Soil Fertility

The plant depends on soil not only for anchorage but required elements for its structural build-up and physiological processes. All the elements that have been identified as essential for crop-plant growth and yield are obtained from the soil with the exception of C which is obtained from the air through the stomata. Hydrogen and oxygen are obtained from water absorbed through plant roots. The remaining elements – N, P, K, Ca, Mg, S, and the micronutrients, which are referred to as plant nutrients, are obtained directly from the soil. Thus the plant depends on the soil for its nutrition.

All the plant nutrients are present in the soil. However, the mere presence of plant nutrients in the soil does not mean that such a soil is fertile. Plants absorb nutrients in ionic forms dissolved in soil solution. Also, for optimum performance of crop, there must be sufficient amount of all the nutrients enough to meet the minimum requirement of the crop. Thus the soil must be able to supply adequate amount of plant nutrients, in forms which can be absorbed by the crop, within its lifespan. Thus soil fertility is defined as the ability of the soil to supply plant nutrients in adequate quantity and in available forms

Available forms of plant nutrients are the forms (ionic) which can be absorbed by the growing plant.

FACTORS AFFECTING THE FERTILITY OF SOIL

The ability of soil to supply plant nutrients in the available forms is affected by many physical, chemical and biological factors, including management practices.

Soil water

Plants tend to get their nutrients from the water in the soil. This water is usually referred to as the soil solution because it contains dissolved materials (cations and ions) as well as suspended colloids of clay and organic matter.

Soil solution does not contain sufficient nutrients at any one time to last the life of the plant. It has to be replenished from the pool of nutrients adsorbed onto soil colloids (exchangeable nutrients) and those bound up in solid form as minerals or organic matter called the stable pool

Cation Exchange Capacity (CEC) and Base Saturation

Cation exchange capacity is generally defined as the ability of the soil to adsorb cations.

Many of these nutrients are absorbed in the form of cations. Most soils have at least some ability to hold onto these ions at negatively charged sites within the soil. The amount that they can hold is called the Cation Exchange Capacity. The cations are held to the edges of particles within the soil. This is referred to as adsorption. (Use magnets to demonstrate attraction of positive and negative.) The cations in the soil are divided into acids and bases. The acids are predominantly hydrogen and aluminum. The bases are primarily calcium, magnesium, sodium, and potassium.

CEC is technically defined as the sum of exchangeable bases plus total soil acidity at a specific pH value, usually 7.0 or 8.0.

When acidity is expressed as salt-extractable acidity, the cation exchange capacity is called the effective cation exchange capacity (ECEC) because this is considered to be the CEC of the soil at the native pH value. It is usually expressed in centimoles of charge per kilogram of soil (cmol kg-1) or millimoles of charge per kilogram of soil.

The CEC of the soil is dependent on the following:

Amount of clay: Higher amounts of clay mean higher CEC.

Type of clay: Certain kinds of clay (smectites, montmorillonite) have higher CEC than others (such as kaolinite).

Amount of organic matter: Higher amounts of organic matter mean higher CEC pH dependent CEC: Amorphous clay minerals and organic matter have a CEC that varies with pH. As pH increases, so does the CEC. For every pH unit above 4.5 there is a 1 cmol kg^{-1} increase for each percent organic matter.

Base saturation

Base saturation refers to the percentage of exchange sites (negatively charged sites on clay and organic particles) that are occupied with bases (usually Ca^{2+}, Mg^{2+}, K^+ and Na^+) as opposed to ions that make the soil acid (H^+ or Al^{3+}). In technical terms it is the ratio of the quantity of exchangeable bases to the cation exchange capacity. The value of the base saturation varies according to whether the cation exchange capacity includes only the salt extractable acidity (see cation exchange capacity) or the total acidity determined at pH 7 or 8. It is often expressed as a percent.

Exchangeable bases: Charge sites on the surface of soil particles that can be readily replaced with a salt solution. In most soils, Ca^{2+}, Mg^{2+}, K^+ and Na^+ predominate. Historically, these are called bases because they are cations of strong bases. Many soil chemists object to this term because these cations are not bases by any modern definition of the term.

Soils with high base saturations are considered more fertile because many of the “bases” that contribute to it are plant nutrients. Usually the base saturation is 100 percent when the pH is above about 6.5. Since rainfall tends to leach bases out of the soil, areas with higher rainfall tend to have lower base saturations than areas with lower rainfall, unless the parent material is high in bases (such as limestone).

Soil Reaction

Soil reaction refers to the degree of acidity and alkalinity of the soil. It covers the attribute of the soil in terms of its being acid, acidic, alkaline, alkali, sodic or saline. The degree of acidity or alkalinity of a soil can be denoted by its pH

What is pH?

The pH of a soil is defined as the negative of the log of the concentration of hydrogen ions (moles per liter); it is a number between 0 and 14. (Water, H_20 or HOH is usually in equilibrium with its constituent ions, H^+ and OH^- and has a pH of 7.) In acid soils (pH < 7), H^+ ions predominate. In alkaline soils (pH > 7), OH^- ions predominate. Soils with pH of 7 are neutral.

Effect of pH on nutrient availability and uptake

pH does not directly affect plants. It does affect the availability of different nutrients and toxic elements to plants. This is mostly due to the fact that pH changes the form of many of the nutrients and many of the forms are relatively insoluble.

Low pH causes nutrient deficiency, especially calcium phosphorus, and nitrogen. Extreme pH reduces the population of some useful organisms, such as bacteria and earthworms.

Soil acidity

Acidity refers to the condition of the soil when the exchange complex is dominated by hydrogen and aluminum ions. There are two forms of soil acidity:

Exchangeable acidity (salt-replaceable acidity) - The aluminum and hydrogen that can be replaced from an acid soil by an unbuffered salt solution such as KCl or NaCl.

Total acidity, total - The total acidity including residual and exchangeable acidity. Often it is calculated by subtraction of exchangeable bases from the cation exchange capacity determined by ammonium exchange at pH 7.0. It can be determined directly using pH buffer-salt mixtures (e.g., $BaCl_2$ plus triethanolamine, pH 8.0 or 8.2) and titrating the basicity neutralized after reaction with a soil.

Factors which contributes to a soil becoming acidic include

Le*aching*: Refers to the washing down of plant nutrients below the soil beyond the reach of the plant roots leaving behind hydrogen ion.

Use of acid fertilizers: The use of acid fertilizers like ammonium sulphate and ammonium nitrate can easily cause acidity in the soil.

Nutrient uptake by plants: the absorption of soluble minerals by plants results in the accumulation of hydrogen ions which cause soil acidity.

Presence of acid parent materials: The presence of acid parEnt mateials results in the easy dissolution of the rocks, leaving behind minerals rich in hydrogen ions. .

Presence of sulphur in the soil: sulphur undergoes oxidation and dissolution to form acid in the soil.

Soil acidity can be ameliorated through

liming and application of organic manure can also be used on the soil to remove acidity

Distribution of acid soils

Acid soils usually occur where there is sufficient rainfall or other sources of precipitation to leach the bases out of the soil. When this happens, the exchange complex becomes dominated by hydrogen (lowers pH) and aluminum (toxic). In the U.S. there is a fairly strong correlation between precipitation and pH, with soils receiving more than about 30 inches of annual precipitation having a pH less than 6. (See map on page 163 of *Start with the Soil*.)

3. Problems associated with acidity

<u>Aluminum toxicity</u>: Aluminum is the third most common element in the earth's crust. It becomes more available at low pH's, and can be toxic to plants.

<u>Manganese toxicity:</u> This may occur in soil that are high in Mn and that have a pH less than 5

4. Acid soils and liming

Lime (calcium carbonate) is added to acid soils to raise the pH. Calcium replaces hydrogen and aluminum on exchange sites.

Alkalinity, Alkali, Salinity, and Sodic Soils

1. Definitions

Soil alkalinity: The degree or intensity of alkalinity in a soil, expressed by a value > 7.0 for the soil pH

Alkali soil: (i) A soil with a pH of 8.5 or higher or with an exchangeable sodium percentage greater than 0.15 (ESP>15). (ii) A soil that contains sufficient sodium to interfere with the growth of most crop plants. See also saline-sodic soil and sodic soil

Saline soil: A nonsodic soil containing sufficient soluble salt to adversely affect the growth of most crop plants. The lower limit of saturation extract electrical conductivity of such soils is conventionally set at 4 dS m^{-1}(at 25°C). Actually, sensitive plants are affected at half this salinity and highly tolerant ones at about twice this salinity.

Sodic soil: A nonsaline soil containing sufficient exchangeable sodium to adversely affect crop production and soil structure under most conditions of soil and plant type. The sodium adsorption ratio of the saturation extract is at least 13.

Saline-sodic soil*:* A soil containing sufficient exchangeable sodium to interfere with the growth of most crop plants and containing appreciable quantities of soluble salts. The exchangeable sodium ratio is greater than 0.15, conductivity of the soil solution, at saturated water content, of > 4 dS m^{-1}(at 25°C), and the pH is usually 8.5 or less in the saturated soil.

2. Some elements contributing to alkalinity

Calcium: Calcium is common in many soils in arid areas. It helps the soil to form aggregates. (Because it has a +2 charge (divalent), it can bind to two clay or organic particles).

Magnesium: Behaves similarly to calcium in helping to form aggregates.

Potassium: An important plant nutrient

Sodium: Toxic to plants at high levels

Soil Organic Matter

Soil organic matter (SOM) is that fraction of the soil composed of plant and animal remains in various stages of decomposition and synthesis. It includes cells and tissues of soil organisms, and substances from plant roots and soil microbes. Soil organic matter can be divided into two parts: the well-decomposed part in which the original precursor cannot be distinguished anymore known as humus. Humus is dark brown, porous, spongy in appearance with, earthy smell. The other part of SOM is referred to as the non-humic substances and contains fragments of the original substances as identifiable in the original plant and animal remains. Humus also referred to as humic substances consist of three major chemical fractions: fulvic acid, humic acid and humin.

Plants produce organic compounds by using the energy of sunlight to combine carbon dioxide from the atmosphere with water from the soil. Soil organic matter is created by the cycling of these organic compounds in plants, animals, and microorganisms into the soil. In most soils, the organic matter accounts for less than about 5% of the volume.

Soil organic matter is a dynamic entity. It can be lost through natural processes such as erosion, ecological processes such as decomposition, and human activities that promote the processes. Soil organic matter is utilized by soil microorganisms as source of energy and nutrients to support their own life processes. Some of the material is incorporated into the microbes, but most is released as carbon dioxide and water. Some nitrogen is released in gaseous form, but some is retained, along with most of the phosphorus and sulphur.

Importance of organic matter to soil fertility and plant nutrition

- Stabilizes and holds soil particles together. thus reducing the hazard of erosion.

- aids the growth of crops by improving the soil's ability to store and transmit air and water;
- stores and supplies such nutrients as nitrogen, phosphorus, and sulphur, which are needed
- retains nutrients by providing cation-exchange and anion-exchange capacities;
- maintains soil in an uncompacted condition for easy growth of root

Factor influencing level of soil organic matter

The amount of soil organic matter is controlled by a balance between additions of plant and animal materials and losses by decomposition. Both additions and losses are very strongly controlled by management activities. The amount of water available for plant growth is the primary factor controlling the production of plant materials. Other major controls are air temperature and soil fertility. Salinity and chemical toxicities can also limit the production of plant biomass. Other controls are the intensity of sunlight, the content of carbon dioxide in the atmosphere, and relative humidity.

The proportion of the total plant biomass that reaches the soil as a source of organic matter depends largely on the amounts consumed by mammals and insects, destroyed by fire. or produced and harvested for human use.

When soils are tilled, organic matter is decomposed faster because of changes in water, aeration, and temperature conditions. The amount of organic matter lost after clearing a wooded area or tilling native grassland varies according to the kind of soil. but most organic matter is lost within the first 10 years.

Rates of decomposition are very low at temperatures below 38 °F (4°C) but rise steadily with increasing temperature to at least 102 or: (40°C) and with water content until air becomes limiting. Losses are higher with aerobic decomposition (with oxygen) than with anaerobic decomposition (under waterlogged conditions).

Available nitrogen either in the organic matter or from external sources (such as fertilizer application) also promotes organic matter decomposition.

Organic matter level in the soil can be decreased by such management and agricultural practices that leads to decrease the production of plant materials as

- replacing perennial vegetation with short-season vegetation,
- replacing mixed vegetation with monoculture crops,
- introducing more aggressive but less productive species,
- using cultivars with high harvest indices,
- Increasing the use of bare fallow.
- As well as those those that decrease the supply of organic materials such
- burning forest, range, or crop residues,
- over-grazing,
- removing plant products

Maintenance of soil organic matter

Soil organic matter level can be maintained or build up through activities that lead to increase in primary production of plant materials, addition of organic materials to the soil, and reduction in the rate of organic matter decomposition or loss.

Activities that lead to increase in production of plant materials include:

- irrigation,
- judicious us of fertilizer to increase plant biomass production,
- planting of cover crops

- improved vegetative stands,
- introduction of plants that produce more biomass,
- reforestation,
- restoration of grasslands.

Level of organic materials returned into the soil can be increased by

- controlled grazing rather than by harvesting,
- applying animal manure or other carbon-rich wastes,
- applying plant materials from other areas.

Loss of soil organic matter in the soil can be reduced through

- zero or minimum tillage,
- keeping the soil saturated with water (although this may cause other problems),
- keeping the soil cool with vegetative cover.
- protecting from fire.

ESSENTIAL NUTRIENTS/ ELEMENTS

Definition: They are elements needed by plants for growth and reproduction without which plants cannot complete their life cycle (Vegetative, Flowering and seed production).

Criteria for nutrient essentiality:

- Plant cannot complete its life cycle without it
- The function of the element cannot be replaced by another element
- . The element is directly involved in the plant's growth and reproduction

Essential elements include the following:

- Carbon (C), Hydrogen (H), Oxygen (O)

(The above are considered to be non-mineral nutrients because they are derived from air and water)

- Nitrogen (N), Phosphorus (P), Potassium (K), Calcium (Ca), Magnesium (Mg), Sulfur (S)

(These are considered as mineral elements because they are derived from soils and minerals, they are also known as macronutrients because they are required by plants in large quantity).

- Iron (Fe), Manganese (Mn), Zinc (Zn), Copper (Cu), Nickel (Ni), Boron (B), Molybdenum (Mo) Chlorine (Cl) Cobalt (Co)

(These are mineral elements and known as micronutrients because they are required in minute quantities by plants)

Element	Source of supply
C	Air
H	Air/Water
O	Air/Water
N	Air/Soil
P, K, Ca, Mg, S, B, Cl, Cu, Fe, Mn, Mo, Ni, Zn	Soil

Elements	Available forms
C	CO_2
H	H_2O
O	H_2O, CO_2, O_2
N	NO_3^-, NH_4^+

P	$H_2PO_4^-$, HPO_4^{2-}
K	K^+
S	$SO4^{2-}$
Ca	Ca^{2+}
Mg	Mg^{2+}
Fe	Fe^{2+}, Fe^{3+}
Mn	Mn^{2+}
B	BO_4^{2-}
Zn	Zn^{2+}
Cu	Cu^{2+}
Mo	MoO_4^{2+}
Cl	Cl^-
Ni	Ni^{2+}

Physiological roles and deficiency symptoms of essential nutrients

Element	Functions	Deficiency symptoms
Nitrogen	Amino acid formation, plant growth and dev. Enzymatic reactions, photosynthesis, component of vitamins, Improves quality and quantity of dry matter in leafy vegetables and protein in grain crops	Stunted growth, chlorosis, lowering of protein content of seeds and vegetables

Phosphorus	Photosynthesis, respiration, energy storage and transfer as ADP and ATP; DPN and TPN, increases resistant to diseases, part of RNA and DNA, aids roots dev., flower initiation , seed and fruit development	Dark to blue green coloration of leaves purpling of leaves and stems under severe deficiency, delayed maturity, poor seed and fruit development
Potassium	Enzyme activator, promotes metabolism, Regulates plants use of water, photosynthesis Regulates plants use of water, maintains the balance of electrical charges at the site of ATP production, promotes translocation of sugars	Chlorosis along the edges of leaves, slow and stunted plant growth, weak stems, lodging
Calcium	Cell wall membrane formation, maintains cell integrity and membrane permeability. Acts as detoxifying agent by neutralizing organic acids in plants, reduces soil acidity when limed.	Growing tips of roots and leaves turn brown and die, sticking together of newly emerging leaves at the margins.
Magnesium	Major constituent of chlorophyll molecule, assists the movement of sugar within the plant	Interveinal chlorosis, premature leaf drop
Sulfur	Plant protein formation, metabolism of B vitamins, biotin and thiamine, seed production, aids in seed formation.	Chlorosis, stiff, thin and woody plant stems
Boron	Pollen germination and growth of pollen tube	Stunted growth, leaves tend to be thickened, may curl and become brittle

Copper	Photosynthesis, part of chloroplast protein, plastocyanin, which part of the electron transport chain	Distortion of younger leaves, necrosis of apical meristem, multiple sprouting at the growing tips of trees
Chlorine	Photosynthesis, increases cell osmotic pressure and water content of plant tissues	Chlorosis, plant wilting
Iron	Photosynthesis and respiration, nitrate and sulfate reduction	Interveinal chlorosis
Manganese	Involved in oxidation reduction processes, activates several metabolic functions	Marsh spots in legumes
Molybdenum	Required by some soil organisms for N fixation in soils	Chlorosis, stunted plant, leave margins roll inwards
Zinc	Protein and RNA synthesis	Interveinal chlorosis, dropping of dead tissue out of the chlorotic spots
Nickel	Nitrogen metabolism in legumes, stimulates nodule weight and seed yield of soybeans	Accumulation of toxic levels of urea in leaf tips