THE SOIL – HOW IT SUPPORTS PLANT GROWTH

By

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Soils are the medium in which crops grow to feed and to clothe the world. To understand soil fertility is to understand a basic need of crop production. How can a grower produce his crops efficiently and competitively without fertile soils ? How can agricultural advisors help him and supply him without understanding basic soil fertility ?

Soil fertility is vital to a productive soil. But a fertile soil is not necessarily a productive soil. Poor drainage, insects, drought and other factors can limit production, even when fertility is adequate. To fully understand soil fertility, we must know other factors which support or limit productivity. To understand soil productivity, one must recognize existing soil-plant relationships. Certain external factors control plant growth; air, heat (temperature), light, mechanical support, nutrients and water. The plant depends on the soil (atleast partly) for all these factors except light. Each directly affects plant growth. Each is linked to the others. Since water and air occupy the pore spaces in the soil, factors that affect water relations necessarily influence soil air.In turn moisture changes affect soil temperature. Nutrient availability is influenced by soil and water balance as well as by soil temperatures. Root growth is also influenced by soil temperature as well as soil water and air.

Essential plant nutrients

Sixteen chemical elements are known to be essential for plant growth. They are divided into two main groups, non mineral and mineral. Non-mineral nutrients are carbon (C) hydrogen (H) and oxygen (O). These nutrients are found in the atmosphere and water. They are used in photosynthesis in the following manner.

$$\underset{\text{Carbon dioxide}}{6\,Co_2} + \underset{\text{Water}}{12\,H_20} \xrightarrow{\text{light}} \underset{\text{Oxygen}}{9\,0_2} + \underset{\text{Carbohydrates}}{6\,(CH_20)}$$

Products of photosynthesis account for most of the increased plant growth. Insufficient carbon dioxide, water or light reduces growth. But the amount of water used in photosynthesis is so small that plants will show moisture stress before water is low enough to affect photosynthesis rate. The 13 mineral nutrients – those coming from the soil – are divided into three groups: primary secondary and micronutrients.

Primary Nutrients	Micronutrients
Nitrogen (N)	Boron (B)
Phosphrous (P)	Chlorine (Cl)
Potassium (K)	Copper (Ca)
Secondary Nutrients.	Iron (Fe)
Calcium (Ca)	Manganese (Mn)
Magnesium (Mg)	Molybdenum (Mo)
Sulfur (S)	Zinc (Zn)

The primary nutrients usually become deficient in the soil first, because plants use relatively large amounts. The secondary and micronutrients are usually deficient less often and smaller amounts are used. But they are just as important as primary nutrients to improve and maintain fertility. Plants must have them when and where they need them.

Soil texture and structure

Soil texture is determined by how much sand, silt and clay are in the soil. The smaller the particle size the closer to clay, the larger the particle size the closer to sand, for example: 1. A soil high in sand is classified in texture as "sand" 2. When small amounts of slit or clay are present, the soil becomes either "loamy sand" or "sandy loam" 3. Soil composed mostly of clays are "clay" 4. When sand, silt and clay are present in equal proportions, the soil is called a "loam".

Soil texture and structure influence the amount of air and water, growing plants can secure. Particle size is important for two reasons. 1. Smaller clay particles are more tightly fitted than larger sand particles. This means small pores for air and water. 2. Smaller particles have much higher surface areas than larger ones. For example, the largest clay particle has about 25 times the surface area as the smallest sand particle. As surface area increases, the amount of water absorbed (held) increases.

Thus, sandy-soils hold little water because their large pore spaces allow water to drain freely from the soils. Clay absorb relatively large amount of water and their small pore spaces retain it against gravitational forces. Although clay soils have greater water holding capacities than sandy soils, not all the moisture is available to growing plants. Clay soils (and those high in organic matter) hold water more tightly than sandy soils. This means more unavailable water, and therefore clay soils hold more water than sands, but more of it unavailable.

The term, "field capacity" defines the amount of water remaining in a soil after gravitational flow has stopped. It is expressed as a percent by weight. The amount of water a soil contains after plants are permanently wilted is called the "permanent wilting percentage". Water is still present at this point, but is held so tightly that plants are unable to use it. Water available to growing plants is that amount contained in the soil between field capacity and permanent wilting percentage.

Sandy soils cannot store as much water as clay soils. But a higher percentage that is present is available in sandy soils. So there is no constant relationship betwen soil texture and available water. Fine textured soils (clays) are easily compacted. This reduces pore spaces which limits air and water movement through the soil. This causes much rainfall to run off. Clays are sticky when wet and form hard clods when dry. Hence, proper moisture content is extremely important when tillage is done.

Sandy soils are inherently drougthy because they hold so little water. They are loose, less likely than clays to be compacted and are easy to till. However, soils containing high proportions of very fine sand are easily compacted.

Soils high in silt are often the most difficult of all in terms of soil structure. The particles fit very closely together and are compacted quite readily.

Soil structure sharply influences root and top growth. As the soil becomes more compacted, the proportion of large pore spaces decreases, root growth is restricted and production declines.

The ideal soil for crop production looks like this:
Medium texture and organic matter for air and water movement.
Sufficient clay to hold reserve soil moisture.
Deep, permeable subsoil with adequate fertility levels.
Environment for roots to go deep for moisture and nutrients.

Good management maintains or develops a good structure that encourages an extensive root system. Size and shape of granules determine structure and quality. The best structure is blocky and granular, with particles aggregated, to allow for free air and water movement.

Soil colloids and ions

As soils are formed during the weathering processes of rock, some minerals and organic matter are broken down to extremely small particles. Chemical changes further reduce these particles until they cannot be seen with the naked eye. The very smallest are called "colloids".

Scientists have learned that mineral clay colloids are plate like in structure and crystalline in nature. In most soils, the amount of clay colloids exceed organic colloids. Colloids are primarily responsible for the chemical reactivity of soils.

The kind of parent material and the degree of weathering determine the kinds of clays present in the soil. Since soil colloids are derived from these clays, their reactivity is also influenced by parent material and weathering.

Each colloid (clay and organic) has a net negative (–) charge, developed during the formation process. This means it can attract and hold positively (+) charged particles; as unlike poles of a magnet attract each other. Colloids repel other negatively charged particles, again as like poles of a magnet repel each other.

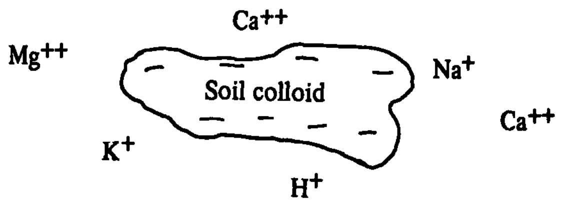
An element with an electrical charge is called an "ion", potassium, sodium, hydrogen, calcium and magnesium all have positive charges. They are called "cation". They may be written in ionic form as shown in the table below. It may be noted that some cations have more than one positive charge.

Nutrient	Chemical symbol	Ionic form
Potassium	K	K^+
Sodium	Na	Na^+
Hydrogen	H	H^+
Calcium	Ca	Ca^{++}
Magnesium	Mg	Mg^{++}

The negatively charged colloids attract cations and hold them like a magnet holding small pieces of metal. This concept is shown below.

like poles (charges) repel each other

unlike poles (charges) attract each other.



This characteristic of colloids explains why nitrate nitrogen (NO_3^-) is more easily leached from the soil than ammonium nitrogen (NH_4^+). Nitrate has a weak negative charge, like soil colloids. So nitrate is not held by the soil, but remains as a free ion in soil water to be leached through the soil profile in some soils and under some rainfall conditions.

Ions with negative charges, such as nitrates and sulphate (SO_4^{--}) are called "anions". The table below shows some common anions.

Anion	Ionic form
Chloride	Cl^-
Nitrate	NO_3^-
Sulphate	SO_4^{--}
Phosphate	PO_4^{---}

Cation exchange capacity

Cations held on the soil colloid can be replaced by other cations. This means they are exchangeable. Calcium can be exchanged for hydrogen and/or potassium or *vice versa.* The total number of exchangeable cations a soil can hold (the amount of its negative charge) is called its "cation exchange capacity" or CEC. The higher a soils CEC the more cations it can retain. Soils differ in their capacities to hold exchangeable K^+ and other cations. The CEC depends on amounts and kinds of clay and organic matter present. For example, a high-clay soil can hold more exchangeable cations than a low-clay soil. Also, CEC increases as organic matter increases.

The CEC of a soil is expressed in terms of milligram equivalents per 100 grams of soil and is written as meq/100g. The only reason this is reported is to show the relative CEC of clays and organic matter. Clay minerals usually range from 10 to 150 meq/100g in CEC values. Organic matter ranges from 200 to 400 meq/100g. So, the kind and amount of clay and organic matter content greatly influence the CEC of soils. In areas, where soils are highly weathered and organic matter levels are low, CEC values are low. But, where less weathering has occured and organic matter levels are usually higher, CEC values can be quite high. Clay soils with high CEC can retain large quantities of cations against potential loss by leaching. Sandy soils, with low CEC, retain only small quantities.

Anion retention in soil

There is no clear-cut mechanism for the retention of anions by the soil. Nitrate, for example, is completely mobile and moves freely with soil moisture. Under high rainfall, it moves downwards. Under extremely dry weather, it moves upwards with soil moisture, causing nitrate to accumulate on the surface. Sulphate can be held, rather loosely, in some soil under certain conditions. At low pH's, positive charges can develop on broken edges of clays such as Kaolinite. Soils containing hydrous iron and aluminium oxides (either in topsoil or subsoil) absorb some sulphate through positive charges developed. But this small retention is of little consequence above pH 6.0. Good quantities of sulphur can be retained through accumulations of gypsum in arid and semi-arid regions. Sulphate salts can be held on the surface of soil colloids, and the sulphate ion may be loosly held by other complexes which are absorbed. Organic matter sometimes develops a positive charge. When it does, sulphate can be attracted to it.

Soil organic matter

Soil organic matter consists of plant and animal residues, in various stages of decay. Adequate levels benefit soil in many ways. (1) Improves physical condition. (2) Increases water infiltration. (3) Improves soil tilth. (4) Decreases erosion losses. (5) Supplies plant nutrients. Most benefits are derived from products released as organic residues are decomposed in the soil. Organic matter contains about 5 percent total nitrogen, so it serves as a storehouse for reserve nitrogen. But nitrogen in organic matter is in organic compounds and not immediately available for plant use, since decomposition usually occurs slowly. Although a soil may contain much organic matter, fertilizer nitrogen is needed to assure non-legume crops an adequate source of readily available nitrogen, especially those crops requiring high nitrogen.

Other essential plant elements are also contained in soil organic matter. Plant and animal residues contain variable amounts of mineral elements such as phosphrous, magnesium, calcium, sulphur, and the micronutrients. As organic matter decomposes, these elements become available to growing plants. Organic matter decomposition tends to release nutrients. But nitrogen and sulphur can be temporarily tied up during the process. Micro-organisms decomposing the organic matter require nitrogen to build protein in their bodies. If the organic matter being decomposed has a high carbon/nitrogen ratio (C/N) – meaning low nitrogen – these organisms will use available soil and fertilizer nitrogen. So, when residues of cotton stalks and paddy straw are incorporated into the soil, additional nitrogen should be applied if a crop is to be planted soon after. If this is not done, crops may suffer temporary nitrogen deficiency. Eventually nitrogen immobilized in the bodies of soil organisms becomes available as the organisms die and decay.

Some soils contains very little organic matter. In some areas, most soils are inherently low in organic matter because warm temperatures and high rainfall speed up decomposition. In cooler areas, where decomposition takes place more slowly, native organic matter levels can be quite high. But some of these soils are losing their organic matter under intensive cropping practices. With adequate fertilization and good management practices, more crop residues are produced. In high yielding corn fields as much as 8 tons of residues are left after the grain is harvested. They help maintain or increase organic matter levels in soils. They benefit physical, chemical and microbial soil properties. They should be added regularly to sustain crop production. The important point then is to keep sufficient amounts of residues passing through the soil.

Other factors affecting soil productivity - soil depth.

Soil depths may be defined as that depth of soil material favourable to crop production. Plants need plenty of depth for roots to grow and secure nutrients and water. Roots will extend 3 to 6 feet or more when soil permits. Some plant roots may reach 30 feet deep.

Rooting depth can be limited by physical and chemical barriers as well as by high water tables. Hardpans, hale beds, gravelly layers, and toxic levels of materials are extremely hard to correct. But a high water table can usually be corrected with improved drainage.

The table below rates general soil productivity by soil depth.

Soil depth usable by crop roots (feet)	Relative productivity (percent)
1	35
2	60
3	75
4	85
5	95
6	100

Surface slope

Land topography largely determines the amount of runoff and erosion. It also dictates irrigation methods, drainage and other management practices needed to conserve soil and water. The steeper the land, the more management is needed, increasing labour and equipment costs. At certain slopes soil becomes unsatisfactory for row crop production. The ease with which surface soils erode, along with percent slope, is a determining factor in a soil's potential productivity. The next table, shows productivity by soil slope and erodability:

Soil slope (percent)	Relative productivity (percent)	
	Soil not easily eroded	Soil easily eroded
0 - 1	100	95
1 - 3	90	75
3 - 5	80	50
5 - 8	60	30

Soil organisms

Many groups of organisms live in the soil. They range in size from microscopic (bacteria, nematodes and fungi) to groups readily visible to the naked eye (earthworms and insect larvae). Some of the microscopic organisms cause many favourable soil reactions, such as decay of plant and animal residues. Other reactions are injurious such as the development of organisms that cause plant and animal deseases.

Most soil organisms depend on organic matter for food and energy, so are usually found in the upper foot of soil. Factors affecting the abundance of soil organisms include; moisture, temperature, aeration, nutrient supply, soil pH and the crop being grown.

Nutrient balance

Nutrient balance is a vital concept in soil fertility and crop production. Nitrogen (N) may be the first limiting nutrient in non-legumes. But without adeqauate amounts of the other nutrients, nitrogen can't do its best. As nitrogen fertilizers increase yields, the crop demands more of the other nutrients. On the other hand ammonium (NH_4) and potassium (K) affect the uptake of magnesium. Thus, heavy dressings of ammonium sulphate or potassium chloride can aggravate Mg deficiency. Although there is antagonism between K and Mg but it seems to be confined to the deficiency range of nutrient availability. Under such conditions, increasing the supply of one nutrient aggravates the deficiency of the other. Usually high contents of Mg can be found in plants deficient in K (plants try to keep the sum of cations K, Ca, Mg, Na fairly constant). Application of potash fertilizers to correct K deficiency leads to a gradual decrease of magnesium content in the plant. Provided that the soil is well supplied with available Mg, leaf magnesium will not fall off to dangerously low values but remains above the critical level even at the high rates needed to exploit the genetic yield potential of the plant. When both, K and Mg, are deficient, it is advisable to improve the magnesium status of the soil by adequate Mg fertilizer dressings before applying heavy doses of K.

Many factors control soil productivity, fertilizer use is only one. Failure to employ sound production practices reduces the potential benefits of fertilizer and limits productivity.