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-- SOIL FORMATION. --

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REFERENCES.

- "Rocks, Rock-weathering and Soils" - - - - - Merrill.
"The Soil" - - - - - King.
"Soils and Fertilizers" - - - - - Snyder.

OUTLINE.

1. Phase of subject to be treated.
2. Soil in general.
3. Primary source and formation of soils in general.
4. Rock-forming minerals.
5. Organic matter.
6. Elements of the Soil.
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8. Essential elements which are abundant.
 - (a) Iron.
 - (b) Magnesium.
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9. Essential elements which may be deficient.
 - (a) Calcium.
 - (b) Potassium.
 - (c) Phosphorus.
 - (d) Nitrogen.

Owing to the magnitude of the subject, it would be practically impossible to treat it as a whole, therefore it will be the aim to confine our attention to the source of the elements and compounds of the soil most necessary to plant growth, with special attention to those most likely to be deficient. It is also the intention to treat the subject, as nearly as possible, from a chemical point of view, dealing with only such of the physical phenomena as are, owing to the intermingling of the two, impossible to be easily separated.

Soil in General.

Soil is defined as disintegrated and pulverized rock, mixed with animal and vegetable matter, the proportions of each being variable, ranging from a trace to quite a large percentage of either constituent. The rock particles are of different kinds and sizes, and are in different stages of disintegration. The kind of rock disintegrated influences the character of the soil formed both chemically and physically; the former from the minerals it contains, the latter from the size of particles it yields, and other physical phenomena. Consequently we have on the one hand "sandstone", "limestone", "alkali" and soils of like nature, on the other, based upon the fineness of the particles, "sand", "silt", "loam" and "clay" soils, and various modifications of each.

Soils are also divided as to relative position. The upper portion, in humid regions from six to twelve inches, is known as "soil", while that below is "subsoil".

Soil and subsoil may be widely different in character, both chemically and physically, or they may be identical. In humid regions the subsoil is often found unproductive and of a different color from the soil. In arid regions these differences disappear.

The difference in subsoils, as well as in soils, of humid and arid regions is probably due to the different arrangement of the minute particles of the deeper soils. It is a well known fact that, while fine clays remain suspended in water, upon the addition of lime they are precipitated, or become flocculated. The soil of arid regions usually contain salts of lime in more abundance than those of humid regions. Thus in the presence of these salts the clay particles, becoming flocculated, would not be aggregated to such an extent in the deeper soils, as if these salts were not present.

Primary Source and Formation of Soils.

It is generally accepted that the earth was at one time in its formation a solid mass of rock surrounded by water and air, containing various vapors and gases. This rock mass, acted upon by the water, air, gases, vapors and influence of temperature, began to disintegrate. It is not the intention to discuss here the action of weathering, glaciers, rivers, winds, micro-organisms, vegetation, animal life and the various other agents which by their action through countless ages have brought about such remarkable changes and made the soil what we today find it.

Rock-forming Minerals.

In as much as soil is derived from rock, it follows that the chemical constituents of soils were derived wholly or in part from these rocks, therefore it will be necessary to understand the chemical nature of rock and the rock-forming minerals, as a basis on which to work.

Rock is composed either of a single mineral or a combination of several minerals, the minerals entering into the combination varying in relative proportions. This same fact holds true in the

composition of minerals, as they may be composed of one chemical compound or an assorted mixture of chemical compounds having no constancy of relative proportions, and one compound may be entirely replaced by another.

In as much as rock is composed of a mineral or a mixture of minerals it will suffice, in this argument, to know the chemical nature of some of the most important rock-forming minerals. These minerals are either original, i.e., those formed upon its first consolidation, or secondary, those which result from changes in rock subsequent to its first consolidation due in great part to chemical action of percolating water. And the original source of elements used as plant food must have been the original minerals, vapors and gases. While many changes have taken place, producing new minerals from the old, new rocks from the old, by means of the water vapor and gases, it is only through such a succession of changes that plant food is available. To study these changes would require more space and time than this discussion affords. Among the most common rock-forming minerals used in the production of soil are quartz, feldspar, mica and hornblende. A study of their chemical nature will show how, by their disintegration, certain plant foods are found in the soil.

Quartz.-- One of the most common minerals in rock formation. Pure quartz is silicic anhydride, SiO_2 , is practically insoluble, very hard, and found generally distributed. White sand is nearly pure SiO_2 .

Feldspars.-- These are silicates of aluminum and potassium or sodium in which the sodium may be replaced to a greater or less extent by calcium. Sodium feldspar is known as Albite and is represented by the formula $\text{AlNaSi}_3\text{O}_8$. Potassium feldspar is known as

Orthoclase, AlKSi_3O_8 , and contains about fifteen percent of potash.

The feldspars are very common, are insoluble in acid, and when disintegrated give rise to kaolin or clay, $\text{Al}_4(\text{SiO}_4)_3, \text{H}_2\text{O}$, the potash being removed and water of hydration taken up. Kaolin when pure is without direct value as a plant food, is insoluble and is pure white in color, although when formed in nature it is usually colored red or yellow from the presence of iron compounds or other impurities.

Mica.- A very common rock of complex nature. It is a polysilicate containing variable amounts of silicon, aluminum, iron, calcium, potassium, manganese and magnesium.

Horneblende.- An insoluble silicate of magnesium, calcium, iron and manganese, and may also contain phosphates of iron.

Augite.- A double silicate of magnesium, manganese, calcium and iron.

Apatite.- Composed of calcium phosphate, $\text{Ca}_3(\text{PO}_4)_2$, with traces of chlorine and fluorine.

Dolomite.- A double carbonate of calcium and magnesium.

Gypsum.- Calcium sulfate with water of hydration, $\text{CaSO}_4 + 2\text{H}_2\text{O}$.

While most of the rocks found in nature are insoluble in water and dilute acids a simple experiment by Pelouze, a French chemist, will throw some light on the subject of how these insoluble rocks are disintegrated. He boiled water continuously five days in a carefully weighed and dried flask and found, upon weighing it again, that it had lost little or no weight. Then he broke off part of the same flask, pulverized it and placed it in the water and boiled the water again for the same length of time. Upon drying and weighing carefully both the flask and the pulverized residue, he found

that fully one-third of the total weight of the flask had gone into solution in the water. This shows us that the rock in a pulverized state, as it becomes by various physical phenomena, is more easily soluble.

In addition to the rocks studied is a class of secondary minerals known as zeolites. These are polysilicates of aluminum, calcium and sodium or potassium and all contain water of hydration. Zeolites are soluble in dilute acids and are very useful in storing and yielding to plants food supplies. Experiments by Way and Voechler show that soils having been deprived of zeolites lose their powers of fixation. Fixation is the term applied to the chemical phenomena that soluble salts in the presence of other bases have a tendency to interchange to form insoluble salts. The importance of this power of fixation may be appreciated when we consider the amount of soluble plant food that might be lost by leaching, drainage, etc., were it not rendered insoluble, but easily available to plants through this natural tendency.

Organic Matter.

The definition described soil as disintegrated rock particles mixed with animal and vegetable matter. The source of the disintegrated rock particles being shown, there remains the organic matter.

Undoubtedly the primary source of all organic matter is rock, air and water, yet organic life contributes really to the store of plant food in as much as it modifies and recombines these original elements and compounds into new and different compounds, often changing those totally unavailable into directly useful foods.

Organic matter, both animal and vegetable, in the soil is called humus. Humus may be in any state of decomposition, and var-

ies widely in composition owing to the chemical nature of the original substance. If from animal sources it may be rich in nitrogen, if from wood, rich in cellulose, or the elements may be well balanced.

Humus in the soil is acted upon by micro-organisms, ferments, which change the composition and give rise to organic products of an acid nature. These organic acids unite with bases in the soil, forming neutral salts called humates. It has been proven that phosphoric acid and other mineral elements derived from humus are used in plant structures.

Elements of the Soil.

The elements of the soil having been derived from the foregoing sources are divided into two great groups, the acid-forming and the base-forming elements, as follows:

<u>Acid-forming.</u>		<u>Base-forming.</u>	
Oxygen	Chlorine	Aluminum	Iron
Silicon	Phosphorus	Calcium	Manganese
Carbon	Nitrogen	Magnesium	
Hydrogen	Fluorine	Potassium	
Sulfur	Boron	Sodium	

While these are not all of the elements found in soil, they are the most abundant and of the most importance to plant growth. These in different combinations and in various amounts are in different soils causing the differences in their chemical natures.

These elements mentioned may be divided in another way into several classes, and it is this grouping with which it is the intention to deal, viz.,

(1) Elements which are essential and most likely to be deficient. This class includes nitrogen, phosphorus, potassium and perhaps calcium.

(2) Elements which are essential but are in sufficient quantities. It includes iron, magnesium and sulfur.

(3) The remaining elements form the third class. Of these silicon, one of the most abundant elements, forming from one-fourth to one-third of the earth's crust, was once supposed to be of vital importance to plants, particularly the cereals. It is found abundantly in the stem and leaves and was supposed to give stiffness to the plant. However, analysis showed the silicon to be more abundant in the upper leaves of the plant than in the lower leaves where it would naturally be required if its office were to give strength. Thus it would seem that such is not its office. Later authorities claim that silicon, although not essential to the plant, is required by the crop, its office being to retard the woody growth, thus stimulating the work of reproduction and the formation of larger, better seeds. Oxygen is probably the most abundant element of the soil, constituting about one-half of the earth's crust, and being also present in the free state. Although oxygen in and of the soil is one of the most important factors, assisting in plant growth by its action on other materials of the soil, yet the oxygen of the soil does not enter into the formation of plant tissues, but, with hydrogen, is obtained from water. Carbon, also of this group, is obtained from the carbon dioxide of the air.

Thus while some, if not all, of these elements may assist materially in plant growth they are not so vitally important as the preceding groups, therefore we will confine our attention to groups one and two.

Essential Elements Which Are Abundant.

This group consists of iron, magnesium and sulfur.

Iron, Fe., is found in all soils, ranging in extent from one to four percent. It occurs in nature in the form of oxides, hydroxides, carbonates, sulfids and silicates, as magnetite, Fe_3O_4 ; haematite, Fe_2O_3 ; brown iron ore, $\text{Fe}_2\text{O}_3(\text{OH})_6$; siderite, FeCO_3 , and pyrite, FeS_2 . These minerals may exist alone or go to make up the constituents of rock. The oxides and silicates are components of granite, hornblende, mica and augite and are released by the disintegration of these rocks. Oxides of iron are generally yellow or red in color, and the yellow and color of rocks is due in most cases to the presence of these oxides, kaolin or clay usually exhibiting it clearly.

Iron is essential to plant and animal growth, being used in the formation of chlorophyll and proteid bodies, therefore in the decomposition of plant and animal tissues it is given back to the soil and is in this matter more widely distributed. The amount used by plants is so small and the percentage in soils is so large that all demands may be easily supplied.

Magnesium, Mg., occurs in nature very widely distributed as carnallite, $\text{MgCl}_2 \cdot \text{KCl} + 6 \text{H}_2\text{O}$; magnesite, MgCO_3 ; dolomite, a double carbonate of magnesium and calcium; soapstone; serpentine; meerschau, a silicate of magnesium, and kieserite. These minerals may occur alone or in combination with others to form rock, asbestos and hornblende both containing silicates of magnesium, while many spring waters contain the sulfate in solution. Magnesium is a very important plant food and is found collected in the seeds of plants, as high as twelve percent being found in the ash of wheat. However,

it is so well distributed and in such quantities as to be adequate to the demands made upon it.

Sulfur, S., is found in the free state in nature in the neighborhood of volcanoes, but for agricultural purposes it is derived from combinations with other elements. Sulfur occurs in nature as iron pyrites, FeS ; copper pyrites, FeCuS_2 ; galenite, PbS ; gypsum, $\text{CaSO}_4 + 2 \text{H}_2\text{O}$; kieserite, $\text{MgSO}_4 + \text{H}_2\text{O}$, and heavy spar, BaSO_4 . Sulfur is used by plants in the formation of proteid bodies, which by their decomposition help to distribute sulfur compounds. Rain water is also a great agent in the distribution of sulfur. Dr. Angus Smith states in his work "Air and Rain" that there is contained from 2.06 to 70.19 parts of sulfuric acid in one million parts of rain water, the percentage being greater near large cities. This sulfuric acid is probably derived from the combustion of organic substances. Some of the salts of sulfur are easily soluble in water, and from this fact and its abundance the distribution is quite general.

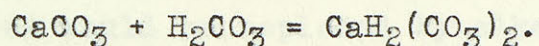
Essential Elements Which May be Deficient.

Nitrogen, phosphorus, potassium and calcium comprise this group and of the four calcium is least likely to be deficient.

Calcium, C., occurs quite extensively in nature and its shortage is due largely to its unequal distribution. The salts of calcium are often quite soluble as compared with other salts found in nature, and much calcium has been lost from soils by drainage. It may occur in soils in amounts from .01 to 20.0 percent. It is found chiefly as the carbonate, -limestone, marble and chalk; the sulfate, -gypsum; the phosphate, -apatite and phosphorite, and as the fluoride, or fluorspar. The most common salt is calcium carbonate,

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or limestone, of which whole mountain ranges are often comprised. Limestone mixed with a considerable amount of clay is called marl. Much of the calcium carbonate in nature comes from the remains of microscopic animals, chalk being formed from the shells of such. The salts of calcium are more or less soluble, and natural waters are often highly impregnated with them. Limestone slightly soluble in water is easily soluble in water charged with carbon dioxide, probably through the formation of an acid carbonate, a soluble salt:



While calcium salts are found in nature extensively, the original source of calcium must have been the potash-lime-bearing silicates, as feldspars, micas, amphiboles and pyroxenes. By decomposition, leaching, precipitation and fixation it was converted into the secondary forms we now find. Many of these are easily soluble in dilute acids and are therefore available to plants. Calcium is found more in the stem and leaves of plants than in the seed, being used in the building up of new tissues. While it is extensively used in plant building, probably its most important use is of a secondary nature. In the soil it improves capillarity, precipitates clay when suspended in water, aids in nitrification, liberates potassium by fixation, and unites with the humic acid of the soil, forming humates of lime, neutral salts.

Potassium, K. The original source of potassium in the soil is probably the same as calcium, - the potash-lime-bearing silicates, feldspars, micas, amphiboles and pyroxenes, thus a large percentage of the primary rocks contain this factor. Potassium is also found in nature in combination with nitric acid as salt petre, and in the zeolitic silicates. The process of these formations has been

explained by Bischof. He states: "When meteoric waters containing carbonic acid filter through rocks containing alkaline silicates, the first action is the formation of alkaline carbonates which are dissolved. If these waters then come in contact with calcareous silicates another change takes place, and the calcareous silicates are replaced by alkaline silicates, and calcium is removed as a carbonate." In case salts of nitric acid were present, as would naturally be the case in the proximity of decomposing organic matter, the alkaline carbonates would be replaced by alkaline nitrates. The solution containing these alkaline nitrates upon evaporation gives rise to salt petre. In case the alkaline carbonate from the feldspar come in contact with salts of sulfuric acid, we would have the formation of alkaline sulfates, etc., the solution, on evaporating, leaving such salts as kainit, K_2SO_4 , $MgSO_4$, $MgCl + H_2O$, one of the Stassfurt salts found in enormous deposits. Potassium salts are also distributed by the oxidation of vegetable matter. When wood is burned the ashes may contain as high as ten percent of potassium carbonate.

It has been stated that the potash of the soil exists in zeolites and that these secondary products supply that element in great part for plant use. The theory of their formation would lead to this belief, i. e., certain weak acids in the soil dissolve from the rock particles such compounds as are easily soluble, the alkalies especially; these salts are precipitated and form zeolites. But as a fact only five out of the twenty-three known species of zeolites contain potash as an essential element. The probability is that the most important source of soil potash is from decomposition products of the feldspars, such as nepheline, scapolite and allied minerals.

Potash is found in plants in the leaves and stems and is one of the most essential elements as plant food. Owing to its solubility and the great demands made upon it by vegetation it may be lacking in available forms in agricultural lands.

Phosphorus, P. The primary source of phosphorus is probably the original mineral apatite, $\text{Ca}_3(\text{PO}_4)_2$. Apatite is a common accessory in crystalline rock of all ages, both eruptive and metamorphic. The disintegration and leaching of phosphatic material from older rocks and its redeposition in clefts, etc., give rise to the secondary mineral, phosphorite, of the same composition. Phosphates are generally distributed in the soil, though not in large quantities. It occurs in the oldest known rocks, and from the disintegration of these and the building of new it has always been present.

As a secondary source it is present largely in the seeds of plants and, from this fact, in the excrement and bones of animals, bone containing about 85 percent of calcium phosphate. Remains of marine animals and sea water with phosphates in solution account for the large deposits of phosphates found. The salt found in nature is tri-calcium phosphate, $\text{Ca}_3(\text{PO}_4)_2$. This may be rendered soluble by the action of sulfuric acid, forming acid calcium phosphate, a soluble and available salt. The reaction is represented thus:



The dearth of phosphates in the soil is due to the draft upon it by the removal of crops. Often it is merely a dearth of available phosphates and by proper cultivation and fertilizers the unavailable supply can be utilized.

Nitrogen, N. The most important of all the elements, and the one most likely to be deficient is nitrogen. A glance at its

function in plant structure will elucidate its importance. Plants obtain their food from the air, water, and soil, the elements being united into starch, sugar, proteids, etc., through the action of chloroplasts. These chloroplasts are proteid bodies composed of carbon, hydrogen, oxygen, nitrogen and possibly sulfur, differing in composition from starch, cellulose, etc., only in the elements nitrogen and sulfur. Without these chloroplasts tissue-building could not proceed, starch, albuminoids, amides, etc., could not be formed. Thus it has been said that nitrogen is the life-giving element of both plants and animals.

Nitrogen in the soil has its primary source, in all probability, in the free nitrogen of the air. While in the beginning nitric acid may have existed as a vapor, and nitrates may have been precipitated and existed in the first rock formation, owing to their solubility they could not now exist in exposed rocks or soils. Thus the nitrogen of the soil is not derived from rocks or minerals. Small quantities of nitric acid and ammonia have been found in rain water, a larger percentage often in the vicinity of volcanoes, accompanied by sulfuric and hydrochloric acids. These may come from the decomposition of certain compounds by heat in the interior, or the nitric acid may be wholly formed from the oxidation of nitrogen by flashes of lightning. The fact is well established that, either the nitrogen in the air is oxidized by electricity, forming nitric acid, or the ammonia of the air is oxidized by the action of ozone to form it. However, the amounts of nitric acid and ammonia in rainfall are too small to have any direct bearing upon the case.

The source of the nitrogen important as plant food is the free nitrogen of the air through the agency of micro-organisms found in the soil. While free nitrogen is unavailable to plants

certain plants of the family Leguminosae have upon their roots small excrescences or tubercles, caused by the action of these micro-organisms having located themselves thereon, and these tubercles are found swarming with the bacteria.

These bacteria have the power of fixing free nitrogen and making it available to the plant. In time the plant decays and the nitrogen is given to the soil in the form of organic compounds, proteid bodies. In this organic form it is yet unavailable to plants and micro-organisms again come to our aid. The organic nitrogenous bodies in the soil are acted upon by nitrifying bacteria which break them down, converting them by a series of changes into nitric and nitrous acids. The nitrous acid, which is immediately oxidized to nitric acid, acts upon certain bases of the earth, forming nitrates which may be used by the plant or leached away to be precipitated and form deposits of nitrates. This process of nitification of organic matter is probably the source of the vast deposits of nitrates found in Chili and other South American states. Leguminous plants first fix the free nitrogen of the soil; it is given back to the soil as organic matter; it is nitrified to form nitrates, which are used by plants; these plants are eaten by animals, and the nitrogen taken into their tissues or given off in their excrement, where it is again nitrified and alkaline nitrates are formed, and these are leached away and deposited by precipitation. The deposits of Chili are accounted for by the excrement of birds and bats, with the bodies of the dead animals being nitrified.

While the supply of nitrates may be great there are many ways by which it is lost. This salt is easily soluble, and when not used by plants is leached away. Then, whereas nitrogen is fixed in the soil by micro-organisms, it may be released by them. Denitri-

fyng bacteria, acting upon nitrates and liberating free nitrogen gas, helps in no small way to deplete the stone. One of the greatest demands upon nitrates is vegetation being removed from the soil upon which it grew, a very common practice in agricultural communities, with no equivalent supply of organic nitrogen being given back.

These three sources of loss often leave agricultural lands without an adequate supply of this life-giving element. So great has been the impoverishment of agricultural lands in this respect that many are worn out. The alarmist views with terror the fact that, owing to the increasing rate of population, the demands upon plant food will be proportionately increased, while the store of natural nitrogenous fertilizers is constantly being diminished.

However, considering the investigations along this line, the best efforts of scientific men, the recent discoveries in the preparation of sodium nitrate from the nitrogen of the air by electricity, the investigations concerning free nitrogen-fixing organisms, and a general knowledge, by the agriculturist, of crop rotation and the conservation of waste products as fertilizers, will bring about a solution of the problem, and in turn establish a system whereby he may secure the greatest gains in crop production with the least loss to his soil.