

HANDBOOK OF FOOD AND AGRICULTURE

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PREFACE

Food and agriculture constitute the largest American industry. The past decade has shown an amazing increase in research in both fields. The impact of this research on the practical, present-day development of agriculture and food has been tremendous. New mechanical equipment, new varieties of fruits and vegetables, improvements in the storage and handling of agricultural raw materials, utilization of by-products, greater attention to nutritional values of foods and feeds, improvements in storage and transportation facilities—all have contributed to the spectacular growth and present important position of these industries.

It is recognized that the field of agriculture and food is so large that it is not possible within the confines of a single volume to present, even in brief form, adequate information on all phases of all problems in both agriculture and food. Reluctantly, we have had to exclude discussions of such important fields as horticulture, agricultural engineering, genetics, plant pathology, animal breeding, climatology, and many others.

In the chapters which are included in this volume every effort has been made to bring the information on their respective subjects up to date, with additional references in each chapter to supplement, where desired, the reader's available information.

No effort has been made to present the various chapters in a uniform style. Each author has employed his own method in developing the subject matter of his chapter. Editorial changes have been kept to a minimum.

We have incorporated authoritative, hard-to-locate material from widely different sources in the appendix. We believe and hope that this supplemental material will add to the usefulness of the book and to the reader's interest.

The editor and publisher are deeply indebted to the distinguished list of collaborators whose cooperation and self-sacrifice have made possible the presentation of this volume. The editor also expresses his appreciation to the many individuals who kindly gave permission to reproduce published figures, charts, data, and photographs. These have been acknowledged in the appropriate places in the text. The development of this volume has been made possible by the vision, encouragement and advice of G. G.

Hawley, Executive Editor, Reinhold Book Division. To him the editor expresses his deep gratitude and appreciation.

We fully realize that much more material of an even wider range could well have been incorporated in this publication. However, limitations of space and cost had to be considered. It is our hope that the "Handbook of Food and Agriculture" will earn a useful place on the desk of every worker who has to do with foods. The man with easy access to the excellent libraries of large laboratories should find it a convenient *vade mécum*. We have particularly designed this book to meet the needs of the small laboratory or factory with a limited number of reference books. If this volume proves to be a ready source of information otherwise difficult to obtain, the collaborators, the editor, and the Reinhold Publishing Corporation will feel fully rewarded for their efforts.

Pittsburgh, Pa.
March, 1955

FRED C. BLANCK

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1. SOILS

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The purpose of this chapter is to describe the important properties of soils that influence the growth of land plants. Little or no attention will be given to those soil properties and kinds of soil behavior which are of concern chiefly in the use of soil as an engineering material, such as in the construction of roads, as building foundations, and the like. Comprehensive treatises exist in this general field of soil mechanics.

Soil consists of the upper layers of the unconsolidated rock material at the surface of the earth, and serves as the natural medium for the growth of land plants. Soil, at any place, is a natural body which represents the integrated effect of the environmental factors, five of which are recognized, namely, climate, vegetation, parent material, relief, and time. There are many possible combinations of these five environmental factors and, hence, a wide range in properties of resultant soils.

A given soil is a three-dimensional section of the landscape, the properties of which are relatively uniform in either horizontal direction within its area of occurrence. However, the vertical section of the soil, or the soil profile, usually exhibits more or less distinct horizons or zones, due to variations in the influence of environmental factors with depth. Three major horizons are usually recognized in cultivated soils, and other horizons are often present as well. The A horizon, which may consist of one or more subhorizons, represents a layer with an accumulation of organic matter; or it may be a layer that is lighter in color than the underlying horizon and which has lost clay minerals and oxides of iron and aluminum, in which case it is high in such resistant minerals as quartz; or it may be a layer which has both accumulated organic matter and lost clay minerals. The A horizon is most directly exposed to the influence of climate, plants, and animals, including man, and represents the horizon of maximum biologic activity. In soils which have not been cultivated, there may be a layer of more or less decom-

posed organic matter resting on top of the A horizon, which is referred to as A_0 .

The B horizon is characterized by an accumulation of clay and/or oxides of iron and aluminum, with small amounts of organic matter; or it may be a horizon which shows a more or less blocky structure and stronger color in contrast to the horizons above and below; or it may be a horizon that exhibits both enrichment of clay and sesquioxides and a blocky structure with contrasting color. Part of the clay, organic matter and sesquioxides may be derived from the A horizon by downward movement and accumulation.

The C horizon represents a layer below the B horizon which is unconsolidated and relatively little affected by living organisms, and presumably represents material similar in character to that from which the overlying A and B horizons have been developed.

In general, the abundance of roots and microorganisms decreases with depth in the soil profile, and on this account studies of soil properties have been most detailed in the upper horizon. Accurate information on properties of all horizons, however, is important for studies relating to the broad classification of soils and to the grouping of soils for most effective use and management in the production of crops.

Properties of Soil Horizons

Physical Properties. Physical soil properties such as texture, structure and pore space are of major importance in determining water-holding capacity, permeability to roots, air, and water of each horizon, and therefore the suitability of any given soil for producing crops.

Texture refers to the size of soil particles. Texture is essentially constant over a period of years in any given soil horizon. Soil particles are classified on the basis of size into groups called "soil separates." Finest particles are called clay, with the groups of succeedinglly coarser particles being termed silt, sand, and gravel, respectively (Table 1-1). The cohesion and plasticity of a moist soil sample is closely related to its textural composition, and form the basis for recognizing the different textural classes in the field. Most soils consist of a mixture of particles of all size ranges. If the properties of each size group of particles, sand, silt, and clay, are expressed to about the same degree in a soil sample, its texture is designated "loam." The textural names given to soil samples of different mechanical composition are shown in Figure 1-1.

Structure refers to the arrangement of the individual soil particles into aggregates which may differ as to size, shape, and distinctness of development. Very sandy soils often have single grain structure, that is, no aggregates can be recognized. Soil samples high in clay and/or organic matter may show a variety of structural forms. Structure is very important in

TABLE 1-1. SIZE LIMITS OF SOIL SEPARATES FROM TWO SCHEMES OF ANALYSIS*

U. S. Department of Agriculture scheme		International scheme	
Name of separate	Diameter range	Fraction	Diameter range
	mm		mm
Very coarse sand†	2.0-1.0	I	2.0-0.2
Coarse sand	1.0-0.5		
Medium sand	0.5-0.25		
Fine sand	.25-.10	II	0.20-0.02
Very fine sand	.10-.05		
Silt	.05-.002	III	.02-.002>
Clay	Below .002	IV	Below .002

* Soil Survey Staff¹⁸, p. 207.

† Prior to 1947 this separate was called fine gravel. Now fine gravel is used for coarse fragments from 2 mm to ½ in. in diameter.

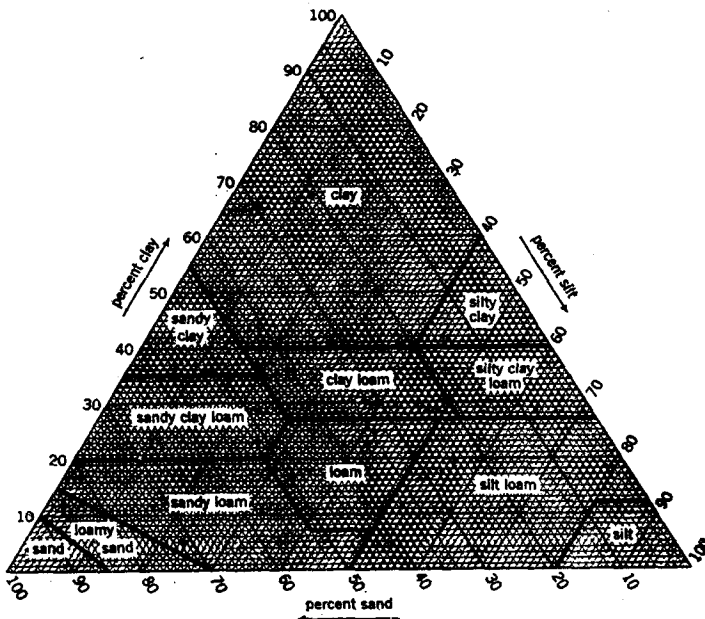


FIGURE 1-1. Guide for textural classification of soils. (Courtesy Soil Conservation Service)

determining the porosity, and hence the permeability of soils, particularly of those high in clay. The terminology for aggregates of different size and shape is given in Table 1-2.

Structural forms in the surface layer of granular or crumb-like nature

TABLE 1-2. TYPES AND CLASSES OF SOIL STRUCTURE*

Class	Plate-like with one dimension (the vertical) limited and greatly less than the other two; arranged around a horizontal plane; faces mostly horizontal	Prism-like with two dimensions (the horizontal) limited and considerably less than the vertical; arranged around a vertical line; vertical faces well defined; vertices angular		Block-like; polyhedron-like, or spheroidal, with three dimensions of the same order of magnitude, arranged around a point		
		Without rounded caps	With rounded caps	Faces flattened; most vertices sharply angular	Mixed rounded and flattened faces with many rounded vertices	Block-like: blocks or polyhedrons having plane or curved surfaces which have slight or no accommodation to the faces of surrounding peds
	Platy	Prismatic	Columnar	(Angular) blocky†	Subangular blocky†	Relatively nonporous peds
Very fine or very thin	Very thin platy; <1 mm	Very fine prismatic; <10 mm	Very fine columnar; <10 mm	Very fine angular blocky; <5 mm	Very fine subangular blocky; <5 mm	Very fine crumb; <1 mm
Fine or thin	Thin platy; 1 to 2 mm	Fine prismatic; 10 to 20 mm	Fine columnar; 10 to 20 mm	Fine angular blocky; 5 to 10 mm	Fine granular; 1 to 2 mm	Fine crumb; 1 to 2 mm
Medium	Medium platy; 2 to 5 mm	Medium prismatic; 20 to 50 mm	Medium columnar; 20 to 50 mm	Medium angular blocky; 10 to 20 mm	Medium subangular blocky; 10 to 20 mm	Med. crumb; 2 to 5 mm
Coarse or thick	Thick platy; 5 to 10 mm	Coarse prismatic; 50 to 100 mm	Coarse columnar; 50 to 100 mm	Coarse angular blocky; 20 to 50 mm	Coarse subangular blocky; 20 to 50 mm	Coarse granular; 5 to 10 mm
Very coarse or very thick	Very thick platy; >10 mm	Very coarse prismatic; >100 mm	Very coarse columnar; >100 mm	Very coarse angular blocky; >50 mm	Very coarse subangular blocky; >50 mm	Very coarse granular; >10 mm

* Soil Survey Staff¹², p. 218

† (a) Sometimes called nut. (b) The word "angular" in the name can ordinarily be omitted.

‡ Sometimes called nuciform, nut, or subangular nut. Since the size connotation of these terms is a source of great confusion to many, they are not recommended.

are usually associated with favorable permeability, even in soils of fine texture such as clays. Subsoil structural forms of a rounded and irregular nature usually indicate higher permeability than forms with sharp angular corners.

Pore space of a soil is that volume not occupied by solids. Texture and structure largely determine the total amount of pore space as well as the size and continuity of pore openings. Friable surface soils average about 50 per cent total pore space, whereas subsoil horizons usually run somewhat below this figure in total pore space.

Pore space in soil is occupied by air and water in proportions that vary reciprocally. In average surface soils in optimum condition for plant growth, the volume composition approximates solids 50 per cent, gas 25 per cent and liquids 25 per cent. Excess moisture in soil displaces air which is essential for proper functioning of most plant roots. Thus, proper drainage of agricultural soils is extremely important for optimum crop production.

Density of soil-mineral particles averages approximately 2.65 g/cc. which is close to that for one of the most abundant soil minerals, quartz. Soil horizons high in organic matter will have an average particle density below 2.65 because of the low density of organic matter itself. Bulk density, or volume weight of a soil horizon is influenced both by the specific gravity of the soil particles and the total pore space. A representative value for bulk density of surface samples is 1.3 g/cc. Subsoil samples average somewhat higher, in extreme cases going as high as 2 g/cc.

Soil temperature is important in relation to root activity, microbiologic activity, and rate of chemical transformations. However, measures to control soil temperature are usually incidental to the accomplishment of other purposes. Drainage to remove excess water will permit the soil to warm up more rapidly in the spring, since the specific heat of soil particles averages about 0.2 as compared to water. Surface covers (mulches) of crop residues such as straw or building paper used to reduce evaporation and control weeds in special situations, will keep the soil cooler in summer and warmer in winter. Dry soil is a poor heat conductor; wet soil conducts heat somewhat better but still at a slow rate, and presence of water increases the specific heat of the soil mass; therefore, subsurface and subsoil temperatures are lower in spring and summer and higher in fall and winter than surface soil and air temperatures. Furthermore, the magnitude of daily and seasonal temperature fluctuations decreases rapidly with depth, and subsoil temperatures at moderate depths are about constant.

Soil air usually is somewhat higher in carbon dioxide and lower in oxygen than the atmosphere; also, the humidity of soil air approaches 100 per cent most of the time except in the surface layer under extremely dry conditions. Removal of carbon dioxide and renewal of oxygen in soils is dependent

TABLE 1-3. CHEMICAL COMPOSITION OF REPRESENTATIVE SURFACE SOILS

	Clinton ¹ silt loam, Iowa	Cecil ¹ fine sandy loam, N. C.	Tama ¹ silt loam, Iowa	Mohave ¹ loam, Ariz.	Nipe ² clay, Cuba
SiO ₂	79.57	88.02	70.80	67.44	3.28
TiO ₂	0.63	0.22	0.69	0.60	0.80
Fe ₂ O ₃	2.34	.76	3.82	5.31	63.04
Al ₂ O ₃	8.86	4.47	11.48	14.40	18.46
MnO	0.20	0.01	0.13	0.10	0.42
CaO	.75	.04	.98	2.04	.12
MgO	.61	.07	.92	1.52	.33
K ₂ O	2.03	1.19	2.05	2.72	.06
Na ₂ O	1.48	0.35	0.93	1.73	.47
P ₂ O ₅	0.07	.02	.18	0.22	.03
SO ₂	.05	.65	.15	.10	—
Ignition loss	3.70	4.63	8.39	3.35	12.74
N	.10	0.07	0.24	0.03	0.02
Organic matter	—	—	—	—	1.02

¹ Data from Marbut¹².² Data from Bennett and Allison².

largely on diffusion, the rate of which is influenced by the size and continuity of those pore openings not filled by water.

Chemical Properties. Analyses of several representative surface soils from the United States and one from Cuba are given in Table 1-3. In addition to the constituents listed in Table 1-3, most soils contain small quantities of many other elements; in fact, spectographic studies show most elements to be present in at least trace quantities.

Silica is the major constituent of most soils in the temperate to cool regions, with aluminum oxide and iron oxide, respectively, being next in amount. Many soils of equatorial and tropical regions, such as the Nipe from Cuba, are relatively low in silicon dioxide and consist chiefly of sesquioxides. Soils of dry regions are usually higher in basic elements, such as calcium, magnesium, potassium, and sodium than soils of humid regions which are subject to greater leaching; furthermore, the larger soil particles in humid regions tend to consist of quartz or other very resistant materials; in dry regions differentiation in composition between coarse and fine particles is less pronounced.

Loss on ignition represents chiefly organic matter plus water of hydration and constitution. Approximate values for organic matter content can be obtained by multiplying the per cent nitrogen by 20. Organic matter includes all plant and animal residues in soils, as well as the various decomposition products therefrom. Organic matter content is higher in cool regions than in warm regions because the rate of decay is slower at low temperatures. Organic matter is higher in the subhumid grassland regions than

in the arid regions because of greater plant growth at higher moisture levels. Organic matter is often high in wet and swampy soils because excess water excludes air (O_2) necessary for rapid decay.

Most of the sulfur and nitrogen and part of the phosphorus in soils are found in the organic fraction. Subsoil layers usually are lower in organic matter, and hence in nitrogen and sulfur than surface layers. In humid portions of temperate regions, subsoil layers are lower in silica and higher in sesquioxides than the surface, whereas in dry regions subsoils usually contain accumulations of calcium and magnesium carbonates. Little variation in composition with depth is observed in such soils as the Nipe in Cuba which is very high in sesquioxides.

In soils of humid regions, practically all of the elements exist in such insoluble forms as quartz, aluminosilicates (feldspars, mica, clay minerals), sesquioxides, apatite and organic matter. In soils of arid regions, other materials of a more soluble nature occur in addition, such as calcium and magnesium carbonates, gypsum, and even small quantities of sodium carbonate, sodium chloride, and potassium sulfate in situations where drainage water accumulates and evaporates.

Total analysis of a soil sample indicates the total reserves of fertility present. However, most essential elements must be in soluble or even ionic form to enter plant roots, thus total analysis alone is not a suitable criterion of the amount of any element available to plants. The rate of transformation of insoluble to soluble forms, in relation to rates of plant removal and leaching, must be considered. Details relating to formation of compounds and ions available to plants are given in Chapter 2 on Soil Fertility.

Fifteen elements are recognized as essential for plant growth. The three used in greatest quantities, carbon, hydrogen and oxygen are obtained chiefly from water and air; the other twelve are obtained entirely, or in part, from the soil. The elements nitrogen, phosphorus, potassium, calcium, magnesium and sulfur are used in relatively large quantities by plants, whereas iron, copper, boron, manganese, zinc and molybdenum are needed only in very minute quantities, and often are referred to as "trace" elements. Other elements occurring in soluble or available forms in the soil, in particular silicon, aluminum and sodium, are usually found in plant tissue but have not been proved essential for plant growth.

The essential element most commonly deficient for optimum plant growth in agricultural soils is phosphorus. Deficiencies of nitrogen are equally widespread for nonlegume crops which depend entirely on the soil for nitrogen supplies. Soils of humid regions usually are deficient in available calcium, magnesium and potassium, though the total quantities present, in many instances, as shown by total analysis (Table 1-3) would seem to be adequate. In humid regions the soluble and available forms of these basic elements

are leached from the soil and deficiencies for plant growth thereby result. Commercial fertilizers used in humid regions are formulated to provide chiefly the elements nitrogen, phosphorus, and potassium. In arid regions fertilizers provide chiefly nitrogen and phosphorus. In humid regions calcium and magnesium are supplied chiefly in liming materials. Deficiencies of sulfur, iron, copper, boron, manganese, zinc and molybdenum are observed less frequently and, in general, cannot be predicted from total analyses of soil samples. (See Chapter 4 on Fertilizers and Chapter 2 on Soil Fertility).

Colloidal Properties. From the colloidal viewpoint all soils except those consisting entirely of sand and/or silt, may be considered as modified gels when at a moisture content suitable for plant growth. Soils differ from gels in possessing a third phase (gas) and in containing more or less noncolloidal material (sand and silt). The major groups of colloidal materials present in soils include the following:

- (1) "humus" (organic colloids)
- (2) mineral colloids
 - (a) alumino-silicates
 - (b) hydrous oxides
 - (c) miscellaneous

The major properties of each group that significantly affect soil behavior will be outlined briefly.

"Humus". This is a black, amorphous, nonplastic material which occurs chiefly as a coating on mineral soil particles. It is decomposed only slowly by microorganisms. Humus averages about 50 per cent carbon and 5 per cent nitrogen, with smaller quantities of phosphorus and sulfur. Humus consists of many compounds, few of which have been well-defined as to composition and structure. A lignin-like fraction is abundant in humus, and polyuronides have been identified as a constituent. Humus possesses a high cation exchange capacity at pH 7 (200–250 milliequivalents per 100 grams). The acidic groupings which account for this exchange capacity probably are carboxyl, phenolic hydroxyl, and perhaps several others.

From a colloidal viewpoint humus properties are analogous to those of soaps in many ways. Calcium salts are completely insoluble and flocculated; sodium salts are highly dispersed; humic acids are slightly dispersed. The lyotropic series of the major soil cations for flocculation is $\text{Ca} > \text{Mg} > \text{H} > \text{K} = \text{NH}_4 > \text{Na}$. Humic materials tend to act as protective colloids in soils, and where calcium and magnesium are the dominant exchangeable cations, humus will stabilize soil structure.

Alumino-silicates. These are dominantly plate-shaped microcrystalline particles which exhibit high plasticity in the gel condition, as do all gels consisting of rod or plate-shaped particles. The crystal structure is of two

major types, the so-called 1:1 structure characteristic of kaolinite, and the 2:1 structure characteristic of montmorillonite and illite. The 1:1 unit structure may be visualized as a sheet of Al ions within an octahedral arrangement of O and OH ions, held by shared O ions to a second sheet consisting of Si ions which are within a tetrahedral arrangement of O ions. The external surface of the alumina sheet consists entirely of OH ions, whereas the external surface of the silica sheet consists of O ions. Adjacent unit structures of the 1:1 type are held together strongly by hydrogen bonding between the layer of OH ions and the adjacent layer of O ions. Thus, crystals of the 1:1 structure type form relatively large colloidal particles that are very stable. Very few cation substitutions, such as Al for Si or Mg for Al, occur within the crystal lattice to give a net negative charge to the lattice that would be balanced by exchangeable (surface) cations. Cation exchange capacities at pH 7 are low being of the order of magnitude of 10 milliequivalents (ME) per 100 grams.

The 2:1 unit crystal structure consists of one alumina sheet "sandwiched" between two silica sheets, the three sheets being held together by shared O ions. Adjacent unit structures of the 2:1 type are held together less strongly than those of the 1:1 type since there is much less possibility for H-bonding. In certain 2:1 type crystals like montmorillonite, the forces of surface attraction between unit structures are so weak that the units separate enough in water to permit exchangeable cations to penetrate between adjacent unit structures. Ionic substitutions, such as Al for Si and Mg for Al, are very common within the 2:1 type crystal lattices. The excess negative charge resulting from such substitutions is balanced with cations that are exchangeable. Cation exchange capacity values at pH 7 for 2:1 structures are, in general, higher than 1:1 structures and in the case of montmorillonite, may reach values approaching 90 to 100 ME per 100 grams.

The lyotropic series for flocculation of all aluminosilicate colloids is $H > Ca > Mg > K = NH_4 > Na$. The reason that H is displaced from its expected position between Mg and K is that H ions dissolve or displace Al ions from the lattice, at corners and edges particularly. Trivalent Al ions then become exchangeable ions and the colloidal system is really an H (Al) rather than an H system. On this account, in the absence of humus, aluminosilicate colloids form less stable aggregates when the exchangeable ion is calcium than when it is dominantly hydrogen.

Hydrous Oxides. This group includes colloidal particles consisting of oxides and hydroxides of iron, aluminum, titanium and manganese, and perhaps other elements. Hydrous oxide colloids appear to be amorphous, exhibit low plasticity, and possess no cation exchange capacity at pH 7. They do show anion exchange with phosphate, arsenate, and to a lesser degree with sulfate, particularly below pH 7. Mutual flocculation effects

are observed with oppositely charged (negative) alumino-silicate and humus colloids. Drying also causes flocculation. Once flocculated, hydrous oxide colloids are difficult to disperse. Thus, if they are present in appreciable quantities they tend to produce stable soil aggregates and structure.

Miscellaneous Group. In general, this group seldom exerts significant influence on soil properties and behavior. It consists mostly of colloidal silica and partly weathered mineral fragments of colloidal dimensions.

Biological Properties. A great variety of living organisms exist in soils of the world. Plant roots usually represent the largest total mass of living material in ordinary soils. Large animals, such as earthworms, insects, rodents, and the like, are found in many if not most soils. In addition, microorganisms in a great profusity of kind and number are always present. These include small animals such as nematodes and protozoa, as well as small plants such as fungi, bacteria, and actinomycetes.

The entire population of soil organisms bears two major and very significant functional relationships to soils and soil properties. First, soil organisms including crop plants and their roots, synthesize organic compounds and constitute the source of organic matter in soils. Secondly, soil organisms bring about the decomposition of organic material that accumulates in the soil. Such decomposition is important in the prevention of undue residue accumulation as well as in making available for future plant generations the nutrients contained in the organic residues. Soils would soon become a tangled mass of dead plant remains were it not for the decomposition activities of soil organisms.

Higher plants, including crop plants, are influenced in a very significant way by three functional relations of the soil microorganisms. The first of these is that of symbiosis which is best illustrated by the nitrogen fixing bacteria in legume root nodules. The activity of bacteria in legume nodules accounts for a large portion of the nitrogen available for crop production. A second important relationship is that of pathogenesis; and the control of disease-organisms in the soil is an important aspect of soil management. Thirdly, microorganisms compete with crops for available nutrients in the soil. When fresh residues of highly carbonaceous nature, such as straw, are turned under, the competition for available nitrogen between crops and microorganisms may be so extreme that the crop will be seriously retarded in growth. Details about the behavior of microorganisms in the soil are given in Chapter 3 on Soil Microbiology.

Exchangeable Cations in Soils. The kind and proportion of exchangeable cations held by soil colloids (humus and alumino-silicates) have a controlling influence on (1) soil fertility, (2) soil reaction (pH), and (3) soil structure.

The usual order of abundance of exchangeable cations in soils of dry