THE ABC
of
SOILS

By

Jacob S. Joffe

Professor of Pedology, College of Agriculture,
Rutgers University
and
Research Specialist in Soils, New Jersey
Agricultural Experiment Station, Rutgers University

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PREFACE

In 1931-1932, the late Dr. Jacob G. Lipman, the internationally known Dean of the College of Agriculture, Rutgers University, and Director of the New Jersey Agricultural Experiment Station, asked me to relieve him of teaching the introductory course in soils. It was then agreed that the presentation of the subject would have to be revamped in the light of pedology, *the science dealing with the natural laws governing the origin, formation, and geographic distribution of the soil as a distinct body in nature.*

During the 20 odd years of Dr. Lipman's teaching, to quote his own words: "Very few changes had been made in the presentation of the subject of soils." Back in 1915, as an undergraduate, I listened to Dr. Lipman's interpretations and comments on text assignments in soils. These comments were, to be sure, far more interesting and informative than the text material. There was personality and wide experience in his presentation, scholarly appreciation of many phases of the subject, and a broad outlook of agronomic problems in relation to soil conditions. Essentially, however, the introductory course in soils was limited to a presentation of accumulated facts on the physical, chemical, and biological properties of soils under cultivation in the humid regions in relation to crop production.

Agriculturists of Lipman's period had little appreciation of the soil as an organic unit in nature. The fundamental differences of soils under various climatic environments have scarcely been touched upon in English, French, and German textbooks. The subject matter revolved primarily around problems of fertile and poor soils and local methods of handling these. Courses in soils and their management consisted (and in many schools the world over still consist) of discussions of agronomic experiments with the plowed layer of different soil classes (texture). Problems of acidity, liming, organic matter, fertilizer practices, and of methods of working the land had been treated as independent subjects, with little or no relation to the specific properties of soils in their climatic-geographic location. No consideration had been given to the profile characteristics of the soil groups of the world.

We have as yet no texts in soils and their management, treating the subject from the pedologic point of view. My aim is to provide such a text. I have attempted to present the fundamental facts in the light of our modern knowledge of pedology. The teacher as well as the competent reader may enjoy the opportunity of adding their interpretation of the

During my 10 years of teaching the introductory course in soils at Rutgers, I generally followed the presentation as given in this text. From time to time, the topics of Chapter X were discussed before those of Chapter VIII; on other occasions, the topics of Chapters VI and VII were discussed after those of Chapter IX. Experienced teachers will surely use their best judgment as regards the sequence of topics.

No bibliography is inrluded in this text, since beginners ever avail themselves of references to literature. Experienced teachers will recognize that this approach is followed in introductory texts in chemistry, physics, botany, zoology, and other scientific disciplines.

New Brunswick, N. J. JACOB S. JOFFE
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PART I

THE SOIL AS A NATURAL BODY

Introduction

To wrest from nature its bounties
one has to appreciate it.

A systematized study of any object in nature begins with the question: "What is it?" To answer this question we examine and study the object with the aid of our natural senses: sight, touch, smell, taste, and hearing. This approach is the ABC of science and should also be applied in answering the question: "What is a soil?".

The commonly accepted definition of a soil is that *it is a mixture of rock and mineral material with organic matter.* This concept fails to bring out the fact that the soil is a distinct object in nature, endowed with an independent existence and individuality. In a sense, the soil is a living body, inasmuch as it has an embryonic state, followed by a period of growth during which it passes from youth to maturity. Besides, the soil body is teeming with life, plant and animal, on which it depends in no small measure for the supply of ingredients that go to maintain its existence and its functions. The soil as a body in nature may be examined by 4 out of the 5 natural senses. No sounds of significance emanate from the soil, and the sense of hearing is of no aid in studying it.

The old concept of the *soil* being a mixture of mineral material and organic matter has just as much justification as to call a macerated plant body a plant. The name for that is plant material. An animal put through a meat grinder is not an animal body; the name for that is animal material. And a mixture of rocks, minerals, and organic matter is not soil; it is nothing but soil material.

A perusal of the history of natural science reveals that the recognition of units in nature as distinct bodies gave the first clue to the answer of the searching question: "What is it?" Without a through and concrete understanding of the body as such, the discovery of the natural laws that govern the behavior and functions of that body is most improbable.

Botany, one of the oldest scientific disciplines, began with an analysis of the plant as a unit object in nature. Botanists were pioneers in developing the modern methods of morphology in the study of plants. The external, and in some measure, the internal attributes, such as color, size, shape and form, hardness, odor, and texture of the various parts of the plant body, were characterized in terms of the natural senses. Because of this natural approach in their studies, the botanists made remarkable progress. No other science can boast of so long and so thorough an investigation of a natural object. A probable stimulus to the keen interest in plants was their use as ingredients for compounding medicines.

Great as were the advances made in botany solely through the application of our natural senses, they can not be compared to the achievements realized when plant studies have been accompanied with scientific experiments and deduction. Anatomy, histology, and physiology of plants have revealed the complexities of plant life and opened new vistas in botany, thanks to the application of the fundamental sciences, chemistry, physics, and mathematics.

Zoology reveals a similar story. A recognition of the external and some internal characteristics of the animal body led to a classification system of the animal kingdom and to the development of anatomy and physiology. These stores of knowledge have served as the springboard for still greater achievements. Man reached out for answers to the questions: "What is life? What is the mechanism of life?" Chemistry, physics, and mathematics have been called in to find the answers. Modern biology came into its own, marching forward on the road of still greater accomplishments for the benefit of mankind.

Such is the history of the development of science; its origin is readily traced to the curious in the Garden of Eden who asked, "What is it?"

This approach, so successfully used in other sciences, has not been extensively applied to the study of soils. From the time man emerged from the nomadic state and took to settled agriculture he has been confronted with soil problems. As his needs increased, or as the land became exhausted and refused to yield sufficiently to meet requirements, man commenced to look for new lands. From the fabulously rich lands of the valleys of the Euphrates and Tigris, the supposed cradle of mankind, early man wandered from fertile to less fertile soils.

Colonization and land settlement of the North American continent did not follow the pattern of the Old World. The early settlers occupied the relatively infertile soils of the Coastal Plain. The pioneers gradually moved westward to the more fertile soils of the Piedmont, to the better soils of the Eastern Prairie, and finally to the black soils of the Western Prairie and of the Great Plains regions.

As long as there was enough land, there was no pressing need for soil studies. With the increase in population, the demand for living space was met in many ways. One of these was the building of colonial empires, with the disastrous result of neglecting the soils of the mother country. The fall of the Roman Empire has been in a large measure attributed to the decay of its home agriculture. At present, the tendency is perforce towards internal colonization. This means the extension of the carrying capacity of the land available; in other words, increased yields per acre.

Some fruitful ideas about soils, primarily with reference to productivity, have developed all through history. Systems of soil management, such as fallowing the land, use of legumes, and turning cultivated land into sod, have been employed from time immemorial. The Bible prescribes resting the land one year in seven. Leaving land in sod for several years was another practice of soil improvement. Burning the steppe country in late summer to improve the pasturage for next year, a practice still in use, originated in the nomadic period of human history. These ancient practices which foreshadowed modern soil fertility studies were known to the Egyptians, Hebrews, Chinese, Greeks, and Romans.

As late as the 19th century land taxation was the chief source of state revenue, and the fertility of the soil, its capacity to yield, and its adaptability to various crops had to be evaluated in order to fix a just tax rate. The productivity of land was the moving force in advancing the knowledge of soils. But the feudal lord, the state, and other agencies engaged in land problems were not concerned with the soil as a distinct body in nature.

The Science of Pedology

All through recorded history scientists in many fields have been interested in the study of soils. Ancient philosophers, naturalists, alchemists, modern physicists, chemists, geologists, microbiologists, and plant physiologists, all have contributed their share in this field. Although their contributions uncovered many secrets of soil behavior in relation to plant growth, none of these scientists appreciated the soil as an independent natural body. In their determined efforts to divulge the secrets of high yields, the investigators in the various fields of science failed to give sufficient analytical consideration to the very obvious question: What, after all, is the soil?

With the introduction of pedology,[1] *the science dealing with the laws of origin, formation, and geographic distribution of the soil as a body in*

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[1] The Russian scholar Vasilii Vasilievich Dokuchaev (1846-1903) was the first to enunciate the fundamental principles of pedology in 1878. His collaborator, Sibirtzev, and a number of his pupils have furthered these principles, the work having been done exclusively in Russia. Because of language barriers, the Russian school did not come to the attention of Western European and American workers until the book of the Russian scholar, Glinka, entitled "Major Soil Groups of the World", was translated in 1914 into German. The English translation was made by no less a scholar than Curtis F. Marbut, the late chief of the Division of Soil Survey, United States Department of Agriculture.

nature, the answer to the question "What is a soil?" was forthcoming. Pedology teaches that the soil is a distinct body in nature consisting of definite parts, each one possessing chemical, physical, and biological properties of its own. The parts are closely related and interdependent.

For an "ABC of Soils", the first prerequisite is a through knowledge of the soil body as it appears in nature. What does the soil body look like, what are its constituent parts, what are the forces responsible for its creation, what are the materials that go to make up the mass of the soil body, what is the geographic distribution of soils, and what are some of the specific features of the different soils? Part I of this book thus deals with the pedologic aspects of the soil as a body in nature. This part also deals with the materials and components that make up the soil body and their physical, chemical, and in some measure biological properties.

CHAPTER I

THE SOIL PROFILE

When Dokuchaev began his soil studies, he was impressed by the constitution of the soil body. He noted that the soil body when cut open displays a series of layers, later designated as horizons.[1] Upon further study he discovered that each horizon is endowed with certain morphological, chemical, and physical characteristics. These horizon-forms were found to repeat themselves, with great regularity in their broad features, through all the soils of the world. *The succession of horizons, as viewed in the exposed anatomy of the soil body, is known as the soil profile.*

To study the soil body, the pedologist applies the methods used in other sciences. First of all, a typical specimen has to be found. For that the pedologist goes to the undisturbed woods or virgin prairie where the soil body still lies in its natural habitat.

Having chosen the right spot, the pedologist proceeds to operate on the soil body. His instruments differ from those of the surgeon; they are somewhat cruder. In place of fine scissors and scalpels, the pedologist uses a shovel, a pickaxe, a trowel, pruning shears, and chisels. A pit is dug, 2 to 2.5 feet wide, 8 to 10 feet long, and 3 to 5 feet deep. What does the exposed anatomy of the soil body, the soil profile, show?

The A_0 Layer. — From the surface to a depth of from one half-inch to an inch or two, depending on the climate and drainage, there is a deposit of organic matter. Its makeup varies with the type of natural vegetation. In the forest zone, it consists of the following: on the very surface there are leaves from the previous autumn, some twigs, branches, trunks of trees, and residues of herbaceous and grass vegetation. This material does not show any visible signs of decomposition. It is fairly simple, for instance, to identify the species deposited there by the bark or by the shape and markings of the leaves. Under this layer there is material of a similar nature which, however, has undergone considerable decomposition. The color is dark brown. The general form of the leaves is still apparent, though nothing but the veins and midrib remain. Their sources of origin may still be determined. Immediately beneath, there is a layer of organic matter, dark brown to black in color, called humus; the origin of this material can no longer be recognized. The entire deposit of organic matter,

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[1] The term layer implies deposits, usually separated from each other by a straight line of demarcation. The layers in the soil body are separated from each other by a curved line and are therefore called *horizons*. The humus-decay accumulative deposit, designated as the A_0 layer, somehow retained the layer designation.

as described, is called *the humus-decay accumulative layer* and is designated by the symbol A_0. In the meadow, prairie, and grass country of the plains, the A_0 layer consists of a mat of dead grass and herbaceous vegetation of the sod.

The A_0 layer of forests is referred to as *forest floor*, or *forest litter*. Foresters differentiate it into two layers, "F and H." The latter refers to the humus at the bottom of the A_0 layer and the former to the overlying forest floor debris. In coniferous forests, the A_0 is frequently permeated with an extensive system of surface feeding roots. These roots form an entangled and intertwined mat of organic material. Foresters call this type of mat *duff*. In deciduous forests, the material of the A_0 is friable and loose. Foresters call this type of mat *mull*.

The A Horizon. — Below the A_0 layer begins the mineral portion of the soil body. The surface of this horizon, because of the humus, is generally dark brown to black. In the soils of the prairie and of the plains this color extends to a considerable depth. In the soils of the forest regions, the color tends to change with depth to gray, brown, yellow, or red, depending on the geographic location. The A horizon is impregnated with humus and honeycombed with dead and living roots, the quantity varying with the geographic position. The structure (see Ch. V) too is characteristic for each soil, depending upon its distribution on the earth's surface. In some geographic regions the structure is granular; in others, it may be laminated, nutty, crumbly, prismatic, or lumpy. The depth of the A horizon fluctuates widely; from 6 to 8 inches in the semidesert region, to more than 2 feet in the semiarid great plains region, and to 15 to 16 inches in the humid temperate region. In the northerly section of the humid temperate zone, the lower portion of this horizon is sometimes ash-gray and is generally lighter in color than the upper portion. This detailed feature divides the A horizon into two subdivisions: the A_1 and A_2 horizons.

The B Horizon. — This horizon lies immediately below the A horizon and is readily recognized by a distinct change in color, texture (see Ch. V), and structure. Generally, the texture is heavier and the material is, therefore, more or less compacted. The structural units of the B horizon increase in size irrespective of the geographic location of the soil. The depth of this horizon exhibits variations similar to those of the A horizon; in some soils its total depth exceeds that of the A horizon. As a rule, the B horizon contains very little organic matter.

In the semidesert, arid, and semiarid regions, the B horizon is lighter in color than the A horizon and contains veins and concretions of carbonates of calcium and magnesium and sometimes also gypsum. It is only slightly more compacted than the overlying A horizon.

In the humid temperate region, the B horizon contains no carbonates of lime and the color is usually a brown or reddish-brown, generally more intense than in the A horizon. The compactness of the B horizon increases with depth, down to a certain point, and then begins to decrease. Sometimes this horizon may have iron or iron-humus concretions or even an entire layer of these. Such a layer is known as *ortstein* or *hardpan.*

The C Horizon. — Below the B horizon begins a layer of material known as the C horizon. As a rule, it is lighter in color than the overlying A and B horizons. Its texture is not as heavy as that of the B horizon, if the soil has formed from a column of weathered material of homogeneous texture. The texture of the C horizon can be heavier or lighter than that of the B horizon, if the soil has formed from alluvial or other sedimentary deposits which may vary in texture from point to point in the column. In these deposits one may find a clay layer where the A horizon is formed, a sandy layer where the B horizon is formed and a clay layer below it or vice versa. Under such circumstances, the C horizon will be heavier or lighter in texture than B, depending on the texture of the material when deposited.

The C horizon varies in depth, according to the geologic history of the deposits. If, for instance, the C horizon is of sedimentary origin it may be either fairly shallow, as in the soils formed on outcropping red shale, or very deep, as in the soils of the Coastal Plain. If the C horizon is of residual rock deposits, its depth depends on the depth of the weathered material. In general, the constitution and formation of this horizon is outside the realm of pedology; it belongs to geology. From the standpoint of pedology, the soil body terminates a few inches below the surface of the C horizon. Below that lies the subsoil.[2]

The Ap Layer. — With cultivation, the soil body becomes distorted. The first plowing operation destroys the A_0 layer, mixing it with the upper portion of the A horizon. The plowed layer rarely extends into the B horizon and being a part of the A horizon, it is designated by the symbol Ap. Soils heavily eroded may have the plowed layer in the B horizon. In such a case, this layer should be designated by the symbol Bp. Thus far no such distinction has been made.

Soil Defined

Before the advent of pedology, the definition of the term soil varied. The general run of the definitions was: "The soil is a medium for plant growth"; or "The soil is a mixture of mineral material and organic mat-

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[2] The term "subsoil" is erroneously applied to material below the plowed layer. Pedologically speaking, subsoil is material of the C horizon.

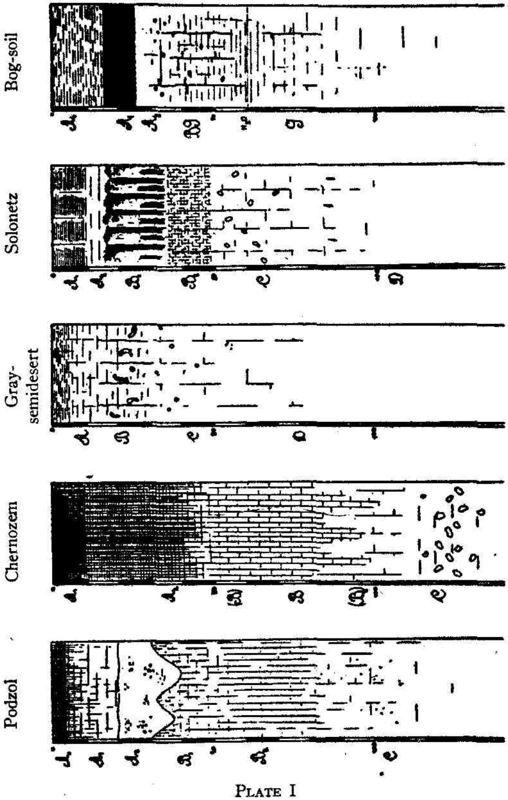

PLATE I

Schematic presentation of several zonal and other soil types
(After Zakharov)

ter." Hilgard, the savant of American soil investigators, defined soil as "the more or less loose and friable material in which, by means of their roots, plants may or do find a foothold and nourishment as well as other conditions of growth." One need not scrutinize the definitions very closely to recognize in them the concept of the soil being a medium for plant growth. From this point of view, the solution and sand cultures of the physiologists are also soils, for they too are media for plant growth.

A good definition should convey to the reader or listener the fundamental inherent characteristics of the object by which it can be identified and recognized. Pedology defines *soil* in terms of its internal characteristics as a body in nature. In the definition that follows lies the answer raised earlier, "What is a soil?"

The soil is a natural body of mineral and organic constituents differentiated into horizons which differ among themselves as well as from the underlying material in morphology, physical makeup, chemical composition, and biological characteristics.

General Remarks

The characteristic features of the soil profile just described are true for a mature soil, i.e., one with well differentiated horizons which are not subject to change, unless the environmental conditions change drastically. In other words, a mature soil is one which is full grown and in which the reactions responsible for growth have come to equilibrium, eliminating further changes in the characteristics of the soil body. Thus, the chemical composition and physical makeup of the horizons remain practically constant.

On land surfaces where the materials are constantly disturbed, no soil body can be found. Examples of such lands are flood-plains which are still in the process of formation or sections where erosion keeps on removing the A horizon and sometimes even the B horizon. It should not be inferred that such land, even though not carrying soils in the pedologic sense, is not suitable for crop production. These soils are immature and may be just as fertile as mature soils, or even more so. Not being differentiated into horizons, they do not possess the attributes of a soil body. In cultivated areas of the forest zone, one may also encounter spots where no profile is apparent. These spots are the former locations of uprooted trees, whereby the profile was destroyed.

The depth of the soil body varies, depending on the depth of the horizon. It seldom exceeds the 10-foot mark. Soils of such depths are encountered among the dark colored soil "race," the chernozem. Other soil "races" have shallow soil profiles. And within each individual soil group there are always departures from the normal, a phenomenon in nature that is true also for plants and animals.

From the sketchy outline of the soil profile, as anatomized by a pedologist, it may be logically inferred that the occurrence and distribution of soils are an outgrowth of the play of forces in nature. Soil formation is governed by natural laws which are universal and operate uniformly the world over. Indeed, we find the soil body with its distinctive fundamental profile features wherever conditions are conducive for its formation, in the arctic regions or in the tropics. In either of these extremes, the soil body may be found with the characteristic constitutional makeup of a soil profile. There are minor features specific for the soil profile of every geographic-climatic region. Because of these features, we have, as will be seen in the subsequent chapters, a number of geographic-climatic soil zones.

CHAPTER II

THE EARTH, ROCKS, AND MINERALS

The soil body is made up of four components: mineral, organic matter, water, and gas. Under natural conditions, the mineral and organic components remain fairly constant in any individual soil type. The water and gas components vary from day to day, even from hour to hour.

From the standpoint of bulk and weight, the mineral component ranks first in the soil body. For a proper appreciation of the soil body as such and the relation of soils to crop production, it is essential to know something about the evolution and nature of the mineral component. This leads us to a brief digression into the field of *geology, the science dealing with the origin and evolution of the earth as revealed in its rocks.*

The Origin and Evolution of the Earth

Among the many hypotheses concerning the origin of the earth, the planetesimal hypothesis of T. C. Chamberlain and F. R. Moulton is the most generally accepted. It was first proposed in 1900 and has been extensively developed since that time. Important clues in deciphering the earth's history have been discovered through studies of present day activities of our solar system. Such phenomena as the ejection of masses of matter, in the form of flaming gaseous outbursts, rising thousands of miles above the surface of the sun are examples of these activities. Such outbursts were common thousands of millions of years ago.

Physicists state that, according to their calculations, no mass of matter can remain in space and produce a planet by accretion with additional bolts of matter unless certain conditions are fulfilled. First, the mass must be ejected with a speed of at least 385 miles a second. Second, the forces required to produce planets from the sun must cause greater eruptions than are now observed, must pull the erupted masses of matter far enough from the sun, and then start these masses off in an orbital motion which will prevent their falling back into the sun. It is postulated that such forces were exerted by a star which passed near the sun thousands of millions of years ago. Whether such a chance passer-by may come again is problematic. That it has not come in all the billions of years since our planet originated is assurance of the future stability of the earth.

It is further postulated that the gravitational force of such a passing star drew the erupted masses far enough from the sun so that the latter's force was not strong enough to pull them back. Nevertheless, the sun's gravitational force remained strong enough so that the erupted masses could not "fly away." Simultaneously, the gravitational force of the passing star caused the mass which had escaped from the sun to spin in an elliptical orbit. In the words of R. T. Chamberlin:[1]

> Each bolt was gaseous when it left the sun. As the ejected gas cloud moved outward into space, it expanded greatly and its gravitational attraction for its outer portions became correspondingly reducd. Much scattering of its materials, both of accompanying minor whirls of gas, and of the main bolt itself, seems highly probable. Condensation inevitably followed cooling through loss of heat to space. A coalescence of material in the heart of each of the main gas bolts early produced nuclei for the planets. Out of the rest of the erupted sun gas, inumerable small liquid, and eventually solid, bodies condensed, somewhat like raindrops and hailstones in cooling humid air. These masses pursued individual courses, some controlled by the gravity of the planetary nuclei, others following independent paths around the sun. Those in independent orbits around the sun were called planetesimals (very small planets) by the authors of this theory.

And so, we can picture the beginning of our earth as an emergence of glowing masses of gas eruptions from the sun "into the unformed and void, into the darkness upon the face of the deep." These masses later cooled off into solid matter. Of course, in the transition from the gas to the solid, the mass had to go through the liquid state.

Myriads of these solid planetary nuclei and planetesimals swarmed in their orbits around the sun. Because their paths intersected, these planetesimals and planetary nuclei collided and sometimes united, the larger absorbing the smaller. At other times, explosions resulted, and finally, in the course of hundreds of thousands of millions of years, most of these planetesimals combined into units and formed our solar system.

As the earth grew larger and larger by the accretion of small planetesimals, the impact caused by the bombardment of these was not sufficiently strong to develop enough heat to melt the entire globe or even a large portion of it at any one time. And yet, this heat and that caused by the planetesimals speeding through space appear to have been sufficient to cause large portions of the contacted solid surface of the earth's core to melt. The gases liberated from the molten masses escaped into space until such a time as the earth became large enough to exercise a gravitational force of its own and to hold the escaping gases. Thus the ***atmosphere*** was formed. In the dawn of our earth's atmosphere, heavy gases only (nitrogen, carbon dioxide, and water vapor) were attracted. Gradually, as it grew in size, the earth developed enough gravitational pull to hold on to the gases which make up our present atmosphere. A gas such as hydrogen was too light to be attracted by the earth's gravitational force and it escaped into space. And it is just as well that it did escape, for hydrogen is very explosive and would have not stayed peacefully on our

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[1] R. T. Chamberlain, The Origin and History of the Earth, The World and Man as Science Sees Them. University of Chicago, 1937.

earth in close contact with oxygen. There is hydrogen in the sun's atmosphere, and the explosions caused by its presence are observed by astronomers in our own times.

It seems probable that long before plants appeared on the scene, the atmosphere was charged with large quantities of carbon dioxide liberated by the flaming planetesimals. Our present day meteorites, when fused, give off large quantities of carbon dioxide. This may serve as proof that the ancient planetesimals behaved similarly.

Very likely the carbon dioxide also entered into chemical reactions with the rocks. In combination with water vapor, carbon dioxide forms carbonic acid. Though weak, carbonic acid slowly dissolves many rock and mineral substances.

While the active carbon dioxide entered into many reactions, more and more of the inert nitrogen accumulated until it reached its present concentration equilibrium with the highly reactive oxygen and the rapidly disappearing carbon dioxide. Now nitrogen makes up about 79 per cent of the atmosphere, oxygen about 20 per cent, and carbon dioxide only about 0.03 of a per cent. The rest consists of the rare gases: helium, neon, argon, krypton, xenon, and others.

When the atmospheric temperature dropped to a point where water vapor could condense, it rained upon the dry land and waters accumulated in the depressions, forming lakes and oceans. "And God called the dry land Earth and the gathering together of the waters called He Seas." From then on, the earth's surface, as we know it now, began its long series of evolutionary transformations which were accompanied infrequently, especially in the early periods, by violent geological upheavals.

Rocks and Minerals

Spectroscopic analyses of gaseous masses rising thousands of miles above the surface of the sun disclose the presence of many known elements.

An analysis of other heavenly bodies, such as the stars and comets, show a similar makeup. At one time, all the elements were in a gaseous state. Gradually, they combined and at present the elements of our planet, with the exception of a few, exist in chemical combination. The free elements and some of the combinations may appear in any one of the three forms of matter with which we are familiar: solid (iron, gold, silver, etc.), liquid (mercury, bromine), and gas (oxygen, nitrogen, etc.). We also know carbon dioxide gas in liquid and solid (dry ice) forms. It is common knowledge that water may exist as a liquid, as a gas in the form of steam or water vapor, and as a solid in the form of ice.

In the process of planetary nuclei formation from the masses of flaming gases, upon cooling, the elements began to combine. It was not a random chemical union, but a systematic and orderly selection, as destined by nature. Arranging themselves in the magma, many of the compounds aggregated into large masses, the different compounds combined into units, giving rise to simple and complex substances, mineral and rocks.

A mineral may be defined as a *natural substance, usually inorganic, having a definite chemical composition and commonly a definite molecular arrangement which is usually expressed in geometric form.* A rock may be defined as an aggregate of one or more minerals. Thus, an aggregate of the single mineral calcite gives rise to crystalline limestone, whereas a granite is a combination of several minerals.

The Earth's Crust

As the earth increased in size by the acquisition of planetesimals and meteors, it suffered growing pains, exemplified by geologic revolutions. Earthquakes and volcanic eruptions, of magnitudes capable of destroying any living matter that might have been present, were frequent occurrences. Earth movements of all kinds and drastic changes in the atmosphere were then also very common phenomena. Continents appeared and disappeared. Finally, the earth shaped itself in approximately the form in which we know it now, with contours ascending to heights of five or more miles above sea level (Mount Everest, for example) and descending to depressions of ten miles or more below sea level (the depth of the ocean around Japan).

The earth's crust is taken as a layer 10 to 15 miles deep. The surface of this crust is generally composed of loose and unconsolidated materials known as *mantle rock* which overlies the native, solid bed rock. The chemical composition of the bulk of the earth's crust is fairly simple. Ten of the ninety-six elements comprise more than ninety per cent of the lithosphere.[2]

The following table, taken from Clarke,[3] give the relative percentages of the elements in the lithosphere:

Oxygen	46.46	Hydrogen	0.14
Silicon	27.61	Phosphorus	0.12
Aluminum	8.07	Manganese	0.09
Iron	5.06	Carbon	0.09
Calcium	3.64	Sulfur	0.06
Magnesium	2.07	Chlorine	0.05
Sodium	2.75	Barium	0.04
Potassium	2.58	Fluorine	0.03
Titanium	0.62	Strontium	0.02

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[2] The earth is made up of a series of spheres: 1, lithosphere ,the solid sphere; 2, hydrosphere, the liquid sphere which covers more than two thirds of the globe; 3, atmosphere, the gasous sphere, the blanket of air surrounding both the lithosphere and the hydrosphere.

[3] F. W. Clarke's "Data of Geochemistry," U. S. Geolog. Survey Bul. 770, 5th Edition (1924), is a highly technical treatise and yet so popularly written that even

Thus, oxygen and silicon comprise approximately 75 per cent of the total, and these, together with the sixteen other elements enumerated, comprise more than 99 per cent of the earth's crust. About one half of one per cent of the crust takes in all other elements.

Classification of Rocks[4]

With respect to origin, three great divisions of rocks are recognized: *igneous, sedimentary* or *clastic,* and *metamorphic.*

Igneous Rocks. — Rocks which form from a molten condition are known as igneous. They make up 95 per cent of the earth's crust. When the planetary nuclei and planetesimals accrued in the formation of the earth, its surface became a molten mass. As this mass cooled, the original igneous rocks formed. Even today igneous rocks are being formed by volcanic eruptions and other geological disturbances. Those which formed from the magma before it had a chance to appear on the surface of the earth are termed *plutonic* or *intrusive.* Those rocks which formed near or at the surface as volcanic lavas are termed *extrusive.* Granite, basalt, diorite, syenite, pumice, pitchstone, and obsidian are typical examples of igneous rocks.

Sedimentary or Clastic[5] *Rocks.* — Exposed to the elements, rocks and minerals weather (see Ch. III), giving rise to loose masses of crushed, crumbled, and mellowed material. This material is being eroded constantly, washed into the rivers, and carried into lakes, seas and oceans, forming sedimentary deposits. These deposits remain either as loose material or they consolidate into *sedimentary* or *clastic* rocks. Sandstone, conglomerate, shale, limestone, and argillite are examples of sedimentary rocks. They make up 75 per cent of the total rock mass of the *surface* of the earth's crust, and the combined igneous and metamorphic rocks make up only 25 per cent.

Seaborn sedimentary deposits are very widespread. The materials of the Coastal Plain bordering the Atlantic Ocean and the Gulf of Mexico are an example of these. While under water along the coast, these deposits constitute the *continental shelf,* a gently sloping ocean or sea floor on which the silt loads of rivers settle out in less than 600 feet of water. It extends for distances varying from several to 200 miles into the ocean. The type of material making up this continental shelf is determined by the geologic origin of the drainage basins. From areas of shale, the deposits must of necessity be clay; from areas of sandstone, these deposits will be sands. Usually, however, the continental shelf receives materials from

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[4] See also Chapter III.

[5] From the Greek *Klastos*-broken.

various sources. It is natural for the coarser materials to settle near the shore, the finer materials farther away, and the very finest at the edge of the shelf.

Limestone is a prominent member of the sedimentary group of rocks. Its origin may be traced to precipitation reactions in sea water and to deposition of shells of marine animals (see also Ch. II).

Other rocks form as a result of secondary reactions, precipitating from solution, such as *gypsum*—$CaSO_4.2H_2O$, various kinds of limestone just referred to, and *dolomite*—a mixture of $CaCO_3$ and $MgCO_3$. To the rocks of secondary reactions belong a series of earthy rocks, like the marls, most of which are calcareous clays. They are frequently found in lakes and swamps. They originate from shells of mollusks (the name shell-marl is often used) and some algae which deposit lime in their tissues.

Sedimentary deposits are also found on land within the area of the watershed and are known as alluvial deposits. River flats and deltas, alluvial fans, and river flood plains (the flood plain of the Mississippi covers an area of about 30,000 square miles) are typical illustrations of such deposits. Stratified deposits are encountered along river courses on elevations far above the present flood plain of the river. These deposits represent the flood plains of the river long before it had dug into its present channel. Such formations are known as *river terraces, benches* of first or second bottoms. Similarly, there are lake terraces known as *mesas*. Sedimentary deposits of lacustrine origin, in inland lakes, especially those formed by glaciers. are also common.

Glaciers pick up all kinds of materials in their forward advance. Upon their retreat toward the arctic regions or toward higher altitudes of mountains, glaciers drop their loads, consisting of sediments varying in size from very fine particles of clay and silt to gravel, stones, and boulders. Collectively, these sediments are known as *glacial till* or *glacial drift*. Large quantities of this till are deposited at the edges of the glaciers whenever the melting equals the advance of the glacier. The area over which these debris are deposited is known as the *terminal moraine*.

Sedimentary deposits of eolian origin are also encountered. Rocks formed from dunes, from sand-hills, and from some deposits of loess are examples of these.

The sedimentary deposits formed by the action of wind and glaciers differ from the water-laid deposits, inasmuch as the latter are almost always stratified; whereas the wind and ice-laid deposits are, as a rule, not stratified.

Other sedimentary deposits known are: *colluvial*, rock talus removed by gravity and accumulating at the bottom of slopes; *deluvial*, rock material carried downward from slopes by surface waters.

Consolidated and compressed clay deposits are known as *shale.* Sands pressed into solid masses and consolidated with the aid of some cementing agents, such as siliceous, calcareous, and ferruginous materials, form *sandstone.* Gravels and sands cemented with silica and other materials form rocks known as *conglomerate.*

Originally, sedimentary rocks formed exclusively from the weathered materials of igneous rocks. In later periods of the earth's history and in our own day sedimentary rocks may form from the weathered products of igneous, sedimentary, or metamorphic rocks.

Not all sedimentary deposits are of the same geologic age. Thus, the red shales of the Piedmont are older than Coastal Plain deposits. *The parent materials of most soils, as we see them now, have originated from sedimentary deposits formed in recent geologic time, the Quaternary.*

Metamorphic Rocks. — When igneous or sedimentary rocks are subjected to heat or pressure whereby heat is produced, they undergo some change or metamorphosis and are known as *metamorphic rocks.* Often the metamorphism is so complete that the original rock may not even be recognized. Generally, however, some inherent properties of the original rock remain and the origin of the metamorphic rock is easily recognized. Marble is metamorphosed limestone, slate is metamorphosed shale, gneiss is metamorphosed granite, and quartzite is metamorphosed sandstone.

Classification of Minerals[6]

Although about fifteen hundred minerals have been named and identified in the earth's crust, its bulk is made up of relatively few. The mineral component of the soil body is not comparable to that of the lithosphere as a whole because the soil body is generally the uppermost part of it. In the process of soil formation, the percentage composition of the mineral component is rearranged.

The minerals of igneous and of some metamorphic rocks are classified as *essential* and *accessory.* The primary silicates which are of the essential group comprise the bulk of the rocks, and they determine the family, species, or variety of rock. The accessory minerals make up only a minor fraction of the rocks. They are, however, very important, especially as sources of several plant nutrients. The mineral composition of sedimentary rocks is governed by the mineral makeup of the igneous and metamorphic rocks from which they originate. Sedimentary rocks, however, are richer in silica than other rocks; they contain silica from the weathering of the secondary silicate minerals, besides the quartz of the primary silicates.

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[6] Depending on the preparation and interests of the students, the instructor is to decide whether this section should be taken up.

According to Clarke, igneous rocks are made up chiefly of essential minerals: *feldspars*—59.5 per cent; *hornblende* and *pyroxenes*—16.8 per cent; *quartz*—12 per cent; *micas*, primarily biotite—3.8 per cent; *titanium* minerals—1.5 per cent; *apatite*, an accessory mineral—0.6 per cent; the less abundant minerals make up the remaining 5.8 per cent. Thus, the feldspars predominate, the ferromagnesian minerals come next in abundance, quartz is third, and after that all the other minerals.

Composition of Minerals. — The essential minerals consist of silicon-oxygen nuclei in various combinations. The oxides of different elements, such as Na, K, Ca, Mg, Fe, Al, Mn, H, and others, are attached to these nuclei in one way or another. Because of their silica nuclei, these minerals are known as silicate minerals.

The chemical composition of the various silicate minerals is well known, but the manner in which the chemical elements are held together, in other words the structure, is as yet not clearly understood. The way the valence and other bonds of the various elements are oriented in the lattice structure of the minerals and the position occupied by the elements within the lattice determine the stability and [illegible] other properties of the mineral. For a discussion on the composition of minerals, textbooks on the subject are to be consulted. The material in this text is just to illustrate the simple composition formula of the elements comprising the minerals named. For this purpose, the formula presenting the oxides that make up the minerals has been chosen. For a few minerals, the empirical formula frequently encountered in the literature on soil is also given.

The *feldspars* are the most important group of minerals encountered in soils. Among them are the potassium feldspars, *orthoclase* and *microcline*, $K_2Al_2Si_6O_{16}$. Some mineralogists and chemists divide the formula by two and write it, $KAlSi_3O_8$. Essentially, these minerals are K, Al— silicates, expressed by the formula $K_2O.Al_2O_3.6SiO_2$. *Albite*, the Na feldspar, is represented by the formula, $Na_2Al_2Si_6O_{16}$, or $Na_2O.Al_2O_3.6SiO_2$. *Anorthite*, the Ca feldspar, has the following formula, $CaAl_2Si_2O_8$, or $CaO.Al_2O_3.2SiO_2$. Besides these, there are feldspars consisting of mixtures of the above, like *oligoclase* which is a soda-lime feldspar, or *labradorite* which is a lime-sodium feldspar. The Na and Ca feldspars are known as the *plagioclase* groups.

Closely related to the feldspars are the *feldspathoids;* they include the minerals: *leucite*, $K_2Al_2Si_4O_{12}$, or $K_2O.Al_2O_3.4SiO_2$; *nephelite*, a Na, K, Al — silicate, $3Na_2O.K_2O.4Al_2O_3$; and *sodalite*, $3Na_2Al_2Si_2O_8.2NaCl$, or $3Na_2O.3Al_2O_3.\ 6SiO_2.2NaCl$. The color of the feldspars and related minerals is light with some pink or green. They are hard and yet most of them weather fairly rapidly.

The *pyroxenes* and *amphiboles* are groups containing a large number of silicate minerals; *hornblende* in amphiboles and *augite* in the pyroxenes are typical representatives. Both are much the same in composition but have different crystal forms. Both vary from a shiny black to a greenish black. Crystals of these are easily found in granites. Both are silicates of Ca, Mg, Fe, and Al. Augite is presented as: $CaO.MgO.2SiO_2$ with $(Mg, Fe)O.(Al, Fe)_2O_3.SiO_2$; hornblende, chiefly a Ca, Fe, Mg-silicate, with some Na and Al, $CaO.3(Mg, Fe)O.4SiO_2$ with $Na_2O.Al_2O_3.4SiO_2$ and $2(Mg, Fe)O.2(Al, Fe)_2O_3.2SiO_2$.

Olivine is a glassy-appearing Mg, Fe—silicate mineral, $2(Mg, Fe)O. SiO_2$, green or yellowish green in color, easily recognized (with the naked eye or with the aid of a microscope) in diabase, gabbro, basalt, peridotites, and other rocks. In peridotite, olivine may make up more than one half of the volume of the rock. The olivine group of minerals gives rise to *antigorite*, $3MgO.2SiO_2.2H_2O$, found in serpentine.

The *micas* are well known for their perfect unidirectional cleavage, easily yielding thin laminae when broken. *Muscovite*, $K_2O.2H_2O.3Al_2O_3. 6SiO_2$, is a rock-making mineral, a white K bearing mica, sometimes called *isinglass*. It has admixtures of Na and is found in granites, gneisses, syenites, and other rocks. *Sericite* is a silvery-white variety of muscovite. It is found in soils originating from feldspathic rocks, gneisses, schists, and feldspathic sandstone (arkose). This mineral appears in the form of minute silky scales and fibrous bunches. *Biotite*, $H_2K(Mg,Fe)_3Al(SiO_4)_3$, is black mica, found in many rocks, such as granites, gneisses, syenites, pegmatites, and other rocks. Biotite is very resistant to weathering and can always be detected as glistening specks in practically all soil materials. It is, however, less resistant to weathering than orthoclase or any of the other feldspars. *Phlogopite* is another member of the mica group. It is a K, Mg-silicate associated especially with limestone and dolomite, pyroxene, serpentine, and other rocks. *Chlorite*, a Mg,Al-silicate, with some ferrous iron, resembles mica in its cleavage and certain crystallization properties.

Another important group of minerals is the so-called *zeolites*. They are hydrous Na, Ca, Al-silicates which commonly occur as secondary minerals in cavities of subsilicic (with a low silica content) volcanic rocks, especially basalts.

Accessory Minerals. — The following accessory minerals are important in the soil: *apatite*, a phosphate of Ca, with F or Cl, or both. Fluor-apatite, $(CaF)Ca_4(PO_4)_3$ or $3\ Ca_3P_2O_8.CaF_2$, and chlor-apatite, $(CaCl)Ca_4(PO_4)_3$ or $3Ca_3P_2O_8.CaCl_2$, the fluor-apatite being much more common. Apatite is found in practically all igneous rocks and is the most important mineral in rock phosphate. *Vivianite*, $Fe_3(PO_4)_2.8H_2O$

(hydrous ferrous phosphate), is another phosphorus carrying mineral. *Pyrite,* FeS_2, found in igneous rocks as crystalline specks, is golden in color, hence the name *fool's gold.* Magnetite, Fe_3O_4, a magnetic iron mineral; *ilmenite,* $FeO.TiO_2$; and *rutile,* TiO_2; they are found in many rocks.

(It will be noted that the accessory minerals do not have the silicon-oxygen nuclei.) Instead, they have phosphate, sulfur, or oxygen nuclei. These minerals are the natural source of supply of the important plant nutrients, P and S.

Clay and Clay-Like Minerals

Upon decomposition, many of the primary silicates give rise to a series of clay and clay-like materials which may be looked upon as secondary silicate minerals. These minerals are hydrous Al-silicates, frequently with some replacement of Al by Fe and Mg and with small amounts of alkalies and Ca. These minerals also contain extremely small quantities of other minerals, such as feldspars, pyrite, and others. The clay minerals occur in the clay materials in particles less than about 5μ (0.005mm). Three groups of clay minerals of major importance are recognized: *kaolin,*[7] *montmorillonite,* and *hydrous micas* (*illite*).

Kaolin.— In the kaolin group, *kaolinite* is the most important member; it is a crystalline substance of the composition $Al_2O_3.2SiO_2.2H_2O$. On a percentage basis kaolinite consists of: SiO_2—46.5; Al_2O_3—39.5; water—14. The color of pure kaolinite is generally white, but the grayish white, brownish, bluish, or reddish tinges are not uncommon. *Halloysite* is another member of the kaolin group of minerals. Like kaolinite it is a silicate of Al, but it contains more water than kaolinite. Its chemical composition is $Al_2O_3.2SiO_2.4H_2O$. On a percentage basis halloysite consists of: SiO_2—43.5; Al_2O_3—36.9; water—19.6. *Dickite* and *nacrite* are two other minerals of the kaolin group having the same composition as kaolinite.

Allophane is also a clay-like mineral, found in soils of the humid temperate climate. Its crystalline structure has been demonstrated only in recent years and its composition is not very well established; it is given as $Al_2O_3.SiO_2.5H_2O$.

The kaolin group is pictured by mineralogists as consisting of alternate single sheets of Al_2O_3 and SiO_2. It is of interest to note that all kaolin minerals are poor in Fe and Mg, containing not more than one mol per cent. Other clay-like minerals such as *pyrophyllite, sinopite, sinectite,* of minor importance, are found in sedimentary rocks.

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[7] The name kaolin is a corruption of the Chinese *Kauling,* meaning high ridge, the name of a hill near Jauchau Fu, where the material is obtained (from Dana's *Mineralogy*).

Montmorillonite.— This is a crystalline clay mineral which in recent years has been singled out as one of the most important minerals of the soil, although its name dates back to 1847 when it was found in Montmorillon, France. Its composition is not accurately established; it is given as $Al_2O_3.4SiO_2.5\text{-}7\ H_2O$, usually containing magnesia and sometimes lime and because of that its formula is sometime written $(Mg, Ca).Al_2O_3.5SiO_2.nH_2O$. The ratio of SiO_2 to Al_2O_3 may be as high as 5:1 and higher and as low as 2:1; generally, the ratio is 4:1. In its lattice structure, montmorillonite is represented by one sheet of Al_2O_3 between two sheets of SiO_2. Because of this sheet type arrangement, montmorillonite and the like minerals have the ability to expand and contract along the C axis. Bentonite deposits consist primarily of montmorillonite. If the Al in montmorillonite is completely replaced by Mg, the mineral gets the name *saponite;* if replaced by Fe, the mineral gets the name *nontronite.*

Beidellite is a mineral related to montmorillonite. It has a $SiO_2:Al_2O_3$ ratio of 3:1.

Hydrous Micas (Illite).— These minerals are related to the ordinary micas. The only specific mineral name that has been proposed in this group is *bravaisite,* a mica-like mineral. These minerals contribute to the K resources of the soil. *Glauconite,* a dirty green colored mineral (a K,Al-silicate), one of the components of greensand marl, is somewhat similar in structure to biotite mica.

Trace Elements in Minerals.— In closing the subject, it should be stated that most of the minerals contain trace elements. More and more we are coming to the realization that such elements as B, Zn, Mn, Cu, I, Co, and others are essential for the proper functioning of plants. Some of these elements appear in combination or as independent minerals; others are found as trace elements in the minerals mentioned. For example, Li, Rb, and Cs are found in leucite; the pyroxenes may contain Zn, Cr, and Ti.

The minerals enumerated, and many more which have been omitted because of their minor importance, make up the parent material of the soil body. The transformations which these minerals and rocks undergo are controlled by the processes of weathering and soil formation.

Summary Statement.— The clay minerals are extremely important in the process of forming the soil body, in their supply of K, Ca, Mg, and other elements to plants, in their reactions with fertilizer salts, in their retention and release of plant nutrients, and in their effects on the physical properties of the soil.

CHAPTER III

THE PROCESS OF WEATHERING

Weathering is the process of disintegration and decomposition of rocks and minerals. Two natural forces, physical and chemical, operate in this process.

Physical weathering is instrumental in cracking, crumbling, crushing, and mellowing the rocks and minerals into a mass of material varying in size from boulders to very fine particles. Physical weathering is a kind of mechanical disruption and is termed *disintegration*; it causes a *change in shape, form,* and *size* of the rock and mineral debris, but not a change in the chemical composition of these.

Chemical weathering is instrumental in decomposing the complex substances of the rocks and minerals into simpler ones. Chemical weathering causes a *change* in *composition* and is termed *decomposition*. Some of the decomposition products go into solution; others are split off as gases; and the bulk of them, as a rule, remain in place.

Parallel with the decomposition process, a building up process or synthesis may take place. If a Ca, Mg, Fe, or Al ion should in its downward movement meet a silicate or phosphate anion, a chemical union would take place, resulting in the formation of a silicate or phosphate. Similarly, as a result of certain physical forces acting in combination with some chemical forces, there may be a compression, compaction, or a cementation of the rock debris into solid rock. This may also be considered a building up process. These building up or constructive processes represent a counteraction to weathering which is a destructive process.

Physical Weathering

The agents of physical weathering are: temperature, water, wind, and glaciers.

Temperature.—Like all other substances in nature, rocks and minerals expand upon heating and contract upon cooling. Not all parts of the rock expand and contract at equal rates. The more complex the rock is, mineralogically, the more variable are the coefficients of expansion and contraction. Forces of unequal magnitudes are set in motion upon heating or cooling and cause much more disintegration of rock than a uniform single force resulting from a uniform coefficient of expansion and contraction.

The author had gruesome and mysterious nocturnal experiences in the desert of the Jordan Valley at the foothills of Judea, Israel, and in the mountain desert region of Southern California. The weird rumbling sounds disturbing the stillness of the deep darkness under the brilliant star-lit skies filled one with awe and tenseness. And all the noise was nothing more than the cracking and sliding of rocks, cooling rapidly after a day of sun-bake at a temperature as high as 110-130°F. It is recorded that in the Sahara desert rocks are visibly ruptured as the cool nights come on after a truly hot desert day.

Rocks are poor conductors of heat. The temperature differences between the surface of the rock and a few inches within may cause a crevice to form between the two zones of temperature. When the crevice extends all around the rock, a uniform shell scales off. Such a process is known as *exfoliation.*

In the days before dynamite came into general use, farmers in hilly country made a practice of heating the boulders and large stones in their fields and then splashing water on them. This was an effective way of disintegrating the rocks. It is common knowledge that southern exposures of mountains abound with much more rock fragments than do the northern exposures.

Freezing temperatures, ice formation, and thawing are the principal causes of the shattering of rocks in the temperate and northern climates. Water, as it solidifies, expands and increases its total volume by about 9 per cent with a force of 150 tons to the square foot. In traveling through Finland, the country of sixty thousand lakes with the most northerly located capital, the author was told that every winter, blocks of rock are shattered by pouring water into natural cracks and holes drilled for that purpose. (Old man frost does the rest,) It is claimed that by properly manipulating this operation, the results may be as satisfactory as dynamiting the rocks.

Water.—Water is one of the most potent weathering agents and undoubtedly has been ever since the temperature relations allowed the formation of water basins and watersheds in the early geological history of the earth. In the words of Hilgard[1]: "From the sculpturing of the original simple forms in which geological agencies left the earth's surface into the complex ones of modern mountain chains, to the formation of valleys, plains, and basins out of the materials so carried away, its effects are prodigious. The torrents and streams in carrying silt, sand, gravel, and boulders, according to velocity and volume, do not merely displace these materials; the rock fragments of all sizes not only scour and abrade the bed of the rill or stream, but by their mutual attrition produce more or less fine powder similar to that formed by glacier action. In the United States, the stupendous gorges of the Columbia and Colorado rivers, the former

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[1] Hilgard, E. W. "Soils"—The Macmillan Company, New York, 1906.

cut to a depth of over 2000 feet into hard basalt rock, the latter to over 5000 feet, partly into softer materials, partly into granite, are perhaps the most striking examples of the power of water."

The carrying capacity of flowing waters is enormous; *the transporting power of a stream varies as the sixth power of its velocity.* A current moving six inches a second will carry fine sand; one moving 12 inches a second will carry gravel; four feet a second, stones of about two pounds; eight feet a second, stone of 128 pounds; thirty feet a second, blocks of 320 tons. Such a carrying force can be appreciated only when an area devastated by a flood is visited. The descriptions of the Johnstown, Pennsylvania, flood of 1889 are often cited. Iron bridges were swept away like faggots, and locomotives weighing 20 or more tons were floated and carried like logs.

The abrasive, scouring, breaking, and cracking power of rock loads carried in water is very impressive in mountain streams during high water seasons. Large boulders are smashed into small fragments in high velocity collisions. Angular stones become rounded and smooth. Tons of rocks are carried for miles and miles like floating pieces of wood and everything in their way suffers from their crushing attacks.

Masses of rock split from cliffs accumulate at their base and build up slopes of loose fragments. This is known as *talus.* The largest blocks accumulate at the foot of the talus slope. With further disintegration and decomposition, masses of loose rock are moved by water and wind to expose the bed rock to the forces of weathering. This process is known as normal geologic erosion. It is a gradual process, the effects of which are to be reckoned in long term periods. Slowly but surely the geologic erosion levels the rough contours of the landscape. The wearing down of land surfaces to a condition of low relief, or nearly to a plain is known among geologists as *peneplanation.*

Wind.—As an agent of weathering wind acts somewhat like water. Its abrasive powers are well known. The dust, sand, and gravel carried by winds grind away the surface of rocks. Frequently, winds remove cleavage materials from talus slopes to expose new surfaces to the action of thermal forces.

A remark by the author to a seaman about the bare rocks of the Orkney Islands, off the coast of Scotland, during a voyage in that part of the world, brought forth a series of stories about flying pieces of flagstone and slate during the storms which seasonally visit the area.

The formation of dunes and the piling up of sand along the sides of mountains in desert regions are well known effects of wind. Some of the dunes in the Sahara may reach a height of 1500 feet.

Glaciers. — One need not visit the famous glaciers of Greenland or Alaska, not even of the Alps, to appreciate the force attributed to the movement of these great masses of ice. A chance visit to a minor glacier in Jasper Park, British Columbia, during the summer of 1927, gave the author a glimpse not only of its grandeur and beauty, but also of its force and power as an agent of weathering.

A gigantic mass of ice and compacted frozen snow, like a frozen river, can be seen trapped in a narrow mountain valley; one bank of the valley—a bare rugged mountain side, and the other rising high to a snow clad peak. From this peak, ice and snow slide down, feeding the frozen river, known as a glacier. As it emerges from the valley to the open space on the lower mountain side, the glacier widens and thins out towards its margins which extend in places almost to the timber line. There one finds boulders and stones of all sizes and shapes, a contribution of the glacier to the landscape. In the glowing mid-July sun, the melting ice and snow give rise to many rivulets which roll their waters in crystal clear bluish-green ice channelets, combine into larger brooks, and finally merge at the bottom and empty into an azure-blue lake from which a mountain stream begins its course on a long journey to the ocean. This is Edith Cavell or Angel Glacier.

Glaciers vary in size, from hundreds of feet thick, half mile long, and several hundred feet wide to thousands of feet thick, more than 50 miles long, and three or more miles wide. A glacier moves as a solid mass, and unlike the liquid mass of rivers, does not require a definite stream channel. With its overbearing weight, the glacier advances over hills and valleys and across rivers and lakes. In its unrestricted path, the glacier picks up anything that comes its way, plucking fragments from the bed rock, cracking some with its own weight and using as pounding instruments the boulders it carries. Its rate of movement is very slow. According to measurements made of Alpine glaciers, an advance of one to two feet per day is a very fast rate.

Glaciers, like the last Labradorian glacier which covered a good portion of North America, carried material from the North all the way down to southern Illinois. As the continental glaciers retreated to the north, huge masses of debris accumulated at their margins. At the front of the glacier edge, in the region of the terminal moraine, ponds and lakes formed in the early periods of the ice retreat. In some of these lakes clay sediments of alternating light and dark colored layers, arranged in pairs, are found. The one that settles out in the summer is dark and the one in the winter is light in color. Such sediments are known as ***varved*** clays.

As the ice front receded, much of the load carried by the glacier remained behind. These deposits are known as a *ground moraine*. All kinds of particle size fragments, from clay to boulders, known as glacial till and drift, make up the moraine deposits. They are products of physical weathering.

Summary Statement on Physical Weathering.—The agents of physical weathering commenced their work in the very early stages of the earth's history. At that time temperature was high and was, therefore, more potent as an agent of weathering than moisture. Both of these agents, temperature and moisture, were active prior to the origin of life. And with life, an array of biological reactions came into play, adding materially to the physical agents of weathering; it gained momentum as the earth aged, producing mantle rock. This was nature's way of preparing parent material for the creation of the soil body.

Chemical Weathering

The agents of chemical weathering are: oxidation, carbonation, hydration, and solution.

Oxidation.—The term oxidation, in its narrowest sense, signifies the taking up of oxygen by an element or compound.[2] Oxygen is an electro-negative element which combines with most electro-positive elements. Oxygen is very abundant in nature, making up close to 50 per cent of the lithosphere and about 20 per cent of the atmosphere.

In nature, oxidation reactions are very common. Burning of wood or coal in the furnace, or "burning" of food in the animal system is oxidation. The compounds of iron in rocks and minerals are easily oxidized, forming oxides of iron. Since iron bearing rocks are very widely distributed, the red color of the iron oxide is much in evidence the world over. The oxidation of pyrite, as indicated in the following equation is another example of the action of oxygen on a rock: $2\ FeS_2 + 7O_2 + 2H_2O \rightarrow 2FeSO_4 + 2H_2SO_4$. As shown later, the ferrous sulfate exposed in the air is further oxidized to a basic ferric sulfate.

Hydration.—The property of solids to take on water and to enter into combination with it is known as hydration, and the substances thus formed—hydrates. Bluestone is the name for a hydrate of cupric sulfate, $CuSO_4.5H_2O$. Upon heating, the combined water splits and the anhydrous salt, $CuSO_4$, becomes colorless.

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[2] The chemistry-minded student will recall the equations: $2Cu^{\circ} + O^{\circ}_2\ 2\ Cu^{++}O$— and $2Fe^{++}Cl_2 + Cl^{\circ}_2 = 2Fe^{++\,++}\ Cl_3$. Both express oxidation reactions, but in the latter this process takes place without the agency of oxygen. From the standpoint of valence, oxidation takes place when the valence of an element becomes more positive; reduction, the reverse of oxidation, means a change towards more negative valence or towards less positive valence. It should be stated that in the process of oxidatiin the oxidizing agent is itself reduced.

A great many rocks and minerals contain hydration compounds. While taking on water, the rocks and minerals increase the bulk of their mass. Hydration is thus a contributing factor in the disintegration of rocks. Merrill[3] cites examples of granites from the District of Columbia which when removed from the quarry fell to pieces in a few days because of the hydrated condition of some of the minerals. He states (p. 167): "Natural joint blocks of the rock brought up from the shafts were, on casual inspection, sound and fresh. Closer inspection revealed the fact that the blocks when brought to the surface were in a hydrated condition giving forth only a dull, instead of clear, ringing sound, when struck by a hammer, and showing a lusterless fracture, though otherwise unchanged."

Carbonation.—The term implies the action of CO_2 on rocks and minerals. This gas is found in the atmosphere in small quantities, about 3 parts in 10,000 parts of air. In certain sections, as in the Valley of Death in Java and in the Grotto del Cane near Naples, large quantities of CO_2 issue from the ground. Certain natural mineral waters, like some of those near Saratoga, contain large quantities of CO_2. Rainwater contains large quantities of CO_2; it may hold 15 to 40 times as much as air.

Old marble sculptures and tombstones become etched with age, and carvings and letterings are obliterated because of the carbonic acid effects. Carbonic acid combines with carbonates, forming soluble bicarbonates according to the equation: $H_2CO_3 + CaCO_3 = Ca(HCO_3)_2$. On the other hand, CO_2 in a solution containing free Ca and Mg ions may cause the precipitation of carbonates.

Solutions.—The property of a substance to dissolve in another and to remain dissipated throughout the medium, unless the solvent is removed, is known as solution. Water is by far the most abundant naturally occurring solvent. The solvent action of pure water is slow, but with salts or acids in solution the solubility effects increase tremendously.

No substance is absolutely insoluble even in pure water. Gold, platinum, and silver, considered as the most insoluble substances, may be proved, by X-ray analysis, to be soluble. (Solubility is often measured by the number of grams of a substance which will dissolve at 18°C in 100 cc of water or in 100 grams of any solvent and saturate it.) Thus, a saturated solution of calcium carbonate will contain 0.0013 gms. in 100 cc of water; a saturated solution of gypsum, 0.2 gms. per 100 cc of water. Almost any rock or mineral when shaken with water will give off some bases and other substances. Indeed, the quantity is small, but the magnitude of the

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[3] **Merrill, G. P. "A Treatise on Rock, Rock Weathering, and Soils." The Macmillan Company, New York, 1897.**

reaction is to be measured by the great quantities of water available for solution.

Biological Weathering

Strictly speaking there is no biological weathering. What it amounts to is physical and chemical weathering by biological agents.

Plant roots are potent agents of physical weathering. A very common example of the disintegration forces of plants is the penetration of tree roots into the crevices and cracks of rocks. By expansion, the growing roots crack and split huge boulders. Lichens, mosses, and similar forms of plant life growing on bare rock penetrate into most minute cracks and fractures with their thalli, in search of a foothold and food. They exert a powerful force in disintegrating the rocks on which they grow.

Plant roots secrete carbonic and perhaps other acids which act chemically on the rocks and minerals. An examination of rocks over which roots of plants are distributed reveals marks caused by the solvent action of root secretions. The example of a polished column in Tyrol attacked by lichens is frequently quoted. Not only did the polish disappear, but the marble was also pitted.

Microorganisms are by far the greatest contributors as biological agents of weathering. An array of organic and inorganic acids is produced in the process of organic matter decay. Besides these, one has to consider the acids occurring naturally in plants, such as citric, tartaric, oxalic, and malic. In contact with rocks and minerals, the enumerated acids of biological origin act as agents of chemical weathering.

A number of microbes have been reported capable of decomposing silicates, phosphates, and carbonates. Undoubtedly, the action is both direct and indirect. In other words, both the microbes and their metabolic products may act on the mineral constituents. The well known microbe *thiobacillus thiooxidans* directly oxidizes sulfur into sulfuric acid.

Weathering of Minerals and Rocks

The brilliant hues of the rocks in the canyons of Colorado and Arizona, of Zion Park, Utah, and the stains of brown and red on practically all rocks the world over are primarily due to Fe and Mg splitting off from minerals and forming oxides. The various oxides of iron are responsible for most of the red, brown, and yellowish tinges in soils.

Magnetite, Fe_3O_4, when exposed to the air changes into hematite according to the equation: $4Fe_3O_4 + O_2 = 6Fe_2O_3$. As hematite is not a very stable compound, it is subject to hydration and this action may result in the formation of iron hydroxide: $Fe_2O_3 + 3H_2O = 2Fe(OH)_3$, or

$Fe_2O_3.3H_2O$ (limonite). (Magnetite is considered a mixture of Fe_2O_3 and FeO and, since it is the FeO that is oxidized, the equation is written: $4FeO + O_2 \rightarrow 2Fe_2O_3$).

Pyrite, upon oxidation, first forms, as pointed out earlier, the ferrous compound: $2FeS_2 + 7O_2 + 2H_2O = 2FeSO_4 + 2H_2SO_4$. Upon further oxidation, the ferrous is converted into the ferric sulfate, $Fe_2(SO_4)_3$, which is the less soluble of the two. The ferrous sulfate may also be oxidized and decomposed completely, giving rise to the hydrated forms of iron oxide, the limonite type, $2Fe_2O_3.3H_2O$ and sulfuric acid. The latter acts on other minerals, giving rise to various sulfates: $CaSO_4.2H_2O$ (gypsum), $MgSO_4.Al_2(SO_4)_3.24H_2O$, and others.

Olivine, $(Mg, Fe)_2SiO_4$, is a representative of the salts of orthosilicic acid, (H_4SiO_4). Upon oxidation and hydration it is converted into *serpentine*, $H_2Mg_3(SiO_4)_2.H_2O$ or $3\ MgO.2SiO_2.2H_2O$. In the presence of CO_2, carbonates of Mg and Fe are formed, as indicated by the equation:

$4(Mg, Fe)_2SiO_4 + 5CO_2 + 2H_2O = MgCO_3 + 4FeCO_3 + H_2Mg_3Si_2O_8.H_2O + 2SiO_2$. The $FeCO_3$, under the influence of water and oxygen, is split into $Fe(OH)_3$ and CO_2. The serpentine is decomposed, with the loss of Mg, leaving behind the silicic acid which breaks down into water and SiO_2. Sometimes *talc* is derived from the serpentine.

Pyroxenes (augite) and *amphiboles* (hornblende) are salts of metasilicic acid (H_2SiO_3). When these minerals are acted upon by carbonation and hydration, minerals and compounds of Fe, Al, and Mg are formed. The non-ferruginous pyroxenes, such as *enstatite*, $MgSiO_3$, which is, however, seldom free from iron, break down to form *talc*, $H_2Mg_3(SiO_3)_4$, and $MgCO_3$ according to the equation:

$$4MgSiO_3 + H_2O + CO_2 = H_2Mg_3(SiO_3)_4 + MgCO_3$$

The feldspars and feldspathoids are the most important constituents of all rocks, as far as the parent material for soil formation is concerned. Under the influence of hydration and carbonation they break down into clay-like mineral groups, the kaolins and others. Kaolinization is one of the most widespread processes. It begins with hydration of the silicates, followed by a splitting off of the bases, Ca, Na, K, Mg, and by the separation of silica. A schematic equation for the decomposition of the feldspars is as follows:

$$\underset{\substack{\downarrow\\ \textit{Orthoclase}}}{K_2Al_2Si_6O_{16}} + CO_2 + 2H_2O = \underset{\substack{\downarrow\\ \textit{Kaolinite}}}{H_2Al_2Si_2O_8.H_2O} + K_2CO_2 + 4SiO_2$$

$$\underset{\substack{\downarrow\\ \textit{Albite}}}{Na_2Al_2Si_6O_{16}} + CO_2 + 2H_2O = \underset{\substack{\downarrow\\ \textit{Kaolinite}}}{H_2Al_2Si_2O_8.H_2O} + Na_2CO_3 + 4SiO_2$$

$$\underset{\substack{\downarrow \\ \textit{Anorthite}}}{CaAl_2Si_2O_8} + CO_2 + 2H_2O = \underset{\substack{\downarrow \\ \textit{Kaolinite}}}{H_2Al_2Si_2O_8.H_2O} + CaCO_3$$

Micas, as mentioned earlier, weather more easily than feldspars. It has been shown that *muscovite,* the white variety of mica, splits off its bases more readily than orthoclase. This may also be corroborated by observations that plants may utilize more readily the K from the micas than from orthoclase. *Biotite,* the black mica, is more general in its distribution than muscovite. According to some investigators, biotite decomposes rather easily, forming a kind of bloom on the surface consisting of hydrated Fe_2O_3. Simultaneously, with the separation of the oxide of iron some K is split off. The end product is again, as with the true feldspars, a kaolin. Some micas contain Ti; upon release, the Ti forms rutile, TiO_2. In semi-marshy deposits, Glinka found certain biotites giving rise to kaolin-like materials with the Fe-silicate intact. Kaolin and similar mineral groups may also form from *nephelite, sodalite, leucite, glauconite,* and many other silicate minerals of Al with or without admixtures of other elements.

Other minerals, besides the silicates, also undergo decomposition under the influence of chemical agents. Thus, *vivianite* ($Fe_3(PO_4)_2.8H_2O$) and *paravivianite,* in which Ca, Mg, and Mn are substituted for some of the iron ($(Fe, Mn, Ca, Mg)_3(PO_4)_2.8H_2O$), become oxidized with the separation of Fe_2O_3. Carbonates, like limestone and dolomite, when acted upon by carbonic acid give rise to bicarbonates. Since most of the carbonate rocks and minerals, such as chalk, dolomite, magnesite, lime marls, etc., are not, as a rule, 100 per cent pure, they leave behind, upon weathering, silicates and other impurities which consist of clay-like minerals and other mineral residues, with very little quartz. Soils formed from these materials are never sandy but are clay-like in nature. Whenever limestones are free of impurities, there is practically no residual material which may serve as parent material for the formation of a soil. An example of such a limestone was noted by the author along the Baltic Sea near Tallinn, the capital of Estonia. It was a deposit of Silurian limestone, locally known as *Glint.* The shallow layer of soil material formed on it supports a sparse grass cover instead of the natural forest cover.

As a result of chemical weathering, the bulk of material generally increases. Reactions like hydration, carbonation, and oxidation are additive in character. It has been calculated that the formation of clay from a granite may be accompanied by an 88% increase in bulk. However, such an increase does not actually take place. Large quantities of the products of weathering are removed in solution and some go off into the air as gases.

Among the products of weathering, silt occupies a unique place. It is nothing more than a kind of intermediary product in the kaolinization process. Essentially, the term designates a certain particle size of the mineral component of the soil (see Ch. V).

In the weathering of rocks and minerals, physical agents appeared first on the scene, followed closely by chemical agents. Disintegration paved the way for decomposition. Nature still follows this course.

Igneous Rocks and Weathering

From the point of view of their silica content three classes of igneous rocks are recognized: *acidic, neutral,* and *basic.*

Acidic Rocks.—Igneous rocks with an average composition of 65 to 80 per cent SiO_2 belong to this class. They formed from magma containing an excess of SiO_2 over bases. The granites and gneisses (metamorphosed granite) are typical representatives of acidic rocks. Both have an abundance of quartz and feldspars, primarily orthoclase and some plagioclase which contains a high proportion of albite. Some biotite mica, augite and hornblende, and small quantities of apatite also occur in granites and gneisses.

Upon weathering, acidic rocks give rise to sand and sand-like constituents. Fragments of feldspars, especially orthoclase, are easily detected in the mass of weathered material. Of course, the clay-like minerals are very prominent. Some Al_2O_3 and silicates of Mg are also encountered. In arid regions, the bases are partially retained as carbonates. Because of the low Fe content in this class of rocks, the weathered products are light in color.

Neutral Rocks. — Igneous rocks with an average composition of 70 to 50 per cent SiO_2, with no free quartz, are neutral rocks, originating from magma containing equivalent quantities of bases and silica. The diorite-andesite and syenite-trachyte rock families are typical representatives of this class of rocks. They contain the more alkaline feldspars, predominantly plagioclase. The weathered material is similar to that of the acidic rocks, except for being less sandy in nature.

Basic Rocks.—Igneous rocks with an average composition of 65 to 30 per cent SiO_2, with no free quartz, are basic rocks. Diabase, gabbro, and basalt are typical representatives of this class of rocks. They are rich in Fe, Mg-silicates, as exemplified by the pyroxenes and amphiboles. They also contain some olivine and plagioclase, and particularly the Ca feldspars.

The basic rocks, because of their inherent lack of quartz minerals, upon weathering give rise to products rich in the finer clay-like minerals and

SiO_2 and Al_2O_3 gels. In the arid regions, carbonates of Ca and some Mg are found in considerable quantities. The color of the weathered material is generally dark brown to red. This is due to the coating of iron oxide gels which split off in the weathering of the iron rich rocks.

Sedimentary Rocks and Weathering

Sedimentary rocks, as pointed out in chapter II, are more complex than igneous rocks. They consist of all three groups of rocks, igneous, sedimentary, and metamorphic, and their weathered products. Thus, the stable end-products of the weathered igneous rocks, SiO_2, R_2O_3, and the clays and fragments of the original unaltered igneous and metamorphosed igneous rocks are constituent parts of sedimentary rocks.

An important group of sedimentary rocks is the *clay rocks,* consisting of the finest sedimentary material resulting from land erosion. The predominating material of these rocks is made up of clay and clay-like minerals. Associated with these are quartz, grains of feldspar, mica, hornblende, pyroxene, grains of other rocks, and materials deposited from solution, such as SiO_2, R_2O_3, carbonates of Ca and Mg, gypsum, pyrite, and organic matter. These rocks disintegrate and decompose with less loss or gain than the igneous rocks because a large share of the materials comprising sedimentary rocks had been weathered once before. The minerals and rocks deposited from solution do undergo weathering for the first time. Thus, carbonates dissolve and, depending on the climate, are either leached or translocated in the profile. Further weathering of the clay and other complex minerals in sedimentary rocks may increase the SiO_2 content of the end-products, especially the very fine sands.

Argillite is a typical representative of the clay rocks. It is sometime classified with the metamorphic rocks because of its hardness. Upon weathering, argillite breaks into irregular fragments.

Shale is another clay rock similar to argillite, except that it is laminated. Shales may be gray, black, or red in color, according to whether the original mud was ordinary clay, or mixed with organic matter, or stained red with iron oxide. The gray shales in New Jersey in the vicinity of Princeton are the result of the intrusion of trap rock through the red shale. *Sandy shales* contain appreciable quantities of sand. *Calcareous shales* contain some limestone. *Oil shales* contain oil, sometimes enough to warrant the distillation of petroleum products. Upon weathering, shales give rise to clay-like parent materials containing some altered orthoclase and hematite.

Sandstones consist of sands cemented with oxides of Fe and Al, argillaceous materials, or limestone minerals. The sands may be grains of pure SiO_2 (sand in a chemical sense) or grains of rock or of any mineral (sand in a mechanical sense). Representative rocks in this class are: *Siliceous* sandstone, one in which the quartz grains form practically the entire rock; *micaceous* sandstone, one in which mica is present in abundance; *ferruginous* sandstone, or *ironstone*, one rich in iron carbonate or oxide, either as a cementing material or in the form of grains. Sandstones consisting of sands in the chemical sense, cemented with SiO_2 or with calcium carbonate, upon weathering, give rise to a quartz sand. Sandstones consisting of grains of feldspars, mica, and hornblende will, upon weathering, leave behind besides quartz, also some clay and claylike materials. It should be noted that cementing agents, as a rule, weather first and are carried away by the percolating waters.

Conglomerate and *breccia* (Italian, pronounced Brech'a) are related in their makeup and mode of weathering. Conglomerate, sometimes called puddingstone, is composed of consolidated and cemented sand, gravel, pebbles, or boulders. Breccia is a consolidated and cemented rock of angular fragments, formed from talus which has been transported a short distance.

Limestones and other calcareous sediments, such as marls, give rise to end-products, the composition of which is determined by impurities of the rocks. Mechanically the end-products are, as a rule, clayey in nature. Iron minerals in limestone, upon weathering, frequently give the products a red or brown color. In the case of calcareous sands, the end-products are more sandy in texture, yet containing appreciable quantities of clay. A characteristic feature of the weathered products of limestone is the presence of some organic matter, the result of chemical weathering by biological agents. In general, chemical agents rather than physical prevail in the weathering of limestone.

Climate and Weathering

The intensity of weathering is in a large measure determined by the climate. In the arctic regions where temperatures fluctuate widely within the freezing range during the long winter periods, the physical agents are potent and disintegration predominates. In deserts, the paucity of water inhibits the forces of chemical weathering. On the other hand, sharp diurnal changes in temperature favor physical weathering. It is significant that in the two regions, though widely separated geographically, the type of weathering is identical. The products of weathering consist chiefly of broken rocks with fresh surfaces and sharp edges.

The maximum intensity of weathering is reached in the humid tropics and subtropics. In these regions, the essential and accessory minerals decompose almost completely, and the soluble products of the reactions are removed by the excessive percolation. Basic igneous or related rocks leave behind the oxides of Fe, Al, and sometimes Mn. Most of the SiO_2 of these rocks leaches into the ground waters. Acid rocks leave behind some quartz silica together with the oxides of Fe and Al. The residual products enumerated represent the limits of rock decomposition under the climatic conditions of the tropics and subtropics. These products, known as *allit,* comprise the laterites. Rocks and minerals containing as high as 60 to 70 per cent of SiO_2 are decomposed to a point where 5 to 10 per cent SiO_2 remain in the allitic products of weathering. And yet, in spite of the extremely intensive weathering, appreciable quantities of the clay minerals are found in the tropics. Sometimes, the Fe and Al gels coat the clay particles and protect them from further weathering.

In the humid temperate climate, the intensity of weathering is not as high as in the tropics. The soluble products of chemical weathering are not removed as rapidly as in the tropics. Some of these recombine and form new insoluble compounds. The residual products are, therefore, not the final limits of weathering, the so-called allit. Kaolins and similar formations are the principal end-products. Because of the high clay content, a goodly portion of the soluble salts are absorbed and retained. Also, considerable remnants of the original minerals stay behind. From the standpoint of fertility, the products of weathering in the humid temperate climate are much richer than those of the tropics.

In the semiarid and arid climate, the intensity of weathering is less than in the humid temperate climate. The paucity of percolating waters hinders the removal of some of the soluble salts. This results in the formation and accumulation of carbonates of Ca and Mg. These bases, in turn, keep the medium on the alkaline side, thereby preventing the solution of Fe, Al, and Mn compounds. The montmorillonitic types of clay are the products of weathering in these regions.

CHAPTER IV

SOIL FORMATION

Phases of Soil Genesis—In the genesis of soils, a succession of two phases may be recognized: first, the formation of raw materials from the body of native rocks; second, the conversion of this material into a new body, the soil.

The first phase is accomplished by weathering, primarily a breakdown process accompanied by exothermal reactions and hence liberation of energy. This phase may be traced to the earliest stages of our earth's history, long before life appeared on this earth.

The second phase is associated with the action of the biosphere on the products of the first phase. The first land plants anchored themselves to the mineral constituents in search of nutrients and water. With the death of plants, decomposition sets in, and most of the energy accumulated in the process of photosynthesis is released. Chemical and physical reactions take place leading to a differentiation of the mineral and organic materials into horizons and the formation of the soil body.

Since the formation of the soil body is associated in a large measure with the energy-releasing organic matter, soil genesis should date back to the time of the origin of plants on this earth. Whereas this is true, it should not be inferred that the soils we see now had their origin in those remote days. It is certain that all aboriginal soils were destroyed. Soils have been recreated several times during the geological history of our earth. *Our present soils are of recent origin, the product of the present day climate.*

THE FACTORS OF SOIL FORMATION

The principal factors of soil formation are: *climate* and *biosphere.* These factors in association with the *parent material, topography, age of the land,* and other factors mould the constitution of the soil body.

Parent Material.—As a factor of soil formation, parent material is, in a way, passive. *Different parent materials give rise to the same kind or type of soil whenever the principal factors of soil formation, the climate and biosphere, are the same.* A corollary to this principle is *that similar parent materials give rise to a different kind or type of soil, provided the principal factors are dissimilar.* As Marbut puts it (Marbut, C. F. (1928) A scheme of soil classification, *Proceed. and Papers, First Inter. Soil Sci. Congress* 4:1-31) . . . The soil surveyor was forced to recognize "that although the geological formations of Piedmont, Maryland, for example, and those of Georgia are closely similar in all respects, the soils are widely different; that soils in Georgia overlying granite rocks and undoubtedly developed from their disintegrated products have no single element of similarity to soils on and derived from granite in Los Angeles County, California; that soils on limestone glacial drift in South Dakota and those on limestone glacial drift in Indiana have no single important characteristic in common except texture; that soils derived from loess in Saunders County, Nebraska, Grenada County, Mississippi, or Clermont County, Ohio, are different in every respect from soils derived from loess in Spokane County, Washington."

There are departures from the general behavior of the parent material as a factor of soil formation. There are soils in which the composition of the parent material resists the effects of the climate. Such soils are called *endodynamomorphic* in contrast to the *ectodynamomorphic*,[1] which develop a normal profile as a result of the climate and biosphere. The endodynamomorphic conditions of soils are often temporary, persisting until the chemical composition of the parent material has changed under the influence of the other factors of soil formation. Thus, the soils on the chalk cliffs of England, of Normandy, France, known as rendzinas (see Ch. IX), are black in color, but will become lighter with age. The soils formed on the red shales of the Piedmont or Appalachian geographic divisions are another example of endodynamomorphism. The shales represent erosion material of an aboriginal soil deposited in shallow fresh water basins. The red color indicates that the original soil had large quantities of certain constituents removed and iron accumulated. For this reason, the soils on the shale parent material remain red in spite of the normal brown color of the soils adjacent to the red shale soils in the forest zone. In short, the parent material rather than the climate asserts itself in this case.

Topography.—A hilly or mountainous topography, termed macrotopography, is conducive to endodynamomorphism. The normal geologic erosion, removing from the slopes some of the products of weathering, hinders the development and formation of a distinct soil profile. The soils, therefore, remain immature or young (in the sense that they are undeveloped.) When fresh rock fragments, large stones, and boulders are imbedded within the mass of the young soil body, the soils are called skeletal.

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[1] *Endodynamomorphic*—pertaining to changes brought about by means of the properties of the parent material rather than of external conditions. *Ectodynamororphic*—pertaining to changes brought about by external forces, such as climate. *Endo-* is from the Greek *endon*—within; *ecto* is from the Greek *ektos*—without, external; *dynamo* is from the Greek *dynamis*—power; *morpho* is form.

Slope exposure—north or south—as a feature of topography, influences the type of soil. In general, southern exposure is warmer and drier and is subject to marked fluctuations in temperature and moisture; northern exposure is the converse; the western and eastern exposures occupy an intermediate position. Two distinctly different types of soil develop on northern and southern slopes facing each other. In the Big Horn Basin, Wyoming, one may encounter black soils on one exposure, and gray-brown on the opposite exposure, notwithstanding the absolute similarity of the parent material.

Slight elevations or depressions in topography, termed microtopography, sometimes known as microrelief, give rise to local types of soils that differ in their morphological, physical, and chemical features from those of the prevailing type. Some of the sandy soils of the Coastal Plain have no A_0 layer, except for depressions. Local variations of this nature are often responsible for spots outstandingly good or bad, from the standpoint of crop yields, in an apparently level field.

Age of the Land.—We have mature soils with fully developed profiles and young soils showing only indications of horizon differentiation independent of the geologic age of the land. Mature soils, as a rule, have been acted upon by the principal soil factors for a longer period of time than young soils. Sometimes, however, a soil which has been acted upon for a longer period of time than another mature soil in the same region has remained young. In other words, the time factor infrequently does not affect the maturity of the soil. Soil age is, therefore, to be reckoned in terms of maturity-stage of development of the profile, with no reference to geologic age of parent material. The Penn soils in the Piedmont, formed on parent material of an earlier geologic age than the soils of the Coastal Plain, are younger, in the sense of maturity, than any of the soils of the Coastal Plain. The fact is that the Penn soils have little horizon differentiation, whereas the soils of the Coastal Plain have fully developed mature profiles.

Climate as a Factor of Soil Formation

The climate influences the processes of soil formation directly and indirectly. Directly, the two primary elements of climate, precipitation and temperature, supply water and heat to react with the parent material. Indirectly, the climate determines the fauna and flora (the biosphere) which furnish sources of energy in the form of organic matter. This energy acts on the rock and mineral material by means of acids and salts released in the process of organic matter decomposition. To appreciate the role of the climate in soil formation one must study its individual elements.

Precipitation—Percolation and leaching are the outstanding direct effects of precipitation in the process of soil formation. As the percolating waters come in contact with the parent material, some constituents go into solution. They are translocated, in a way, analogous to the blood circulation in animals or to the movement of sap in plants. Some constituents are removed from one point in the column of mineral material and deposited at another point. In this manner, a differentiation in the mass of the material takes place, and the soil body is formed. In the early days of the earth's history, before land plants made their appearance and established a protective shield against erosion, there could be no soil formation. With the appearance of plants in the sphere of activities on our planet came not only protection against erosion, but also a reservoir of chemical reagents, the by-products of organic matter decomposition. These reagents contribute very effectively in the reactions between the percolating waters and the materials with which they come in contact.

Not all the water reaching the ground is available for percolation. Runoff and evaporation cut down the quantity considerably. It is generally accepted that 15 to 50 per cent of the total precipitation percolates and reaches the ground waters. Texture of material, slope of the land, rain intensity, air and ground temperature, and vegetative cover are responsible for the wide variations in percolation.

In general, the total volume of precipitation dominates percolation volume and its effects. There is no horizon differentiation in the rainless desert because there is no moisture for percolation. The presence of a soil profile in the desert is evidence of an earlier more humid climate. With an increase in precipitation, more percolation takes place and soil horizon formation results. In regions of excessive precipitation, such as in some parts of India, Hawaiian Islands, and Java, where the annual rainfall reaches the startling figures of 120 to 288 inches, the story of percolation is different. Even though a large share of the precipitation runs off, enough of it percolates through the soil body. Very few of the dissolved substances are, therefore, retained in the soil profile. This, of course, influences the specific type of soil profile formation.

In analyzing precipitation as a factor of soil formation, one must consider not only the quantity, but also the forms of water, such as snow and rain, as well as seasonal distribution, surface runoff, evaporation, and humidity.

In regions of the arctic, subarctic, and cold-temperate climates, very little water is available for percolation. As the snow melts, most of the water disappears as surface runoff. Some of the snow sublimates during the periods of low temperatures.

In regions of the Mediterranean type of climate[2] (characterized by winter concentration of rainfall and rainless or nearly rainless summers), *percolation effects, and hence translocation of soil constituents, are limited to the winter season.*

In the arid and subhumid regions, such as the Western prairie, the Great Plains of North America, and the chernozem (black soils) areas of Europe and Asia, seasonal distribution of rainfall must be considered. Summer rainfall occurs in the form of heavy thunder showers and surface runoff is, therefore, of considerable moment. Severe and long winters keep the ground frozen for months and months. On the other hand, the ideal structure of such soils as the chernozems is conducive to entry of water into the profile.

In the Mississippi and Missouri Valleys, we have what is known as the ***Missouri type*** of precipitation with a moderate concentration of rainfall during May, June, and July. This concentrates the percolation effects at a definite season.

Evaporation—By definition, evaporation is *the escape of vapor from surfaces.* It varies from place to place, irrespective of the rainfall. A glance at the evaporation map of the United States shows that from April through September evaporation varies from 25 to 88 inches in different parts of the country.

Evaporation is related to humidity. *The mass of water vapor per* unit volume of air—grams in a cubic centimeter—*is known as the absolute humidity.* In speaking of humidity, though, *relative humidity,* is generally understood. *Relative humidity is the ratio of the actual quantity of water vapor in a given volume of air to the maximum quantity possible in the same space at the same temperature.* The actual quantity of water vapor is the *absolute humidity,* and at saturation the maximum quantity is called the maximum absolute humidity. Hence, the relative humidity equals the absolute humidity of the given sample of air divided by its maximum absolute humidity. Relative humidity is, as stated, a ratio between two masses of water vapor and is expressed as a percentage.

Temperature—With the same precipitation in two different isothermal[3] belts, different types of soil profiles will develop.

In the arctic and subarctic regions, temperature is a negative factor of soil formation. There can be no percolation during the long winter season with its extremely low temperatures. The perpetually frozen layer hinders percolation even during the summer. In the arid regions, the

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[2] In the United States, the Pacific type of rainfall is similar to that of the Mediterranean region.

[3] An *isotherm* is a line drawn through points of equal temperature.

A line of equal rainfall is called *isohyet.*

high evaporation and low humidity reduce greatly the supply of water for percolation.

In the subarctic, in the cold temperate regions, and in the high mountain country where extended severe winters persist, conditions are unfavorable for rapid percolation of water through the profile. The result is thousands of lakes, swamps, and peat and muck deposits. These organic matter accumulations take place in spite of the low yield of vegetation because of the short growing season. Another factor favoring organic matter accumulation in these regions is the restricted activity of the microorganisms during the long winters. Prolonged freezing also favors the stabilization of humus, rendering it more resistant to decomposition by microbes. As a result of these conditions, the A_0 layer of the soils in these regions is frequently deep, a foot or more. In true swampy areas, peat formations extend to great depths. The restricted reactions in the peat deposits under submerged conditions prevent the release of the reagents to react with the mineral component underlying the peat formations. Hence, no soil body forms under peat deposits.

In the humid tropics and subtropics, because of the favorable temperature and moisture relations, there is luxuriant vegetation. Simultaneously, however, these regions offer optimum conditions for a rapid decomposition of plant residues. The result is that very little organic matter may accumulate in the A_0 layer, except in areas of poor drainage where anaerobic conditions prevail. Peat formations are, therefore, also known in the tropics and subtropics, as for example in the Everglades of Florida.

Winds—Winds are indirectly of importance as a factor of soil formation, because they influence the evaporation rate. To a certain extent, however, winds act directly since the fine particles of soil material being carried off impoverish the A horizon. The dust-bowl of the United States is a good example of the devastating effect of winds on the soil body. In the semideserts and along the seacoasts the movement of the sand prevents the formation of horizons.

The Biosphere in Soil Formation

Phytosphere. — Of the two elements of the biosphere, the phytosphere (the plant kingdom) and the zoosphere (the animal kingdom), the former is more important in the process of soil formation. Plant roots penetrate into rock and mineral material and open channels for the movement of water and air. As the roots and other subterranean parts of plants die and decompose, a host of organic and inorganic acids is released. Living roots also excrete carbonic acid and other substances. Entering the circulation of the percolating waters, the acids and other substances react with the rocks and minerals, serving as the reagents of chemical forces on weathering of rocks and minerals. Simultaneously, the reagents, and reaction products, as well as the residual organic matter, are distributed through the column of parent material, moulding the profile and constitution of the soil body.

An important factor in the reactions sketched is the microbial flora, bacteria, fungi, and actinomycetes. Like higher plants they act directly and indirectly on mineral matter of the soil (see Ch. VI).

Zoosphere. — The contribution of the animal kingdom to the processes of soil formation is primarily mechanical in nature. In contrast with the phytosphere, the zoosphere does not always aid in differentiating the horizons in the soil profile. Burrowing animals—ants, earthworms, etc.—dig into the soil body, mix up the material in the horizons, and disturb the soil profile. Rodents are noteworthy for carrying down into their nests (usually located in the B horizon) much material from the upper horizon and bringing up B material into the A horizon. Roots of plants frequently follow the abandoned tunnel borings of rodents, worms, and insects.

Worms. — Darwin pointed out that in certain parts of England earthworms work over and bring to the surface every year more than ten tons of fine dry mould per acre. He stated that "the whole superficial bed of vegetable mould passes through their bodies in the course of a few years." From collections and weighings of excreta deposited by earthworms on a small area during a given time interval, Darwin calculated that the rate of accumulation of the material would amount to one inch in five years. It is of interest that earthworms do their work primarily at night, dragging down leaves and grass from the surface soil into their burrows, thereby mixing the material of the horizons. In any soil profile where earthworms are active their passage channels may easily be observed. These channels serve as routes for water percolation and aeration. Cases have been reported where over 150,000 earthworm burrows have been counted over an area of one acre. The depth to which worms penetrate the soil varies from a few inches to 25 feet.

Generally, earthworms are active in soils rich in organic matter. There is a record of earthworms having consumed in ten months 0.1 per cent of the plant residues of the forest floor. Earthworms prefer a neutral to an alkaline medium. However, they are also encountered in soils under forests which are moderately or even strongly acid. Materials passing through the bodies of earthworms undergo chemical and physical changes. Thus, soil, containing 28.5 mgs. of citric acid soluble P_2O_5, after passing through the bodies of earthworms, contained 34.6 mgs. of P_2O_5. Earthworm excreta contain more lime than the surrounding soil. A pot of soil without earthworms had a volume of 232 cc.; when worked over by worms the volume increased to 296 cc.

Ants and Termites. — Ants penetrate the soil and subsoil, carry material from lower to higher levels, build galleries and underground passageways, throw out a great deal of material to the surface, and frequently form hills and mounds. Shaler, the noted American scholar, calculated that each year over a certain field in Cambridge, Massachusetts, the ants make an average transfer of soil material from the depths to the surface sufficient to form a layer of at least a fifth of an inch over the entire four acres under observation.

Shaler mentions an interesting species of social ants, the *Myrmica barbata* of Texas, commonly known as the "agricultural ant." It has "the remarkable habit of clearing away the natural vegetation, or at least the slight annual undergrowth, from a bit of ground near its habitation. On this surface it plants particular species which afford nutritious grains. If the conclusions of the observers are correct, this creature is the solitary animal besides man which has invented any kind of agriculture."

A species of ants in the Amazon valley locally known as *saubas* or *sauvas* has been reported "to excavate and build galleries which are frequently from 50 to 100 feet long, from 10 to 20 feet across, and 1 to 4 feet high, and contain tons of earth."

The white ants or termites, like the true ants, burrow extensive channels in the ground and build upon the surface huge nests which vary in size from 1 to 12 feet in diameter. Especially large are the nests in the tropical forests, where termites live in earthy structures or in trunks of trees.

In Turkestan, a species of subterranean dwelling termites has been reported with nests and tunnels going down deep to the moist layers of the subsoil. This may mean a depth of 20 to 40 feet. Other termites in Turkestan have been noted to form hills as large as 15 feet in diameter and 2 to 6 feet high.

Hilgard points out that "the work of ants is in some regions on so large a scale as to attract the attention of the most casual observer. Especially is this the case in portions of the arid regions, from Texas to Montana, where at times large areas are so thickly studded with hills from 3 to 12 feet in diameter and 1 to 2 feet high, that it is difficult to pass without being attacked by the insects. The mounds studding a large portion of the prairie country of Louisiana, although not inhabited at present, seem to be due to the work of the ants." The author observed red ants in New Jersey lining the walls of their passageways with limestone and organic matter to a depth of more than 2 feet.

Rodents. — In the treeless arid regions, large numbers of vertebrates birds, mammals, and reptiles are forced to choose the soil as their habitation. Of all the vertebrates, mammals such as the rodents, are most active in the soil. Next to earthworms, rodents have been most extensively studied. The majority of the rodent family makes burrows, sometimes deep, with complicated systems of tunnels and passageways. It is claimed by some naturalists that the pocket gophers, *Thomomys,* in a great degree replace the activity of the earthworms in the arid regions. Besides gophers, prairie dogs, ground squirrels, badgers, the blind mole rats, and other genera make their home in the soil.

Crotovina is a Russian term adopted by pedologists the world over for the passageways and nests of rodents. Literally, it means the nest and passageways of the "Krot," the Russian name for the mole. In the United States, it is claimed moles are the most numerous burrowing animals. They live mostly below the depth of penetration of grass roots, forming a network of ridges which mark the paths they follow.

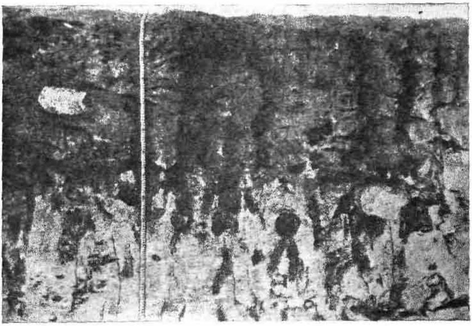

PLATE 2
Crotovinas in a chernozem profile from Ufa
(After Kassatkin)

In humid regions, field mice and moles are encountered. It has been reported that on the island of Martha's Vineyard, Massachusetts, wild mice are so abundant that brushwood areas, often acres in extent, are completely honeycombed with their burrows.

Another animal of importance in certain soils is the crayfish. According to Merrill, "these animals, in searching for their food, bore numerous horizontal channels or galleries sometimes an inch or so in diameter and extending for many feet, usually ending in an upward shaft reaching to the surface, or the margin of a pond or a stream. These form natural drainage channels and allow a more ready access of air, converting what might under other conditions be a heavy, clayey or even marshy soil, unfit for cultivation, into one light and fertile." While in charge of a truck gardening project on a Portsmouth soil in North Carolina, the author examined numerous crayfish channels with their shafts terminating at the drainage canals and ditches. The walls of the channels and shafts were of a bright brown color in contrast to the gray brownish mottled appearance of the surrounding soil. This brown color indicates aeration by way of the crayfish channels.

THE FORMATION OF THE SOIL PROFILE

The factors of soil formation bring about a series of reactions and conditions in the mass of the parent material. Some of these factors are universal in character and effect, and they impart the broad fundamental profile features inherent in the soil body. All soils develop a definite profile constitution, as described in chapter I, irrespective of geographic position. The processes involved in the formation of the soil body, as given presently, will illustrate the workings of the factors of soil formation.

The A_0 Layer

Organic matter of plant or animal origin exposed to the elements is constantly subjected to *humification* and *mineralization*. The former is the process of decomposition of organic matter leading to the formation of humus. The latter is the process of decomposition of organic matter to its fundamental composition, i. e., to CO_2 and other gases, water, and minerals.

The nitrogenous substances of plants, such as the proteins and amides, upon decomposition, give rise to ammonia. Some of the ammonia is absorbed by the soil. Most of the ammonia, however, is converted by the nitrifying organisms first into nitrous and finally into nitric acid. The sulfur of the protein is oxidized by sulfur-oxidizing organisms into sulfuric acid. The carbonaceous portions of proteins and of other plant substances, upon decomposition, give rise to a series of organic acids, such as formic, acetic, citric, lactic, oxalic, butyric, propionic, and others. And above all, CO_2 is formed in the decomposition of any kind of organic matter. A portion of this gas goes off into the air to be utilized by living plants in the process of photosynthesis. Another portion dissolves in water, forming carbonic acid. This is probably the most abundant acid formed in the humification and mineralization processes that take place in the A_0 layer.

The disposition of the decomposition products formed in the A_0 layer varies with the climate. In the subarctic and cold humid temperate climate, the organic acids do not disappear readily. The more soluble acids move with the percolating waters into the A horizon. However, some of the soluble and insoluble acids are adsorbed by the humus. Because of the adsorbed acids and of other acid compounds, the forest floor in these regions is often spoken of as containing raw humus. The acid conditions of the A_0 and the prolonged winter period in these regions curtail the activities of microorganisms. The result is a relatively deep A_0 which is often referred to as the humus-decay-accumulative layer. In the southern portion of the humid temperate climate, microbial activities are more intense; more of the organic acids are mineralized, and the A_0 layer is not so deep. On the sandy soils of this region, the A_0 is, as a rule, very shallow because of the excellent aeration which is conducive to decomposition of organic matter. On some spots of the sandy areas, there is practically no A_0 accumulation.

On similar textured soils, such as loams, the depth of the A_0 varies from 0.5 to 2 or 3 inches. This depth holds true for well drained soils. In poorly drained areas, irrespective of the climatic region, the A_0 layer may extend to a depth of a foot or more, giving rise to peat-like formations.

In the humid tropics and subtropics, most organic acids do not persist for any length of time. Together with other forms of organic matter they are rapidly and completely decomposed. (The rapid disappearance of organic matter in the humid tropics and subtropics is often spoken of as the "burning up" of organic matter). The superabundant supply of CO_2, resulting from the humification and mineralization processes in these climatic regions, is disposed of in a slightly different manner than in the other regions. A large portion of the CO_2 is rapidly reassimilated by the luxuriant vegetation typical of these regions. Another large portion of CO_2 forms carbonic acid which unites with the bases released in the mineralization process, forming bicarbonates. The latter increase the OH ion concentration of the medium. The result is that the material of the A_0 layer in this region is less acid than that of the A_0 in the regions of the subarctic and humid temperate climates. Partly because of lesser acid reaction and partly because of the ideal conditions for microbial activities, the A_0 layer in the tropics and subtropics is not so deep as in the other climatic regions. This is true, in spite of a practically all-year-round growing season and a tremendous turnover of luxuriant vegetation.

In the grasslands, the A_0 layer blends in with the humus materials of the underlying mineral A horizon, and yet partly decomposed and completly humified substances are very much in evidence. The mat of dead vegetation in the sod of the meadow in the humid regions and of the prairie and black soils in the less humid and semiarid regions represent the A_0 layer of grasslands. But there is a difference in the mode of formation and in the composition of the dead sod of the meadow and of the prairie. *In the meadow, the grasses die as a result of low winter temperature,* although there is usually an abundance of moisture. *In the steppe* (grassland of the arid and semiarid regions) *the grasses die very frequently as a result of high temperatures and low moisture supply during the summer.* They revive in the late fall to die again in the winter. The net effect is that the humus of the A_0 layer of the steppe is rich in bases. In general, grasses have a higher mineral content than forest vegetation. This will explain why an acid soil when seeded to grass will, after a few years in sod, become less acid. The grasses circulate large quantities of bases for their metabolism and return them in the processes of humification and mineralization through the surface soil, thereby neutralizing some of the acids.

Summary Statement. — The A_0 layer is the source of origin and reserve supply of reagents produced as a result of humification and mineralization. The quantity and quality of reagents vary with the climate and type of vegetation.

Formation of the A Horizon

Waters filtering through the A_0 layer carry the soluble decomposition products of the processes of humification and mineralization. Coming in contact with the underlying weathered rock and mineral materials, these products react with them and bring about a series of transformations which vary primarily with the climate.

In the reactions just mentioned, Na is the first to be detached from the silicates by the attack of acids. Since Na in water solution forms no insoluble compounds, it is carried, in the form of nitrate, sulfate, bicarbonate, chloride, etc., by the percolating waters into the ground waters; from there to the streams, and finally to the oceans. This behavior of the Na explains why the salts of ocean waters consist primarily of NaCl.

In the next stage of the reactions between the acids and minerals, K, Ca, Mg, Mn, Al, Fe, and any other base attached to the minerals are split off. The order in which the minerals are mentioned does not mean that while Na or K is released, none of the other elements are. The order given does imply the ease with which the elements are split off. As a matter of fact, Ca, because of its combination with bicarbonate and sulfate, leaches out in quantities greater than any of the cations.

If Ca and Mg, in their downward movement, encounter the silicate, phosphate, or carbonate anions, new insoluble compounds are formed.

As for the K, it should be pointed out that the feldspars and other silicate minerals are the chief source of this element and that these minerals hold the K very tenaciously. Besides, K, when subject to alternate wetting and drying, may attach itself to clay-like minerals and other complexes and become insoluble. In other words, although K, like its chemically close relative Na, forms no insoluble compounds, not much of it is carried away into the ground waters.

Whenever any one of the bases is released, its place is taken by the hydrogen of the acids, as may be seen from the following equation:

BX-silicates + HA = HX-silicates + BA, where B = the alkali and alkaline earth bases; X = other bases, such as Mn, Fe, and Al; and HA = any acid, such as H_2CO_3, HNO_3, H_2SO_4, and CH_3COOH (acetic acid). As the H-ions replace the bases in contact with the silicates, the acidity of the materials underlying the A_0 layer increases.

In the soils of the humid regions, enough acids are available to attack the clay minerals. The result is the release of R_2O_3, the sesquioxides (Fe_2O_3, Al_2O_3, and Mn_2O_3), and SiO_2. Generally, this SiO_2 remains behind in the lower part of the A horizon, whereas the R_2O_3 migrate downward and precipitate in the underlying horizon.

The plant residues of the root system in the A horizon, upon decomposition, augment the reagents which enter into reactions with the minerals. Under conditions of subarctic and humid temperate climate, the organic matter of the A horizon is concentrated in the first few inches. More organic matter is found in the A horizon of the soils in the northern than in the southern sections of the temperate climate.

In the humid tropics and subtropics, where the processes of humification and mineralization are intense, decomposition of the organic matter is rapid and the circulation of bases is, therefore, enormous. The net effect of this cycle is that the A horizon is not as acid as in the soils of the humid temperate climate and very little organic matter accumulates in this horizon. It should be noted that, whereas the circulation of bases is high in the tropical regions, large quantities are removed from the profile by heavy percolation.

Because of the abundance of carbonic acid in the soils of the tropics, the $\overline{\overline{CO_3}}$ and $\overline{HCO_3}$ ions are constantly replacing the $\overline{HSiO_3}$ and $\overline{\overline{SiO_3}}$ ions which are washed out by the percolating waters. The bicarbonates are also carried away or chemically broken down. However, there is not enough acididy developed in the soil to solubilize the Fe or Al, hence these elements accumulate as oxides or hydroxides in the A horizon. The net result of the reactions in these climatic regions is a loss of bases (Na, K, Ca, and Mg) and of SiO_2, and an accumulation of the sesquioxides in the A horizon. It is the iron oxides in this horizon that impart the red color to the soils in the tropics and humid subtropics.

In the arid, semiarid, and subhumid climate, the paucity of precipitation precludes extensive percolation; the A horizon does not lose bases to the extent the humid regions do. It is true that Na escapes, while some K, Mg, and a little more Ca move downward. However, enough of these bases return because of the dying grass vegetation and thereby prevent the acidulation of the A horizon.

Summary Statement. — The net result of the reactions involved in the genetic relationships of the A_0 layer and the A horizon is the removal of certain constituents from the surface layer of the parent material. This process is, therefore, known as *eluviation* (washing out), and the A horizon is designated as the *horizon of eluviation.* The reactions and results described are true for all climatic zones, but the soils of each zone exhibit specific variations as to quantity and kind of bases and other constituents removed (see Ch. VIII).

A characteristic result of the removal of constituents from the A horizon is its coarser texture, i. e., its clay and silt content is lower than of the underlying horizon. Because of the lighter texture and prevailing larger amounts of organic matter in the A horizon, its structure is more open and its consistency more mellow and more friable than of the underlying horizon.

In depth, the A horizon varies with the climate. In cold and humid temperate zones it is from 10 to 16 inches deep; in the tropics it is somewhat deeper; and in semiarid and subhumid grass country it is still deeper, 24 to 30 inches or more.

In anatomizing the soil body, pedologists have noted that the A horizon was not homogeneous throughout its depth. Minor aspects of the morphology, especially color, and of some chemical attributes of this horizon necessitated a differentiation of subhorizons, the A_1 and A_2 horizons. The upper part of the A horizon, the A_1, is usually darker in color, has more organic matter, is looser in constitution, and is more porous than the lower part, the A_2 horizon. Other features which justify the subdivision of this horizon into an A_1 and an A_2 will be presented in Chapter VIII.

Formation of the B Horizon

The products of the reactions between the mineral constituents of the A horizon and the reagents furnished both by the A_0 layer and the organic matter of the A horizon are carried by the percolating waters to the B horizon. Depending on climatic conditions, the eluviated substances are in part or entirely retained in this horizon temporarily or permanently.

In the cold and in the humid temperate climates, the presence of acids in the A horizon, some of which are even carried to the B horizon, prevent the formation of carbonates in the profile. Nevertheless, some bases are retained by the clay particles by sorption (see Ch. VII). Because of these bases, the acidity in the B horizon is always less than in the A horizon.

When soluble Fe and Al salts reach this horizon and find the medium less acid, they precipitate as the hydrous oxide gels. Clay dispersions, upon sorbing some bases, also precipitate. In this manner, clay accumulates in this horizon. Some soluble organic compounds follow suit and add to the gel-like formations. Together, these materials clog up the pore space between the larger particles: the sand grains, the silt, and the aggregates of these. Sometimes gels of SiO_2 augment the clogging agents. The result is that this horizon becomes compact and relatively impervious to water.

When gels of Fe and Al in contact with some organic compounds are subjected to alternate wetting and drying, they cement some of the mineral grains, forming hard, stone-like lumps, known as concretions. In some instances, the stone-like formation may prevail as a layer at some point in the B horizon, usually in the upper part. This is known as *hardpan*. It should not be confused with the phenomenon of compaction noted earlier. *Hardpan does not slake in water,* whereas a compacted mass when placed in water does slake (see Ch. VII).

In the humid tropics and subtropics, little soluble organic matter, Fe, and Al reach the B horizon. Enough acids and acid salts percolate the B horizon to prevent the stabilization of carbonates in the profile. However, the clay particles carried from the A horizon are not as acid as hose of temperate and cold climates. Therefore, the conditions in these limatic zones are not so favorable for the formation of a compacted layer s in the temperate zone; nevertheless, the B horizon is compacted. Some f the silicic acid moving through the B horizon, as well as some soluble rganic compounds and some iron carbonate or hydroxide, may serve s cementing agents and give rise to an ironstone type of hardpan.

In the arid regions, some of the bases carried downward by the ercolating waters are caught in the B horizon. The Ca and Mg remaining the B horizon form carbonates and impart an alkaline reaction to the soil. In these regions, negligible quantities of Fe and Al are released from the A horizon. Consequently, not much material is available as compacting agent and the soils, therefore, have a B horizon with little compaction, but with an accumulation of carbonates.

There is wide variation in the depth of the B horizon in the various climatic zones: from 8 to 20 inches in the humid temperate climate; somewhat deeper in the tropics; and deepest in the grass country of the arid, semiarid, and subhumid climates, up to 30 inches.

Summary Statement. — From the preceding discussion it is evident that the B horizon is essentially one where materials accumulate. This horizon serves as a storehouse for various nutrients (Ca, Mg, K, NH_4, Mn and other elements). They are adsorbed by the fine particles inherent in this horizon. Other elements, such as Al, Fe, and P, are precipitated as they reach the B horizon. A number of the constituents that are carried to this horizon enter into mutual reactions, giving rise to new compounds. There is the possibility of the formation of some secondary minerals, such as silicates and phosphates of Ca, Mg, Fe, and Al. These new compounds or minerals in the B horizon are designated as *new formations.* The process of creating the B horizon by washing in materials from the overlying horizons is known as *illuviation,* (washing in), and the B horizon is designated as the *horizon of illuviation,* or horizon of accumulation.

The C Horison

The material below the B horizon is, by definition, the C horizon. It has been pointed out (see Ch. I) that if the material upon which the soil body developed was originally homogenous in its mechanical makeup, the C horizon was to be considered as parent material. As a rule, the residual deposits are homogenous down to bed rock; the C horizon of the soil body on this type of material is true parent material. In the case of sedimentary deposits of fairly uniform composition, such as shale or sandstone, the same holds true. On the other hand, there are sedimentary deposits, such as the unconsolidated clays, silts, sands, marls, and gravels of the Coastal Plain, along the Atlantic seaboard and Gulf of Mexico, where the column of parent material was not homogenous. Vast stretches of land may be found in the Coastal Plain area where the deposits consist of 12 to 15 inches of sand underlain by several feet of clay and silt or vice versa. In such a situation, the compacted B horizon is not exclusively the result of the eluviation of the sandy A horizon, but also of its inherent geologic origin.

An outstanding characteristic of the C horizon is its passive property with reference to the materials which pass the B horizon. Under virgin soil conditions, the quantity of material filtering out of the compacted B horizon is rather insignificant. The substances finding their way into the C horizon are chemically inactive, and the reactions that do take place in the C horizon seem to he reversible. For these, as well as other reasons, the C horizon does not change its chemical and physical makeup in the process of soil formation.

SOIL FORMATION AND WEATHERING

Long before life made its appearance on the earth, the bed rock was crushed, crumbled, and mellowed by the forces of weathering. With no vegetation protecting the loose rock and mineral material, the forces of erosion have constantly exposed fresh rock surfaces and the weathering agents have cut even deeper into the earth's crust. When plants entered the scene, they became the source of new chemical agents of weathering. Simultaneously, however, the biosphere acted in differentiating the mass of weathered materials into horizons and in creating the soil body.

After the soil had matured, very little of the constituents released in the process of weathering passes beyond the B horizon. That which is carried to the C horizon has little or no reactivity; no significant changes or transformations, therefore, take place in the C horizon. In other words, the soil body serves as a kind of protective shield against further weathering.

The sequence of the processes of weathering and soil formation is in accord with the laws of nature—namely: *every action has its counter reaction* and for every destructive process (weathering) there is a creative process (soil formation). Soil formation is thus the counter-reaction to the action of weathering. Were it not for the creation of the soil body, the land surface would have weathered to greater depths.

Under existing conditions in nature, the reactions involved in the processes of weathering and soil formation act simultaneously on the soil mass. Because of the difficulty in separating these processes, the tendency is to identify them as one and the same. Although it is hard to draw a line of demarcation between the two processes, they should be looked upon in their natural historical sequence, namely, the weathering process as the first phase, followed by the soil forming processes as the second phase.

CHAPTER V

MINERAL COMPONENT OF SOILS AND PLANT NUTRIENTS

The bulk of any well drained soil consists of the mineral component. In it plants anchor and find mineral nutrients. It also serves as the chief reservoir for water. Variations in composition of this component influence the processes of soil formation and leave their mark on the constitution of the soil body.

Mechanical Composition of the Mineral Component

Mechanically, the mineral component is made up of rock and mineral particles varying in size. A standardized diameter size of the particles gives them their name. Stones are in the size group of 10 to 100 mm. and more in diameter; gravel, 10 to 2 mm.; coarse sand, 2 to 0.2 mm.; fine sand, 0.2 to 0.02 mm.; silt, 0.02 to 0.002 mm.; and clay, 0.002[1] mm. and lower. This system of particle size classification is the one adopted by the International Society of Soil Science. In the United States, particles ranging in size from 1 to 2 mm. are called fine gravel; those ranging in size from 1 to 0.05 mm. are called sand. The sand group is subdivided into coarse sand, from 1 to 0.5 mm.; medium sand, from 0.5 to 0.25 mm.; fine sand, from 0.25 to 0.1 mm.; and very fine sand, from 0.1 to 0.05 mm.

The separation of the sand, silt, and clay particle size groups of the mineral component of the soil is known as mechanical analysis of the soil. Before a mechanical analysis of the soil is made, the boulders, stones, and gravel are removed by sieving the material, first through a 1 or 2 cm. screen and then through a 2 mm. sieve. The material from the latter, the 2 mm. size particles and smaller, are most important in making an inventory of the mineral constituents of the soil and in evaluating some of its physical properties, such as moisture content and percolation, aeration, supply and retention of fertilizer, and root penetration and distribution. Particles above 2 mm. impart specific properties to the soil, and are to be considered if they exceed 10 per cent of the total volume of the soil. The mechanical analysis of the soil thus resolves itself into a separation of the 2 mm. and smaller particle-size material into the following three fractions, or separates: 1, *sand*—coarse, medium, and fine; 2, *silt;* and 3, *clay.* The names of the separates bear no relation to their chemical composition. To be specific, sand in a chemical sense means silica, whereas in a mechanical

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[1] The 0.001 mm. linear value is known as a micron (μ). Clay particles are, therefore, on the order of 2μ and smaller.

sense it implies particles of a size from 2.0 to 0.02 mm. be they of granite, slate, diabase, mica, hornblende, quartz, or of any other rock or mineral.

Since a mechanical analysis of the soil refers exclusively to a fractionation of its *mineral* component into the three standard separates, the organic matter must be removed before making the analysis. Treating the soil with hydrogen peroxide (the method most commonly used), or with potassium permanganate, are standard methods for the removal of organic matter. If the organic matter content of a soil is small, below two per cent, its removal is not essential in making a correct mechanical analysis.[2]

Methods of Mechanical Analysis. — The two methods of mechanical analysis of soils most extensively used in the United States are: 1, the hydrometer methods of Bouyoucos, and 2, the pipette methods as practiced by the Soils Division of the Bureau of Plant Industry, U. S. Department of Agriculture. A field method for determining the mechanical composition of soil is to rub it while moist (not wet) between the thumb and fingers. This method is, therefore, known as the "thumb and finger test". After a little experience, one can by the feel of the soil determine fairly accurately the relative proportion of sand, silt, and clay, within the limits allowed by the standards set for classifying the soil textural units.

Soil Texture

The fabric of the mineral component of the soil resulting from the relative proportion of the three particle size fractions—sands, silt, and clay—is known as soil texture. It is a soil characteristic most universally noticed. The texture of soils is spoken of as *light* or *heavy*. Neither of the two concepts refers to the weight of the constituents which make up the soil; they refer rather to the ease or difficulty with which the soil may be plowed, disked, dug, or cultivated. Soils containing 80 per cent or more, of the coarse, medium, fine, and very fine sands are spoken of as light, notwithstanding their high specific gravity, about 2.7; on the other hand, soils containing more of the silt and clay are spoken of as heavy soils, notwithstanding their lower specific gravity. Light and heavy soils are referred to as *coarse* or *fine* textured soils, respectively. There is no soil consisting exclusively of one fraction; all are made up of a mixture of the three standard fractions.

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[2] Stones are not considered part of the soil body, but are regarded as foreign intrusions In cultivated soils, the presence of stones interferes with tillage operations and the planting of certain crops. Glaciers and other water transporting agencies deposit in their wake drift boulders and stones. In the glaciated parts of the world farmers know from bitter experience that no matter how thoroughly the surface of the soil is cleared of stones, a new "crop" of stones appears next season. For all that the farmer can see, the stones may have rained down or grown up. What actually happens is that the stones that were deeply imbedded in the soil body have been heaved out from below by the action of frost.

The number of combinations of mechanical mixtures of the three mineral fractions is practically unlimited. Every time the proportion of any one fraction is varied, there results a new mixture. For classification purposes, i.e., for texture designation, soil investigators have assigned *arbitrary percentage limits* for each of the fractions in a mixture. Every mixture within these limits is given a textural name and is known as a *soil class*. Thus, we have loam, sandy loam, fine sandy loam, clay loam, silt loam, loamy sand, sandy clay, and others. If a soil has a large proportion of gravel the class acquires a new designation. We can have a gravelly loam, a gravelly sandy loam, and many other gravelly classes.

TABLE I

Principal soil classes

(According to clay content)

Texture	Limit in percentages of soil separates		
	Sand	Silt	Clay
Coarse sand	80 to 100*	Less than 15 per cent silt and clay	
Fine sand	80 to 100**	Less than 15 per cent silt and clay	
Loamy sand	70 to 100***	From 15 to 20 per cent silt and clay	
Sandy loam	50 to 80	0 to 50	Less than 20
Loam	30 to 50	30 to 50	Less than 20
Silt loam	*0 to 50*	*50 to 100*	*Less than 20*
Sandy clay loam	50 to 80	0 to 30	20 to 30
Clay loam	20 to 50	20 to 50	20 to 30
Sandy clay	50 to 70	0 to 20	30 to 50
Silty clay	0 to 20	50 to 70	30 to 50
Clay	0 to 50	0 to 50	30 to 100

*Including fine gravel.

**Containing 50 per cent or more fine sand and very fine sand.

***Containing 35 per cent or more fine gravel.

Table I presents the limits of the fractions in the principal soil classes as designated by the Soils Division of the Bureau of Plant Industry, U. S. Department of Agriculture (see also Ch. XV).

Gravel and Sand. — Sand and gravel have a very low moisture retentive capacity. Soils consisting primarily of this fraction, 85 to 90 per cent of the total mass, are of minor agricultural value. However, if the water table is high such soils may be used for the culture of special crops. On the Atlantic seaboard—from Maine to South Carolina—poorly drained sandy soils are utilized for the culture of blueberries and cranberries. In the Sanford area, Florida, an extensive celery industry thrives on very sandy soils. This is made possible by extensive fertilization and liming, as well as by an impervious layer at the bottom of the A horizon which prevents the escape of the irrigation water supplied by flowing artesian wells. In the humid temperate climate, sandy soils may be used very advantageously for truck gardening, if water is available for supplementary irrigation. Such soils are spoken of as being "early", i.e., they are ready for the plow much earlier than heavy soils, since it takes much more heat energy to warm up water than an equal volume of rocks or minerals. Sandy soils with a fairly heavy B horizon are also early and have the advantage of an adequate storage capacity for moisture. These soils may be farmed without supplementary irrigation. As much as ten days to two weeks may be gained in planting on sandy soils, and this means an early and more renumerative market.

The sand and gravel fractions are a poor source of nutrients, since they are, as a rule, largely made up of silica. Neither can these fractions absorb and retain the nutrients set free by the humification and mineralization of organic matter or added as mineral fertilizers.

In heavy soils, the presence of gravel is frequently a benefit. The large size particles disturb the uniformity of the sticky mass by being pushed around because of differences in their coefficient of expansion. The pebbles are being heaved out and in that way open channels for air and water.

Clay. — In the language of the mineralogist, clay is the group name for a number of minerals, such as kaolinite, montmorillonite, hydrous mica, and beidellite. However, the *clay fraction* in terms of the soils' men is not associated with its mineralogical or chemical makeup but with its particle size, 0.002 mm. and smaller. The clay fraction of the soil may contain silica in amorphous state, rock and mineral particles other than clay minerals, and organic matter. Because of that, the composition of the clay fraction does not always correspond chemically to that of the pure clay minerals which have a more or less definite composition.

The clay fraction absorbs Ca, Mg, K, NH_4, Mn, Cu, Zn, and many other cations. Besides, the clay fraction carries impurities, and some of these contain nutritional elements. Joined to the adsorbed bases are the phosphates, sulfates, and other complex inorganic and organic anions.

When wet, clay has a tendency to swell. This property is more pronounced when the clay holds adsorbed sodium, potassium, lithium, caesium or ammonium ions. In nature, we do find soils (see Ch. IX) with a portion of their adsorptive capacity for cations filled with Na. The clay then becomes jelly-like and may cause a soil to become waterlogged during a wet spell, or badly cracked when dry.

An outstanding property of clay is *plasticity*. It enables the clay to be molded when wet into a shape which is retained even after the water has evaporated. Pudding of soils is an expression of the plastic property of clay.

Adhesion and cohesion are properties of clay which are important in structure formation. *Cohesion* is the attraction between particles through adjoining liquid films. *Adhesion is the attraction of the liquid on the* surface of the solid.

In the normal soil body, there is more clay in the B horizon than in either the A or C horizons. This is true irrespective of the texture of the parent material. Because of its clay content, the B horizon retains a large share of the nutrients washed out from the A horizon. In the arid and semiarid regions, this retention is permanent; in the humid regions these nutrients linger in the B horizon only temporarily.

Silt. — Silt has the feel of flour when rubbed between the fingers. Silt particles pack, and even though they absorb considerable quantities of water they do not swell; neither do they coalesce or adhere to each other as clay particles do. Silt has very little plasticity and therefore does not puddle when wet, thus making the soil easy to work. Silt is conducive to deep penetration of water and facilitates aeration. Chemically, silt has more potential plant nutrients than clay, because it contains particles of the original rocks and minerals in all stages of weathering.

Summary Statement on Texture. — It should be pointed out, that no economical means have been devised to change the texture of soils. If a soil happens to be of a very coarse sandy texture, or the reverse, of a very fine clay texture, there is little one can do about it. It is, of course, feasible to modify the texture of a small area of a clay soil by incorporating large quantities of sand and silt, or vice versa, add clay to a small area of sandy soil. This practice is sometimes resorted to on a small scale in landscape gardening. On a large scale, such operations are not economical.

Soil Structure

The variously sized grains of the mechanical separates of the soil do not, as a rule, exist in their ultimate unit size. Generally, except in sands, the grains become grouped into compound particles by cohesion, adhesion, and other such forces. *The aggregation of the textural units of the soil mass into variously shaped and sized soil particles forms the units constituting soil structure.* Were it not for structure, heavy soils could scarcely support plant life. The fine grains would clog up the pores, render the soil impervious to water, and impede the free diffusion of air. That is, if structureless, heavy soils could not be a medium for plant growth. It is claimed that soil grains less than 0.02 mm. in diameter, when packed as individual particles, do not provide sufficient pore space for root hairs to penetrate and to function; also that "raw clay", with a grain diameter of less than 0.002 mm., will stop the movement even of bacteria.

Types of Structure. — Fortunately, nature provided for a binding of the individual grains into aggregated particles. As to size and shape, the aggregates, or structural units, are designated by various names, such as pulverized, crumb, granular, nutty, cloddy, laminar or platy, prismatic, and columnar. All of these structural shapes and forms may be classified into three fundamental types: cube-like, with the vertical and the horizontal axes equal; *prism-like,* with the vertical axis longer than the horizontal; and *plate-like,* with the vertical axis shorter than the horizontal. The size of the structural units is determined by the relative length of their axes.

Structure Formation. — The agents responsible for structure formation are clay and organic matter. The adhesive and cohesive properties of clay bind together not only the clay grains, but also the silt and sands. Clay is thus the basis for the formation of aggregates; none may form without it. As a matter of fact, a certain minimum of clay, not less than 8 to 10 per cent, must be present in the soil to give aggregates. The binding force of clay is, however, not sufficient to maintain structural units. When moistened, clay bound aggregates lose their shape and form; they fall apart or slake into their ultimate unit size. The aggregates attain stability only when coated with membranes, or envelopes of organic matter.

A water extract of any organic matter, upon evaporation, leaves behind a glue-like residue. As water trickles through the A_0, it dissolves some organic substances. In combination with bases, the dissolved organic matter forms coatings over the clay-bound aggregates. Upon drying, these glue-like organic coatings or envelopes become less soluble and, under some conditions, attain considerable pliability and strength against the slaking forces of water. In the prairie and Great Plains regions, the frequent thorough drying of the aggregates seems to produce the pliable rubber-like membranes or envelopes. Consequently, the structure of soils in these regions is stable. Soil granules, therefore, retain their shape and form, even after prolonged heavy rainfall. In the humid regions, the glue-like organic membranes have neither the pliability nor the rigidity comparable to those of the more arid regions. In contact with water, the membranes break readily, allowing the clay bound particles to slake.

In the arid and semiarid regions, the structural units are a composite of small aggregated structural particles; each particle is permeated with organic matter and coated with glue-like membranes. Upon breaking or crushing a structural unit of a typical black soil (chernozem), one can see the characteristics just described. The internal stable constitution of the particles seems to exert tremendous cohesive forces which maintain the structure.

In the humid regions, the structural units are not made up of small aggregated particles coated individually with organic membranes. Apparently there is only a single membrane over the larger structural unit. Upon crumbling or crushing a structural unit of soil in the humid region, the brown coloration of the clay, stained with iron oxides, is very apparent. No organic membranes may be noted on the small aggregates.

In the tropics, iron and probably aluminum oxides seem to stabilize the structure in a manner similar to that of organic matter in the arid regions. It is well known that some of the heavy soils of the tropics do not puddle even soon after heavy rains; the thick coatings of the oxides on the clay-bound structural units reduce the adhesive and cohesive forces of the clay.

Importance of Structure. — A favorable soil structure provides pore space which facilitates the movement of water and air through the soil body. Rainwater striking the soil moves through the large pores between the structural aggregates; simultaneously, the aggregates take up water by capillary action. In this manner the conditions of moisture and air supply become close to the ideal physical properties for crop production. Very often low yields of crops may be traced to poor aeration of the soil, caused by poor structure. This condition is conducive to a waterlogged surface which results in increased runoff and hence erosion. On the other hand, the *structureless condition of the silt and clay in the bottom of lakes and rivers prevents water from percolating and disappearing.*

Surface Swamping. — As a result of impeded surface drainage induced by the deterioration of soil structure, water remains on the surface of fields for variable periods depending on the acuteness of the condition. As a rule, such wet spots in generally well drained fields appear prominently in the spring and during wet spells in the summer. In bad cases, the water may remain permanently, giving rise to *water holes* or *ponds.* Actually, this condition represents *surface swamping* resulting in a perched water table which is not in contact with the real water table. Holes dug in these wet spots during the summer may reveal powdery dry soil below the water tight dispersed silt and clay bottom.

The remedy against ponds is to improve the soil structure. A good way of accomplishing this is to treat the soil with a mixture of dolomitic limestone and gypsum, in the ratio of 3:1, at the rate 4000 pounds per acre for sandy loams and 6000 pounds for heavier types of soil. Two thirds of the mixture is to be broadcasted and plowed under; the rest is to be broadcasted on the rough plowed surface. For ponds in meadows or sods in general, the full quantity of the mixture is to be broadcasted sometime in the late fall. The initial lime-gypsum treatment should be continued for several years, with a late fall application (plowed under) of 1500 pounds of a mixture consisting of 1000 pounds dolomitic limestone and 500 pounds gypsum.

Soils that tend to become waterlogged should be kept in the rough without a cover crop during the winter and plowed again in the spring. The rough clods allow the water to percolate through the soil body to a considerable depth. Frost action during the winter and the lime-gypsum mixture tend to establish a favorable structure.

Soils having a coarse textured C horizon, may get immediate relief of surface swamping by boring holes through the profile into the C horizon every 40 or 50 feet throughout the area affected. Post-hole diggers are well suited for this purpose. Excellent methods of preventing the water from entering the pond area are plowing deep as possible with a killifer to open the impervious layer or better yet, digging a trench around the pond to the depth of the pervious layer in the C horizon and filling the bottom with brushwood or stones.

The phenomenon of surface swamping is cited to emphasize the importance of structure in the movement of water through the soil. The structure of the entire profile and not merely that of the surface layer should be considered.

Conditions Involved in Soil Structure. — 1. Sufficient clay must be present in the soil to bind the grains of silt and sand. Since 8 to 10 per cent of clay in a soil is generally considered the lowest limit for structure formation, a 2 per cent increase to a soil containing 6 per cent clay is likely to suffice to induce structure formation. On an acre basis, it would mean the addition of 20 tons of clay to 2 million pounds of soil to a depth of 6 inches. For the highly priced vegetable and flower garden soils in the metropolitan area, the expenses involved in incorporating such an amount of clay might not be prohibitive at all. Much less montmorillonite would suffice to accomplish this end, since it has tremendous cohesive and adhesive powers. Some sandy soils endowed with a heavy B horizon may be improved structurally by deep plowing.

2. The clay must not contain *absorbed* Na, which tends to keep the clay in its ultimated unite size, i.e., in a dispersed condition. Whenever Na finds its way into the clay fraction, as by the excessive use of $NaNO_3$, or by the use of irrigation water containing salts of Na, soil structure deteriorates. The remedy in such cases is gypsum (see Ch. IX) in the arid regions and a combination of gypsum and ground limestone in the humid regions. The quantities necessary are determined by the texture of the soil; the heavier the texture, the more gypsum and lime one has to apply. Recommendations outlined for surface swamping are fairly good guides in this case. Very often, a desirable structure of soils in humid regions is prevented by high acidity. The remedy, of course, is thorough and intelligent liming (see Ch. XI).

3. A supply of organic matter is essential for coating the structural units. As yet no economically satisfactory system of soil management has been devised for improving soil structure in the humid regions, unless a cheap source of manure is available. Inducing deep rooting by proper liming will go a long way in improving soil structure in the humid regions.

PLANT NUTRIENTS AND THE MINERAL COMPONENT

Since the dawn of history, man has tried to fathom the phenomena of plant growth; very little, however, was known about the relation of plants to the soil and atmosphere until the beginning of the 19th century.

How meager the knowledge was may be illustrated by the studies made by the well known physician and chemist, van Helmont, during the first half of the 17th century. His son quotes him as follows: "I took an earthen vessel in which I put 200 pounds of soil dried in an oven, which I moistened with rainwater, and pressed hard into it a shoot of willow weighing 5 pounds. After exactly five years, the tree that had grown up weighed 169 pounds and about 3 ounces. But the vessel had never received anything but rainwater or distilled water to moisten the soil when this was necessary, and it remained full of soil which was still tightly packed and, lest any dust from outside should get into the soil, it was covered with a sheet of iron coated with tin but perforated with many holes. In the end, I dried the soil once more and got the same 200 pounds less about 2 ounces. Therefore, the 164 pounds of wood, bark and root arose from the water alone." Thus, water was considered as the chief nutrient of plants.

What do we know now? Of course, water makes up a large part of any plant, but a goodly portion of van Helmont's willow came from the air. Green plants utilize sun energy and absorb CO_2 with the aid of chlorophyll. Having at their disposal water and mineral nutrients, plants synthesize sugars, starches, fats, celluloses, proteins, and all other constituents of the plant body.

Plant Nutrients

For normal functioning, plants require minerals, water, and air. Collectively these are the plant nutrients. Of the 96 elements, more than a third have been detected in plants. Until about the beginning of the 20th century, plant physiologists considered Ca, Mg, K, Fe, P, S, N, H, O, and C as the 10 essential elements. Since then it was found that plants failed to thrive on highly purified salts. This led plant physiologists to infer that the ordinary "chemically pure" salts contained, as impurities, traces of elements essential to plant life.

Thus far analyses have accounted for more than thirty elements in plant ash. These are: Al, As, Ba, B, Be, Br, Ca, Cl, Co, Cr, Cu, F, I, Fe, Li, Mg, Mn, Hg, Mo, Ni, Pb, P, K, Rb, S, Se, Si, Ag, Na, Sr, Ta, Sn, Ti, V, and Zn. More elements will undoubtedly be added to the list as investigations broaden and the analytical methods of micro-chemistry become more refined. However, the presence of an element in the ash does not necessarily indicate that it is essential.

Chemical Composition of Plants. — Table 2 gives the percentage composition of a few representative crop plants. In general, the bulk of the dry matter of plants consists of 40 to 50 per cent C and 40 to 45 per cent O. The rest of the dry matter is H, 5 to 6 per cent, and N, from 0.1 to as high as 5.0+ per cent. The ash content of plants varies from 1.0 up to 10 and more per cent. It is well to remember that grasses contain the highest amount of ash, deciduous trees less than grasses, and conifers less than deciduous trees.

The average ash content of forest litter, primarily leaves, of conifers is 2.54 per cent, with a minimum of 1.29 and a maximum of 3.31, whereas the average of the hardwoods is 6.63 per cent, with a minimum of 3.85 and a maximum of 11.74. The ash content of wood of various trees ranges from 0.15 per cent for chestnut to 0.92 per cent for post oak, 0.376 per cent for yellow pine, 0.27 per cent for red maple, and 1.0 per cent for sycamore.

The ash content of common hay grasses, such as Bermuda, Bent, Fescue, and Kentucky blue, is about 7 per cent, whereas that of Buffalo grass is 11.5 per cent. The ash content of legumes is higher than that of the hay grasses. Alfalfa, clover, lupines, beggarweed, and soybean hay contain from 6 to 9 per cent of ash. When legumes are cut at blooming time, the ash content is considerably higher: alfalfa may contain 10 and cowpeas as much as 17.3 per cent. It is very obvious that plants in bloom need a more adequate supply of available mineral salts. The high ash content of cowpeas explains its high repute as a green manure crop.

Plant Ash Constituents. — In the process of ashing plant material (ignition at a cherry red heat, about 600° C.), all of the water and most of the carbon are volatilized. Some of the carbon, however, becomes tied up as carbonates of K, Na, Ca, and Mg. Traces of nitrate nitrogen may be found in the plant ash. The metals (K, Ca, Mg, Fe, Na, and Mn) and the metalloids[3] (S, P, and Si), in combination with oxygen, constitute more than 95 per cent of the ash in a majority of plants.

The composition of plant ash varies within wide limits. It is influenced by the composition of the soil, the supplying power of the soil, plant species, cropping system, vegetation period, fertilizer additions, water sup-

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ply, and climate. Thus, plants grown in soils or solution cultures rich in natural Na, or through additions of Na salts, contain a high percentage of this element. Na frequently exceeds the Ca content of plants, even in cases where Ca predominates over Na in the soil solution. Garlic contains 0.11 per cent Na_2O and 0.08 per cent CaO; lentils—0.243 and 0.114 per cent respectively; carrots—0.115 and 0.083 per cent respecively. Under conditions of drought, plants may contain more ash and different quantities of the respective elements than under conditions of excessive moisture.

The ash content of plants in soils of the forest zone vary from 4.7 to 7.3 per cent; of the border zone—between the forests and the grass country—from 5.0 to 15.7 per cent; of the semiarid grass country—from 6.0 to 28.7 per cent; and of the semidesert country—from 6.0 to 31.0 per cent. Generally, however, *within each zone it is the plant species that determines the quantity and kind of ash a plant may contain.*

The specific assimilating habits and intake capacity of minerals by different plant species are exemplified by: the high SiO_2 content of the ash of grasses, from 10.4 to 63.2 per cent; the high Ca content of the ash of clover and alfalfa, an average of 34.91 and 40.67 per cent of CaO respectively; the high K and low Ca content of the ashes of potato tubers and beet roots, as compared with a low K and a high Ca content of the ashes of their vines and leaves; the high Mg and high P content of the ashes of grain; and the high S content of the ashes of cabbage, cauliflower, and other cruciferæ.

In table 2, ash analyses of the more common crops are recorded. It is to be noted that for most of these crops, the data are on the basis of air-dry weight. The absolute dry weight basis (to constant weight at 105°C) is more accurate. However, the difficulties involved in working at 105°C (in the process of weighing, moisture is picked up), and the fact that fluctuations in moisture content of air-dry plants do not introduce serious errors, permit the use of the air-dry weight basis.

The reasons for reporting exclusively N[4], P, K, Ca, Mg, S, and Fe in plant ash analyses are as follows: these elements comprise the bulk of the ash in the majority of plants; they are, as a rule, either deficient in the soil or unavailable, and must, therefore, be supplied by fertilization.

Other elements may often be found in the ash in quantities larger than those enumerated. The ash of some meadow hays contains 6.2 per cent of Cl; the ash of young asparagus stalks may contain from 4.0 to 41.0 per cent of Na_2O and 5.6 per cent of Cl; the ash of spinach is reported to con-

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[4] Even though N is not an integral part of the mineral component and its original source is the air, it is listed here because it is one of the most important constituents of the plant and is deficient in many soils.

TABLE 2

Mineral composition of representative plants of economic importance, per cent of air-dry weight

Crop	Standard moisture		Ash		N		P	
	Grain, root or tuber	Straw or tops	Grain, root or tuber	Straw or tops	Grain, root or tuber	Straw or tops	Grain, root or tuber	Straw or tops
Wheat	10.2	8.4	1.9	5.2	2.08	0.48	0.41	0.11
Rye	9.4	7.1	2.0	3.2	1.76	0.40	0.43	0.11
Oats	9.2	11.5	3.5	5.4	1.92	0.40	0.31	0.10
Barley	9.3	14.2	2.7	5.7	1.52	0.48	0.39	0.09
Corn	14.8	19.0	1.5	5.8	1.60	0.48	0.30	0.27
Rice (rough)	9.6	7.5	2.1	5.5	1.28	0.61	0.23	0.65
Buckwheat	12.1	9.9	3.4	7.9	1.72	0.78	0.29	0.32
Peas			3.5	7.2	3.58	1.04	0.43	0.18
Beans			4.3		4.06	1.63	0.60	0.17
Flax	?	?			3.20	0.48	0.67	0.20
Hemp	?	?			2.62		0.84	0.12
Potatoes	†	†	1.1	8.6†	0.32	0.50	0.28	0.30
Sugar beet	†	†	1.1		0.16	0.30	0.18	0.53
Carrots	†	†	1.2		0.21	0.51	0.30	0.26
Tomatoes	†	†			0.15		0.03	
Cucumbers	†				0.15		0.04	
Alfalfa	8.6	?		8.6	—	2.50	—	0.21
Red clover		12.9		7.1	—	2.08	—	0.19
Grapes**	†				0.19		0.05	
Apples**	†				0.07		0.01	
Peaches**					0.10		0.02	
Oranges**					0.13		0.02	
Walnut**	2.5				1.02		0.36	

Mineral composition of representative plants of economic importance, per cent of air-dry weight

K		Ca		Mg		S		Fe	
Grain, root or tuber	Straw or tops	Grain, root or tuber	Straw or tops	Grain, root or tuber	Straw or tops	Grain, root or tuber	Straw or tops	Grain, root or tuber	Straw or tops
0.51	0.61	0.04	0.19	0.13	0.07	0.17	0.12	0.01	0.02
0.54	0.76	0.04	0.26	0.11	0.08	0.12	0.05	0.02	0.03
0.42	0.86	0.07	0.26	0.11	0.11	0.18	0.22	0.01	0.04
0.45	0.91	0.04	0.24	0.11	0.06	0.15	0.15	0.01	0.02
0.35	0.93	0.02	0.36	0.11	0.16	0.17	0.12	0.01	0.05
0.21	1.25	0.06	0.19	0.13	0.12	0.13	0.15		
0.27	1.89	0.07	1.37	0.17	0.54	0.14	0.13	0.01	
0.95	0.97	0.09	1.33	0.11	0.23			0.01	0.06
1.26	1.88	0.14	1.33	0.12	0.18			0.01	0.04
0.94	0.91	0.19	0.59	0.25	0.14	0.23		0.03	0.06
0.89	0.45	0.81	0.87	0.16	0.16			0.03	0.03
1.89	1.55	0.01	0.36	0.02	0.16	0.14	0.22	0.03	0.17
1.77	4.16	0.04	0.26	0.04	0.20	0.09	0.43	0.02	0.12
1.63	1.26	0.06	0.61	0.03	0.07			0.03	0.24
0.29	—	0.02		0.02		0.02		4.40*	
0.32		0.03		0.01		0.06		3.3 *	
—	1.93	—	1.45	—	0.26	—	0.23	0.02	
—	1.71	—	1.15	—	0.25	—	0.13	0.02	
0.29		0.04		0.01		0.02		6.7 *	
0.12		0.01	—	0.01		0.04		6.00*	
0.21		0.01	—	0.01		0.01		3.30*	
0.19		0.05	—	0.01		0.03		9.60*	
0.12		0.13	—	0.15		0.17		21.40*	

*P.P.M.

**Table portion.

†On basis of oven dry weight at 105° C.

tain 35.3 per cent of Na_2O and 6.9 per cent of Cl. Some plants may even contain appreciable quantities of Al which is generally toxic to plants. The functions of these extraneous elements in the metabolism of plants are very little known.

Mineral Nutrients and Sources of Supply

The exact role of the mineral nutrients in plant metabolism is still obscure. Some important facts have been established. For instance, K cannot be replaced by Na, Li, Rb, Cs, or Ca in plant nutrition; Be or other metals cannot replace Mg; Ca, can be partly replaced by Sr, Mg, but not by Ba; Mn, Co, or Ni cannot replace Fe; As and Si cannot replace P; and Se cannot take the place of S. These facts emphasize the specificity of the elements in plant life.

Sulfur. — This element is a constituent of protein. In some plants, like cabbage, rutabaga, and rape, S is also found in the form of mustard oils; its content reaches an appreciable concentration in some plants, 0.8 per cent in cabbage and 1.0 per cent in rape tops. The bitter principle of radishes and the pungent odor or rotting cabbage are due to certain S compounds. S is taken up by plants in the form of sulfates. The presence of soluble sulfates in the medium is reported to be conducive to extensive root development.

In the soil, S is found in the form of sulfates of Ca and Fe. In the semidesert regions, gypsum is, as a rule, found in the B horizon. Whenever salts accumulate on the surface of the soil (generally in the semidesert and arid regions) sulfates of Na, Ca, and Mg may be encountered. A large proportion of the S in the soil is tied up in organic matter.

Sulfur is also supplied to the soil by precipitation. The quantity of S added to the soil varies according to type of fuel used (soft coal gives off more sulfur than anthracite), industrialization of the area, and amount of precipitation. In Ithaca, New York 26.2 pounds of S per acre are added annually to the soil by precipitation; in Wisconsin, not more than 7 pounds of S are added; about the same quantity is reported by Rothamsted, England, and Catania, Sicily; in the Forest Institute of Leningrad, Russia, precipitation contributes 71 pounds of S per acre.

It is well known that crop yields in soils with a low S supply are below normal. There are cases on record where additions of S to the soil increased crop yields by more than 100 per cent.

In poorly aerated soils sulfides may be found. Fresh manure plowed under in such soils give off H_2S. The author has encountered many cases where crops were injured and yields reduced in wet seasons because of heavy applications of manure. The presence of H_2S was definitely established in these cases. It is claimed authoritatively that this gas is toxic to plants.

A deficiency of S is characterized by the loss of green color in the younger leaves of the plant, including the veins. In extreme cases all the leaves may become light green in color. These signs are similar to those of N deficiency, with this difference: in the case of S deficiency, the lower leaves do not dry up as they do in the case of N deficiency.

Phosphorus. — The role of this element in plant life is similar to that of S and N. It is a constituent part of the nucleo-proteins and lipoids. It is also credited with the power of stimulating cell division. Most P is taken up by plants during two definite periods in their life cycle: soon after germination for a period of several weeks, and then, when the fruit and seed form and mature; P is, therefore, considered to hasten maturity. The P content of plants is considerable. As shown in table 2, it is highest in plants which are high in N.

In many soils, P is found in small quantities as the mineral apatite. Most of the P in the soil is associated with the alkaline earth bases, Ca and Mg, in the arid regions, and as the phosphates of Ca, Mg, Mn, Fe and Al in the humid temperate and tropical regions. Because of the insolubility of the phosphates mentioned, some soils in spite of a high total P content may show a lack of *available* P.

The signs of P deficiency in plants are a purplish color of the leaves along the veins, stunted growth, slow ripening of fruit and delay in maturity. In fruit trees, P deficiency delays the opening of the buds, reduces the number of blossoms, and causes a spindly type of growth.

Potassium. — The role of K in plant life is not clear. It seems to be essential in the vital activity of protoplasm. It serves as a conveyor of other substances. It is claimed to activate starch formation. An overabundance of this element in a nutrient medium or a shortage of it is claimed to decrease the rate of photosynthesis. The young and active regions of plants—the meristematic tissue, buds, young leaves, and living bark—are rich in K. As the plant ages, K is translocated from the old to younger tissues, and very little of it is, therefore, found in woody portions. K makes up a large portion of the plant ash. It is not uncommon for potash (K_2O) to make up 50 per cent of the total ash, seldom is it less than 25 per cent.

In the plant K is in soluble form. No complex organic compounds of this element have been observed or discovered. It is worth mentioning that although K is generally radioactive, no definite effects of this property on plant growth have been demonstrated. Some investigators claim that the radioactivity of K is responsible for the high sugar content of sugar beets which, as a rule, receive a high potash fertilizer.

In the soil, K is carried by the feldspars, micas, greensand marls, and as impurities in other minerals. During the active growth of plant, these carriers being insoluble can not be depended upon for an adequate supply of K, but they do represent a potentially available source of this element. The K absorbed by the mineral and organic colloids is a source readily available for plant use.

Incipient deficiency of K in growing plants is manifested by a bluish green color of the leaf, resembling the condition of an oversupply of N. Sometimes, the color shades into violet, brownish red, or brown. In more serious cases of K deficiency, plants suffer a lack of chlorophyll, imparting to the leaves a pale yellow color, principally between the veins and at the margin of the leaf. The yellowing is a forerunner of the disintegration of the tissues which turn brownish black. The various spots usually appear on the lower leaves first. In many cases, leaves become warped or curled. With progressive deficiency, the leaf margins contract, show little holes, and appear as if gnawed by insects. The individual plant families show specific signs of K deficiency. In clover, the tips of the leaves turn grayish-yellow to brown. In alfalfa, the leaf tips dry up without a previous transition to yellow. In soybeans, the chlorotic discoloration develops into black-brown spots occurring on the leaf margins. Leaves of grapes exhibit at first punctiform spots which change from yellow to brownish red and cover almost the entire leaf. Deficiencies of K are easily overcome by additions of K-carrying fertilizer.

Magnesium. — This element functions in the chlorophyll, both as a constituent of the green pigment and as an agent in photosynthesis. It is considered to be active in building up carbohydrates. Simultaneously, Mg has been found to be essential in the breakdown of carbohydrates, in the process of fermentation. It serves as a carrier of P and seems to be associated with phosphates in the seeds. It is taken up by the plant uniformly throughout its vegetation period. A redistribution of Mg from the older to the younger organs of plants takes place readily.

Generally, Mg in the soil occurs in the form of silicate minerals, anc in arid climates also as carbonates. It occurs also quite extensively a dolomitic limestone. Mg is retained by the soil colloids in absorbed stat and in this form it is readily available to plants. Soils of the humid climat are frequently deficient in available Mg, the latter being replaced by th H ions of the acids prevailing in these soils. There are cases where soil have a sufficient quantity of this element, and yet symptoms of deficienc are apparent. The disturbance may be traced to the unbalanced ratio Ca and K to Mg. Additions of Epsom salt or some other soluble Mg sa quickly remedy conditions of Mg deficiency. Cases have also been report of injury to crops due to an excess of Mg in the soil.

One of the first examples of Mg deficiency noticed among cultivated crops was the sand-drown of tobacco. The sign of Mg deficiency is a characteristic chlorosis. It develops first in older leaves. Veins remain green while the leaf web tissue turns yellow or whitish. The roots become stunted and are sparsely branched.

Calcium. — This element plays a manifold role in plant metabolism. It is a structural component of plant cell walls. It immobilizes the toxic oxalic acid (by precipitating it out as Ca-oxalate) formed when amino acids are being built up. Some investigators believe that Ca- proteinate occurs in plant cells. Ca is also believed to favor transformation of starch and its translocation through the plant. Some plants take in large quantities of Ca and are, therefore, named *calciphiles* or *calcicoles.* Others demand less Ca and are known as *calciphobes.* It is of interest to note that the lower plants, like fungi, can get along with very little Ca.

Repeated extractions with water, dilute acetic, or hydrochloric acid dissolve all of the Ca from any plant material. In most plants, a large proportion of the Ca is located in the leaves. Some plants of the arid regions accumulate Ca in the roots. Since Ca forms insoluble compounds, such as the oxalate, it is relatively immobile in plants. Very little Ca is, therefore, redistributed among the various parts of the plant.

As pointed out earlier, there is a certain relationship between the Ca and Mg content in the soil which has a marked influence on the metabolism of the plant. If the ratio of available Ca to Mg becomes narrow, from 1:1 to 4:1, plants are likely to suffer from an excess of Mg. This condition is rarely encountered. If the ratio extends beyond 15:1 to 20:1 the converse is true, not enough Mg and too much Ca are taken in by the plant.

In the soil, Ca is found in silicate minerals, in gypsum, in apatite, and as impurities in many other minerals. In the arid regions, large quantities of Ca are also found in the B horizon as carbonate. In the humid regions, limestone frequently serves as parent material, and young soils may contain fragments of limestone even in the A horizon.

Calcium is adsorbed by the mineral and organic colloids. In the arid regions, Ca makes up 70 to 80 per cent of the cation adsorptive capacity of the soil; in the humid region, up to 35 per cent, the rest being mostly H, with some Mg and K.

A lack of Ca in the soil causes, among other things, acidity which is injurious to most crop plants. This condition, encountered in the humid regions, is a serious problem (see Ch. XI).

Iron. — This element is indispensable for the synthesis of chlorophyll, even though it does not enter into the constitution of the chlorophyll molecule. Iron is also supposed to act as a catalyst or O carrier in the oxidation processes of the living cell. Iron is taken up by plants in the ferric and ferrous states; its presence in the plant cannot be demonstrated by ordinary inorganic reactions because it forms complex organic ions in the plant tissues. The total quantity of Fe in plants is generally very small, from a high 0.1 per cent in lettuce to a low 0.0001 in apples. Living protoplasm carries traces of it, and the bulk is located in the younger portion of the plant. The composition of the ash of the principal grains and crops like beans, peas, lupines, red clover, flax, and cotton fluctuates from traces to 6.0 per cent Fe.

In the soil, there is usually an abundance of iron. Excessive applications of lime may cause a temporary deficiency of Fe which is indicated by a definite chlorosis. In acid soils, an excess of soluble Fe may become toxic to plants, causing symptoms similar to Mn deficiency; smaller leaves, tapering young leaves, straw colored with peppery brown spots.

Oxygen. — With a short supply of O in the soil plants cannot utilize the mineral nutrients.

The human may get along without food for days and days. His survival period is considerably shortened without water, but he can exist only for a couple of minutes without air. The behavior of plants in this respect is comparable to that of animals. Plants may get along on very short rations of minerals; they will thrive for a long time under arid conditions with practically no water; they must, however, have an ample supply of oxygen for respiration. This phase of plant life in relation to the soil conditions is frequently neglected.

Oxygen is important in the process of root activity. Less of the mineral nutrients are taken up when the rhizophere is short of oxygen. Plants, such as lettuce, tomatoes, and corn, when drowned out, actually die not from a lack of O but from a shortage of water which they cannot imbibe, because of the low O supply caused by waterlogging of the soil. However, if the water supply is aerated and moving, there is enough dissolved O for the roots to function even if the soil is waterlogged. Stagnant water has very little dissolved O, and plants suffer. The failure of many soils to respond to fertilizer treatments may be traced to the problem of O supply because of a waterlogged condition of the soil. One should also remember that the temperature of the source of water is a factor in O supply. Cold water contains more dissolved O than warm water. The problem of O supply is, therefore, more serious in the soils of the warm than of the cool climatic regions.

Nitrogen. — This element is not an inherent constituent of the mineral component of the soil; its source is the atmosphere. However, it is supplied to the plants through the soil and is, therefore, briefly mentioned here.

Nitrogen is an integral part of plant protein which is a vital part of protoplasm. A lack of N is marked by chlorosis; an excess of it causes soft and vegetative growth, and most plants can not mature or produce fruit under conditions of an excessive N supply.

Nitrogen is added to the soil by precipitation. This contribution varies with the climatic region. In the tropics, with their frequent and intense thunderstorms, the precipitation may add as much as 30 pounds of nitric acid per acre per year. In the humid temperate climate 4 to 6 pounds of N, primarily as ammonia, are added annually. Large quantities of N enter into circulation through the activities of microbes (see next chapter).

CHAPTER VI

THE ORGANIC MATTER COMPONENT OF THE SOIL

Any material of plant and animal origin found in soils is known as soil organic matter. In popular literature on agriculture and even in technical treatises on soils, the terms *soil organic matter* and *humus* are used interchangeably. Strictly speaking, humus is only a portion, usually a major portion, of soil organic matter. *Humus is the dark brown-black organic matter that has undergone decomposition to an extent that one can no longer determine by inspection the nature of the material from which it was derived.* The plant or animal material of today is the humus of tomorrow.

To appreciate fully the role of organic matter in the soil-plant relationships and in the soil forming processes, one must consider: 1, the sourc of supply of raw materials and their properties; 2, the microbes in relation to the processes of decomposition of organic matter and to the nitrogen cycle in the soil; 3, functions of organic matter in the soil; 4, climat and organic matter supply; and 5, organic matter in farm practices.

COMPOSITION OF PLANT RESIDUES

Plant residues are the chief source of supply of soil organic matte On the average, the composition of plants on the dry matter basis is: C per cent, O 42, H 6.5, N 1.5, and ash 5.0. Departures from the averag especially with reference to N and ash, are common. Thus, tree residu vary from 0.5 to 2.0 per cent N, mosses from 0.6 to 1.5, meadow grass from 1.5 to 3.0, and legume seeds run up to 5.0 per cent and even high Ash constituents may vary from 1.5, as in some conifers, to 10 and 12 p cent, as in certain grasses.

The figures show that C and O make up the bulk of the weight dry matter of plants. The apparently small percentage of H is actua a very impressive figure, since the combinations of the elements wh make up the compounds are not based on percentages but on the equival weights of the elements. Thus, 1.008 grams of H combine with 8.0 gra of O to form water.

Plants are the basic source of food for man and animals. The di tian and husbandman, in their respective feeding problems associate pl with proteins, starches, fats, sugars, celluloses, vitamins, and mine The organic chemist and the biochemist add to the list hemicellul pectins, lignins, tannins, waxes, resins, chlorophyll, alkaloids, and enzy

All of these substances find their way into the soil and contribute, in one way or another, to its source of supply of organic matter.[1]

MICROORGANISMS

The diverse groups of substances that make up the plant residues do not contribute in equal measure to the quantity, composition, and behavior of soil organic matter. Some plant substances decompose in the soil completely; others are partially attacked; and still others remain almost intact. These variations in decomposition are associated with the differential activities and types of microbes which, in turn, are largely influenced by the climate.

Microbes and Life. — Microbes are popularly associated with disease. Fortunately, of the thousands of species of microbes found in nature, only a score or two are parasitic and pathogenic, the bulk being friends of man. Many industrial processes depend on the activities of microbes, the oldest of these being alcoholic fermentation. Pasteur, the father of modern microbiology, inaugurated his epoch-making discoveries with the role of microbes in the process of fermentation. Breadmaking is, strictly speaking, based on this process; so are pickling, vinegar-making, and silage-making. Many other industrial processes depend on microbes: production of acetone, citric acid, and other organic acids; the processing of milk and its products, cheese and butter; and treatment of sewage.

Were it not for the microbes, our earth would eventually become covered with dead animals and plants. Plant life would become extinct because all of the CO_2 would be tied up in the dead plant and animal debris. Food products would disappear and life would cease. Nature, however, provided the microbes as the link in the life cycle on our planet. Being plants, but with no chlorophyll, microbes decompose the organic residues for their nutritional and other life functions. At the same time, they render the dead organic matter available again for plant metabolism, releasing as they do CO_2 and minerals which are rebuilt by plants into food. And so the cycle continues, with the microbes in the role of friends rather than enemies.

We know now that the soil possesses bactericidal properties, more powerful than many of the antiseptics used. The microbes in the soil serve as a sanitary corps. In truth, what becomes of all the pneumonia, cholera, tuberculosis, and other microbes that share the grave with their host? Having finished their job, the pathogenic microbes perish in the soil, some because of unfavorable environment, and many by the antibiotic substances engendered by soil microbes.

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[1] Students who care to learn more about these plant constituents are referred to the *Appendix* at the end of the chapter.

Specific Soil Microbes and Their Functions

It would seem that the soil should easily become contaminated with organisms from without—from the air, sewage disposal, and animal manures. Though the soil does contain some microbes from these sources, it has a flora of its own.

Bacteria. — Of the three forms of bacteria—rods, cocci (ovoid form), and spirals—the first two are most abundant in the soil. The spiral forms are rarely encountered.

Most of the soil bacteria belong to the group of *heterotrophic* organisms. They utilize the energy stored in organic matter for their life processes. The release of the energy is accomplished by the microbes as they decompose organic matter by means of enzymes. Most of the heterotrophic organisms are *saprophytes,* i.e., they thrive on dead organic residues, and just a few are *parasites,* i.e., they thrive on living plant or animal bodies.

A small number of soil bacteria belong to the group of *autotrophic* organisms which do not depend on organic substances for energy; they utilize energy released in exothermic reactions. Examples of autotrophic organisms are the nitrifying bacteria, the hydrogen bacteria, and some sulfur bacteria. The *Thiobacillus thioxidans,* the bacterium that converts sulfur into sulfuric acid, utilizes the energy released in the oxidation of sulfur:

$$2S + 3O_2 + 2H_2O = 2H_2SO_4 + 282 \text{ Cal.}$$

An important group of bacteria in the soil are the *spore* formers. The two best known members of this group are *B. cereus* and *B. mycoides.* Occasionally, they occur in large numbers; the cause of the rise and fall of their numbers is not fully known. Certain substances, such as fresh urine or urea, stimulate the activity of spore formers. While the favorable conditions prevail, the spore formers are very voracious and decompose large quantities of organic matter.

Number of Bacteria. — Under favorable conditions of moisture, temperature, and reaction—neutral to slightly alkaline—the number of bacteria per gram of soil (there are about 28 grams to the ounce) may range in the hundreds of millions. In the soil profile, the largest number is found in the A horizon where organic matter is available for their metabolic activities. The number of bacteria diminishes with depth. In the B horizon, if not compacted, they are still abundant. However, if compacted the number drops off rapidly. Very few organisms are found in the C horizon; at a depth of 3 to 4 feet, their number is very small.

In general, the bacterial count at any one point in the soil profile i not a constant; it varies with the seasons, being lowest in winter. Th bacterial count varies even within each season, from day to day or eve from hour to hour, depending on the temperature, aeration, moisture sup ply, abundance of nutrients, type of plant residues, and many other known and unknown causes.

Bacteria live primarily in the film of moisture surrounding the soil particles. Since they feed chiefly on the residues of dead plants and animals, one would naturally expect more bacteria in contact with those particles containing more organic matter. Indeed, huge numbers of microbes appear in the soil when fresh, juicy organic matter is plowed under. Microbes are also abundant in the root zone, known as the *rhizosphere,* where freshly dying roots provide a favorable nutrient medium.

Composition of Bacteria. — On the basis of one hundred million of organisms per gram of soil, as much as 260 pounds of live weight or 50 to 80 pounds of dry matter of microbial cells per acre may be found in the first six inches of the soil. When a young green manure crop is plowed under, the billion mark of bacteria per gram of soil may not be excessive. This number, however, may last only for a short period.

It is very probable that one of the benefits of plowing under fresh organic matter is the availability of the substance of bacterial cells that rapidly multiply in the process of decomposition. Bacterial bodies may be looked upon as an organic form of fertilizer supplying appreciable quantities of N, P, and K (table 3).

TABLE 3

Representative composition of bacteria, per cent of dry matter

Name of organism	N	P_2O_5	SO_3	K_2O	Na_2O	MgO	CaO	Ash
Azotobacter chroococcum	11.3	4.93	0.29	2.41	0.07	0.82	0.34	9.66
Bacillus mycoides	10.8	4.7	0.49	2.27	0.12	0.48	0.56	8.5
Bacterium fluorescens liquefaciens	9.74	5.02	0.38	2.27	0.21	0.33	0.42	8.8

Bacteria and Soil Environment. — Bacteria thrive best under conditions favorable for plant growth. Acidity is not favored by the general run of bacteria. At least they are not found in large numbers in acid soils, where the fungi and the products of their metabolism crowd out the bacteria.

Bacterial activities are easily thrown out of balance by factors causing disturbance among higher plants. As a matter of fact, bacteria are more sensitive than plants to soil treatment or environmental condition. At one time, it was thought possible to judge the soil by the behavior of bacteria. Attempts have been made to detect deficiencies in soils by following the appearance or disappearance of known species of bacteria or other microorganisms, or by counting the number of microorganisms, or by noting their morphological changes. Thus far these attempts have not proved fruitful.

Fungi. — The fungi, commonly known as molds, are a diverse group of microorganisms. Their cells have a tendency to be arranged in a network of branched filaments known as *hyphae.* The mass of hyphae is called *mycelium,* with spores carried by special fruiting bodies.

Mushrooms are a subdivision of this group of microorganisms, known as higher fungi. The mushroom is nothing more than a fruiting body, large in size, carrying the spores or reproductive bodies. In the ground or decaying wood beneath every mushroom is an immense network of mycelium. These higher fungi are especially active in the destruction of lignin. The pulverized condition of dead trees in the woods, covered with mushroom and fruiting bodies of other fungi, is evidence of the destructive activity of this group of microorganisms. Bacteria and actinomyces are undoubtedly also active in the destruction of lignin, but their contribution in this respect is minor in comparison with that of the fungi. In the tropical jungles, the destruction of vegetation that goes on at a fast rate is due in a large measure to ants.

Fungi seem to thrive best under acid conditions, and, therefore, predominate in the forest floor, especially during the spring when the acidity is highest. Their number probably drops for a short period during the fall when the pH value of the forest floor rises appreciably. It is also probable that during this short period the bacteria predominate numerically over the fungi. Fungi are more prevalent in coniferous forests where the acidity is higher than in the deciduous forests; the higher ash content of the latter keeps the acidity down.

Like bacteria and the higher plants, fungi consist primarily of water, 70 to 85 per cent, with occasional species containing as low as 40 per cent and others as high as 90 per cent. The dry matter is made up of 40 to 50 per cent C, 2 to 8 per cent N, and 6 to 8 per cent ash that may go up to 15 per cent in some species. Most of the ash consists of K and P compounds. As much as 58 per cent of the ash may be K_2O, and 20 to 50 per cent P_2O_5.

One of the specific functions attributed to fungi is the production of a glue-like substance which stablizes the soil structural units. Undoubtedly, many more organisms possess similar properties. The exact nature of the substances responsible for the stabilizing effects of soil structure has not been established.

Mycorrhiza. — Certain fungi belonging to the fleshy type send their mycelium into the roots of many forest species without destroying the tissues of the host. This union of the fungi and roots of trees is known as *mycorrhiza.* The nature of the mutual relations between the mycorrhizal fungi and the roots of trees is not known. Some investigators have attributed to these fungi the power to fix N. Others have ascribed to them the function of transferring water and plant nutrients from the soil to the trees.

Yeasts. — Some botanists classify this group of organisms with the fungi, even though yeasts produce no mycelium. They are frequently encountered in the soil. Their function as fermenting agents in the soil has not been studied to any extent. One would expect alcoholic fermentation in the soil, since most plant residues contain the necessary sugars on which yeasts thrive.

Actinomyces. — This group of microbes is intermediate between bacteria and fungi. Like fungi, the actinomyces consist of delicate branching threads (hyphae). The ends of the filaments often break into bodies that serve as spores and look like bacteria under the microscope. When young, colonies of actinomyces on gelatin or agar plates look very much like bacteria, except for the dull appearance in contrast to the glistening appearance of bacteria. One of the outstanding characteristics of actinomyces is their remarkable power of producing brilliant pigments in certain media; another, is the musty odor they impart to the soil.

Actinomyces are more abundant in sod. In their tolerance of acidity, they resemble the bacteria. The optimum pH for their growth is around 7.0-7.5, whereas for bacteria, it is 6.0-7.0, and for fungi 4.0 to 5.0.

Less information is available on the composition of actinomyces than of either fungi or bacteria; they probably approach the composition of fungi.

Algae. — Among farmers of the days of yore, there was current a belief that a green algae cover in clean fallow was a definite assurance of a good yield. The virtues attributed to fallowed land covered with algae were later explained by the theory that these microscopic plants are capable of fixing N from the air. However, it was shown later that the increase in N might be attributed to the Azotobacter which are favored by the algae. As chlorophyll-bearing organisms, the algae produce sugars and starches that may be used by Azotobacter and other microbes. In general, the activities of algae in relation to soil conditions and plant growth are not well known.

Protozoa. — In comparison with the size of bacteria, protozoa are giants; yet they are in the range of microscopic dimensions. Similar to the microbes that represent the smallest of the plant kingdom, the protozoa are the smallest of the animal kingdom. The unicellular *amoebae, flagellates,* and *ciliates* are typical representatives of protozoa. Their function in the soil is not fully known. At one time, the beneficial effects of partial sterilization of soils in greenhouses were ascribed to the destruction of the protozoa. They were presumed to prey on microscopic plant life thereby impeding the decomposition of organic matter and the release of plant nutrients.

Ammonification and Nitrification

Decomposition of proteins or almost any nitrogenous organic matter results in the formation of ammonia. There is also the possibility of chemical breakdown of amino-acids (the building blocks of proteins) into ammonia. Some of it is adsorbed by the soil, some combines with various anions to form ammonium salts, and some is used by the different groups of soil microbes. The process of ammonia formation in the soil, known as *ammonification,* is primarily biological in nature; fungi and bacteria are most prominent in this process.

Ammonia does not stay in the soil as such. It is converted into nitrites and nitrates by the process known as *nitrification.* Two distinct type of microorganisms are responsible for this process. First come the *Nitrosomonas* and *Nitrosococcus* which convert (oxidize) the ammonia int nitrites. They are followed by *Nitrobacter* which converts nitrites int nitrates. Both groups are autotrophic bacteria, i.e., they utilize the energ released by the oxidation of the ammonia into nitrites and of nitrites t nitrates instead of sun energy or that of organic matter.

Nitrates constitute the chief source of available N for most agricultur plants. True enough, plants can and do utilize small quantities of ammoni as such. Ammonium sulfate, ammonium nitrate, and ammonium phospha are used extensively in fertilizer mixtures. The point is that plants do n tolerate as high a concentration of ammonia as that of nitrates. Nitrific tion is thus nature's method of preparing N for plant nutrition. Nitri cation occurs in practically all soils, except those that are either wate logged or extremely acid. With a favorable soil reaction and ample supp of organic matter (for ammonification), the rate of nitrate formation determined by the temperature and moisture conditions. Of course, supply of available oxygen is essential.

To be specific, the process of nitrification is greatly impeded by l temperatures and during droughts; it is high in the early summer when composition of organic matter is intense; and it is also high in the autu when a supply of plant residues becomes available for decomposition; is low during the winter; and it is high again during spring awakening

Denitrification. — Under anaerobic conditions, i.e., when the air s ply is limited because of poor drainage or excessive applications of ea decomposable fresh organic matter, nitrates and nitrites are reduced certain bacteria to gaseous N or its oxides which go off into the air. T process is known as *denitrification.* In ordinary cultivated soils it is of fling economic importance. In paddy rice fields, the use of ammonia as a source of N is the rule because of the anaerobic conditions and hence dangers of denitrification. In the humid temperate and tropical climates, where temporary surface swamping is a common phenomenon, especially in wet seasons, losses of N by denitrification undoubtedly take place.

Nitrogen Fixation

One of the most unique processes in the soil is the fixation of atmospheric N, inasmuch as bacteria accomplish it without the aid of high pressure and temperature required by the industrial Haber process. There are two types of N fixation: one that is carried out by microbes in symbiosis (partnership) with legumes, and the other that is carried out by microbes without the partnership with plants.

Symbiotic Nitrogen Fixation. — Back in Roman times, legumes were recognized as important in enriching soils. Plowing under a crop of lupines was equivalent to an application of manure. During the eighteenth century, legumes were systematically used in Western Europe as a means of restoring the fertility of run-down soils. At present, the use of legumes is universally appreciated. In the United States, more than a 100 million acres are in alfalfa, clover, vetch, beans, peas, peanuts, and other legumes. It has been estimated that between 100 and 150 pounds of N per acre are fixed annually by cultivated legumes; no estimate has been made on the N fixed by wild species of legumes. It is of interest to note that under favorable conditions sandy soils, poor in natural nutrients, will fix more N than heavy soils rich in nutrients.

The fixation of N by bacteria in symbiosis with legumes was discovered by Hellriegel and Wilfarth in 1886. They demonstrated that this power of fixing N takes place by the combined activity of the legumes and bacteria entering their roots and there producing nodules, known as tubercles. Beijerinck isolated bacteria from legume nodules and grew them on artificial media. He named the organism *Bacillus radicicola;* it has also been known as *Pseudomonas radicicola* and now is called *Rhizobium radicicola.*

Legume organisms may live in the soil independent of their host for several years. There are many cases on record of fields that have retained their power of inoculation several years after the legumes have been kept out.

There are many types or varieties of *Rhizobium radicicola* and some are specific for certain legumes. Some may inoculate several legumes, such as cowpea, peanut, trefoil, and acacia; others are adapted for a single ne, such as soybeans. The practical side of the problem of inoculation is o get the right kind of bacteria for the particular legume. One may use oil for inoculation from a field successfully growing the legume desired. Two to five hundred pounds of soil per acre, evenly distributed, are sufficient. The inoculation should be made on a cloudy day and the material well worked into the soil.

Non-Symbiotic Nitrogen Fixation. — The process of taking atmospheric N and fixing it by bacteria not associated with higher plants has been defined as non-symbiotic nitrogen fixation or *azofication*. In 1885, Berthelot showed that N fixation took place only in unsterilized soils and was, therefore, due to microorganisms. It remained for Winogradskii to demonstrate, in 1893, that certain types of bacteria may thrive in artificial culture media nearly devoid of combined N. He isolated an anaerobic bacterium—*Clostriduim pasteurianum*—which is capable of fixing N (it is claimed that this organism fixes N in association with Azotobacter). In 1901, Beijerinck isolated the N fixing organisms known by the name of *Azotobacter*. The quantity of N fixed by the non-symbiotic organisms is not well established. Estimates run from 10 to 50 pounds per acre, per year. The most favorable environmental factors for N fixation by microbes are: a pH above 5.6 and an abundance of Ca and P in the medium.

Microbial Nutrition. — Soil microbes require the same kind of mineral nutrients as higher plants. They differ from higher plants, however, in not having the mysterious chlorophyll; they cannot utilize the energy of the sun for their life processess and must depend on energy released in the decomposition of organic materials.

Microbes have no digestive system for the intake of solid food. Nutrients enter into their bodies through the outer cell membrane in soluble form. Insoluble plant and animal substances must be rendered soluble by the microbial enzymes.

The efficiency rating of microbes in utilizing the energy of organic matter is low. Only 20 per cent of the energy released is utilized by them; the rest goes off as heat.

Carbohydrates and fats are the primary sources of energy for soil microbes. The proteins also supply some energy, but chiefly they supply N for building up and repairing the body tissues of the microorganisms.

In their metabolism, microbes utilize the mineral products of organic matter decomposition, the K, Ca, Mg, P, S, and other elements. The microorganisms derive their energy and N from the organic substances, making good use of the soil minerals for their mineral requirements.

Humus Formation

Plant constituents vary in the order and ease of decomposition. Sugars, proteins, and starches are most vulnerable to attack by microbes. The protein of the plants are converted into microbial protein and most of it may be found in the humus. However, the sugars and starches are used as a source of energy and very little of these are found in the humus. The hemicelluloses, celluloses, and fats, in the order mentioned, are next to be attacked, while the lignins, resins, waxes, pectins, and alkaloids are last. These substances in various stages of decomposition represent the bulk of the residual products of decomposition, the so-called humus. Dead and living bodies of microorganisms are an integral part of humus. It is higher in N than the original plant residues, because of the high N content of microbial cells. Associated with humus are also organic complexes synthesized from the reaction products of the humification process. *Humus formation is not only a decomposition reaction (one involving the breakdown of a substance of a high molecular order into a low one, such as* $CaCO_3$ *to* CaO *and* CO_2*) but also a synthesizing reaction.* Students of organic chemistry find humus to be far more complex in composition than the original organic material.

Analyses of Organic Matter. — In the study of soil organic matter, it is difficult to differentiate between its humified (humus) and nonhumified portions. Several methods of determining humus have been developed; that of treating the soil with acetyl bromide is short and fairly simple. This reagent extracts all types of plant substance except the humified portion, supposedly the humus. First, the total organic matter of the soil is determined by analyzing for total orgainc C and multiplying the C figure by the factor 1.724[2]. A separate portion of soil is then treated with acetyl bromide and, after removing the excess reagents, again analyzed for total carbon. The percentage of humus can then be calculated. This method, while not perfect, is very useful in determining the difference in humus content of soils.

Soil organic matter may also be analyzed for its chemical constituents by the standard methods worked out by chemists for determining the chemical components of plants. These methods are long, tedious, and complicated. They are, however, useful in following the transformations organic matter undergoes in the soil in the course of humification.

The soil is treated with alcohol and ether, or similar solvents which extract fats, waxes, resins, tannins, and like compounds. Then the soil is treated with cold 8 per cent H_2SO_4, followed with 5 per cent H_2SO_4 on a

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[2] This factor is obtained by assuming that the average carbon content of soil organic matter is 58 per cent; thus 100:58 = 1.724.

water bath. This treatment extracts the carbohydrates and most of the proteins. Whatever organic matter remains behind is considered as humus, with lignin as one of the constituents. Humus also contains some hemicelluloses which have been proved to have been built up by the microbes in the process of decomposition and are not of residual plant origin.

Soils formed under different climatic and hydrologic conditions vary in their humus content. Thus, peat-bog soils contain 46 to 49 per cent humus; podzols, 46 to 52 per cent; rendzinas, 57 to 65 per cent; brown forest soils, 50 to 70 per cent; meadow swamp soils, 81 to 82 per cent; and chernozem, 71 to 91 per cent (see Chapters VIII and IX for a discussion of the various soils).

Although humus is an organic residue resisting decomposition, it is not immune to mineralization. When microbes cannot find more easily decomposable substances, they attack humus and decompose it to completion Were this not the case, soil organic matter would accumulate. It is, however, known to pedologists that *the organic matter content of the respective textural classes of well drained soils in the different climatic belts is* *constant.* It may be varied within narrow limits by soil managemer practices. Attempts to build up and maintain the organic matter cor tent of cultivated soil in the humid regions are doomed to failure, unles the soil is kept in permanent sod. When plowed under, the increase i organic matter resulting from sod disappears within a year or two, fast in light soils and slower in heavy soils. Very often farmers go to needle expense in keeping fields in sod or in cover crops for green manure, wi the vain hope of increasing permanently or for a long period of years t organic matter content of the soil.

Soil Organic Matter Components. — For the purpose of distinguis ing the organic matter of the soil, a number of fairly well defined orga components have been recognized. Some of these, like humic acid a humin, are identified simply by their behavior to some chemical treatme Other components, however, like cellulose and hemicellulose, are defir chemical entities. A list of the components follows:

1. *Bitumens,* 2 to 12 per cent of the total organic matter (the lo figure for the arid and the higher figure for the humid climate); they soluble in organic solvents, such as alcohol, ether, acetone, and ben alcohol mixtures. 2. *Humic acids,* from 10 to 40 per cent; the substar are extracted from the soil with cold 1.0 N alkali, either the carbonat the hydroxide, and subsequently precipitated with acids. Some soils tain in the humic acid filtrate small quantities of soluble organic substa which can be precipitated with copper sulfate. They are known as *cr* and *apocrenic* acids or *fulvic* acids. 3. *Humin,* from 15 to 41 per

insoluble in cold alkali, but soluble in hot strong alkali. 4. *Hemicelluloses,* 10 to 15 per cent. 5. *Cellulose,* 1 to 7 per cent. 6. *Lignin,* 5 to 10 per cent. 7. *Nitrogen,* chiefly as protein and allied compounds, 3 to 5 per cent; less in the soil organic matter of humid regions and more of arid regions; the N is attached primarily to the humic acids and some to the humins. The components 4, 5, 6, and 7 are fairly well defined chemical entities of soil organic matter. Methods of determining these are given in standard chemistry texts.

Functions of Organic Matter in the Soil

1. Organic matter, upon humification and mineralization, supplies the reagents, such as carbonic and other inorganic and organic acids that react with the mineral component of the soil. These reagents set off a series of reactions which release desirable and sometimes undesirable substances for plants and are the starting point in the creation of the soil body, as outlined in chapter IV.

2. CO_2, released in the process of humification and mineralization, besides forming carbonic acid, is used by plants in the process of photosynthesis. An increase of the CO_2 content around the green parts of the plant is helpful in increasing crop yields. The high yields of garden soils, rich in organic matter, and the luxuriant growth made by plants in greenhouses may be partially attributed to a higher concentration of CO_2 in the air blanketing the respective soils. Artificial supply of CO_2 under field conditions has been tried successfully but its practice is as yet uneconomical.

3. The bases and other mineral constituents, released in the processes of humification and mineralization, serve as the primary source of the natural supply of plant nutrients. They, like the acids produced in these processes, are active in shaping the soil body. The bases also help to regulate the acidity and alkalinity of the soil.

4. One of the most important functions of organic matter is the stablizing of structural units as mentioned earlier.

5. The humified portion of organic matter, the humus, has a considerable capacity for absorbing cations. Fresh plant residues absorb small amounts of bases, the degree of absorption increasing with the advance in the stage of decomposition. Well rotted manure is more efficient in retaining plant nutrients (the bases) than fresh manure.

6. Organic mater plays an important role in regulating, in a large measure, the moisture regime of the soil. As the organic matter decomposes, its capacity for water increases. Some peats may contain as much water as 300 to 400 per cent of their dry weight. However, only a portion of this water can be utilized by plants, since a large share of it is hygroscopic

moisture which is not available to plants. The importance of organic matter as a reservoir of water for plant use is generally overestimated. It should be clearly understood, however, that weight for weight, organic matter when saturated or even when appreciably above the hygroscopic coefficient may supply more moisture than mineral matter.

Organic matter serves as a moisture reservoir in sandy soils where water enters easily but leaves just as easily. On the other hand, small rains may be wasted in sandy soils containing large quantities of organic matter because its hygroscopic coefficient is high. Besides serving as a moisture reservoir for sandy soils, organic matter prevents the rapid leaching of nutrients.

In heavy soils, organic matter improves the soil structure and thus facilitates the movement of water. In arid regions, easy entrance of water insures its accumulation deeper in the profile during fall, winter, and early spring for the use of crops during the usually hot dry summer. In humid regions, ease of moisture movement is insurance against waterlogging which is often a real menace in heavy soils. The ease of moisture penetration is also important in erosion control; with more water penetrating the soil profile, less water is available for surface runoff, and hence less soil is carried away.

7. Some soluble organic compounds serve as cementing agents in the formation of concretions and hardpans. The coffee-brown color of these formations in the B horizon of many profiles is due to the precipitation of the soluble organic compounds. These compounds also serve as carriers of the Fe and Al that split off from the minerals and are sent into circulation in the process of podzolization (see Ch. VIII).

8. Decomposition of organic matter releases heat, causing a rise of soil temperature. In regions with a long winter season, an increase in soil temperature during spring offers an earlier start in working the land and hence extends the growing season.

9. Organic matter serves as a culture medium for microbes, whose important activities have been previously discussed.

CLIMATE AND SOIL ORGANIC MATTER

From the point of view of soil organic matter supply, two broad ecologi divisions are recognized: *forests* and *grasslands*.

In the climate of the forest zone, grass vegetation is an artificial schem If left alone, man-made meadows and pastures revert gradually to brus and forest vegetation. While sod is maintained, there is a definite increa in the organic matter content of the soil. As soon as the sod is turned und and the land is put into clean cultivated crops, or into grain, the organ matter content quickly decreases and reverts back to the normal. In other words, grass is a temporary expedient in increasing the store of soil organic matter in the forest zone.

The conclusion reached after 40 years from the long continued soil fertility plots, known as the Jordan Plots, at the Pennsylvania State College, is that "under a proper system of cropping, a gain of soil organic matter takes place during the period in which a soil is left undisturbed in legume, grass, or sod; but this gain is soon lost on cultivation, resulting in a balance or equilibrium between the organic matter gained and lost. Thus, the addition of organic matter to cropped soils counterbalances the gradual diminution that results from cultivation."

Organic Matter Supply in Forests and Grasslands. — The contribution of forests to the supply of soil organic matter consists of tree residues, such as leaves, branches, trunks of trees, bark, and fruit. In the average mature forest, the annual deposit of these residues amounts to 2500 to 3500 pounds of dry matter per acre. Leaves or needles contribute 50 to 70 per cent of the total dry matter[3]; branches contribute about 25 to 45 per cent; and other portions of the tree contribute the remainder of the dry matter. Besides the trees, herbaceous and other vegetation furnish annually 500 to 1200 pounds of dry matter to the forest floor. Of the two types of forests, the coniferous and deciduous, the latter contributes more plant residues.

In the region of the short grasses, the surface vegetation contributes annually about 400 to 600 pounds of dry matter per acre and in the region of the tall grasses, 1200 to 1500 pounds. As a rule, grasslands supply only ⅛ to ½ the quantity of organic residues that forests do.

Natural surface vegetation of grasslands does not compare in weight with the dry matter of most cultivated crops. For example, a corn crop may give as much as 6,000 pounds of dry matter per acre; 3,000-4,000 pounds of alfalfa hay per acre is an average yield, but 5000, 6000, and even more, are not uncommon. Similar quantities of dry matter are produced by other crops.

It would seem that forest lands, receiving by far more organic residues than grasslands, should have a greater accumulation of organic matter in the soil. And yet, grassland soils contain more organic matter. It is apparent that the organic matter content of soils does not depend on the quantity of top growth produced by plants.

1. The source of soil organic matter is the underground plant residues: roots, subaerial stems, rhizomes or root stock. In the forests, roots represent 15 to 20 per cent, and in grasslands as much as 50 per cent and more of the surface vegetation.

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[3] Certain conifers, such as the spruce, contribute a little less than 50 per cent.

2. In the forests, plant residues, upon decomposition, release soluble tannins and other organic substances which are leached from the profile into the ground waters. In the spring of the year, the deep brown to straw color of the slowly moving brooks of level areas in forest country is due to these soluble organic substances. In the grasslands, the soluble organic substances usually precipitate throughout the depth of the A horizon; very little of these reach the B horizon. This is, by the way, a contributing factor in the formation of a deep A horizon (black in color and rich in organic matter) in some of the grasslands (see Ch. VIII).

The well-nigh insoluble organic matter of the forest floor decomposes at a steady rate, with very little of it penetrating into the A horizon. Earthworms and other forms of animal life carry some of the leafmold down into the profile. In the grasslands, the surface plant residues become desiccated and are swept away by the winds and carried off by rainwater to the streams. An insignificant portion of this organic matter finds its way mechanically into the cracks of the soil and a few soluble organic compounds penetrate into the soil profile.

3. Forest vegetation is *low* in ash (see table 2). Percolating waters leach the bases released in the process of humification and mineralization, resulting in an increased acidity of the forest floor. In such an environment fungi prevail, and they destroy the organic residues very rapidly. Even lignins are attacked, especially by the mushroom fungi. The rapid disappearance of organic matter is much more marked in the humid tropics and subtropics.

Grassland vegetation is *high* in ash (see table 2). Percolating waters are not as abundant as in the forest zone, and they do not remove as much of the bases. Because of these circumstances, the sod is, as a rule, either neutral or even alkaline. The microbes prevailing there are the bacteria and actinomyces which are less destructive than the fungi.

4. The forest floor is almost always damp and well protected from the parching sun and desiccating winds. Under such conditions, microbes are not hindered in their activities and they destroy large quantities of organic matter. In the grasslands, the dehydration of the dead surface vegetation and the disinfecting power of the sun's rays constitute unfavorable conditions to microbial activity. Besides, the dead grasses and other forms of organic matter subject to parching effects of the sun become so leathery, so tough, and perhaps so "unpalatable" that even microbes refuse to thrive upon them when moisture becomes available.

Nomadic tribes in the grasslands practice the firing of grazing areas in fall or early spring. The resulting ash enters the soil profile and serves as nutrients for the next grass stand.

5. The life cycle of most grasses is generally short, and with every generation of surface vegetation there is a corresponding generation of roots. It is also known that grass roots continue to develop long after the surface vegetation has died away. Thus, large quantities of organic matter are "generated" in the soil.

Because of the open structure of the grassland soils, roots have no trouble in penetrating the soil body to appreciable depths. With every dry spell the roots go down deeper into the soil body; the depth of the A horizon increases in this manner.

In the forest zone where the B horizon, as a rule, is compact and may even become periodically waterlogged, penetration and extension of the root system are impeded. Infrequently, the soluble Fe, Al, and other toxic substances in the B horizon keep the roots away from it. The result is that the bulk of the roots is concentrated in the first few inches of the A horizon. These facts explain the accumulation of organic matter in soils under forest in the surface few inches and why the total organic matter in the profile under forest is much lower than of the soils in the grasslands.

ORGANIC MATTER IN FARM PRACTICES

The sources of organic matter in cultivated soils include crop residues, animal manures, cover crops, green manures, composts, and a few other organic materials, such as peat, industrial wastes, sewage sludge, and organic fertilizer constituents. The different types of organic matter present a number of problems involved in farm practice. One of these problems is associated with the ratio of C to N in soil organic matter.

Carbon-Nitrogen Ratio. — The C:N ratio in straw is 40:1; in wood, 400:1; in legumes, 15:1 to 20:1. When incorporated into the soil, these organic materials undergo decomposition, and the residual organic matter has an average ratio of 10:1, varying from 8:1 to 12:1. It is clear that hen a legume is plowed under, very little of the excess C has to be used p by the microbes to bring about a ratio of 10:1. However, when straw, wdust, wood-shavings, or similar high C containing materials (used as edding) are plowed under, the microbes have to work on large quanties of carbon before the 10:1 ratio is attained. In this process, the mirobes have to find a source of N for their metabolic activities. Because f the shortage of N in straw, sawdust, etc., the microbes are forced to raw on the available N of the soil. The result is a deficiency of N for rop plants during the decomposition of straw and the like materials. In ompetition for precious N, the microbes win out against the higher plants. y adding extra nitrate of soda, sulfate of ammonia, or other source of N hen carbon-rich organic substances are plowed under, the competition for

N between the plants and microbes is minimized. Even then, straw may cause trouble to the crop by disrupting the balance among nutrients other than N. Straw should, therefore, be applied well in advance of planting. For best results, manure containing large quantities of straw should be composted. In this way, the period of disturbed nutrient balance, caused by the decomposition of the straw, will be over by the time the cash crop is planted.

Crop Residues. — In most crops, the roots contribute the largest share of organic residues to the soil (see Ch. VIII). Crops vary in the quantity of roots they produce. Among the legumes, alfalfa tops the list in this respect, with soybeans supplying the least. Among the grains, rye produces more roots than wheat, wheat more than oats, and oats more than barley. Of course, the supply of nutrients and tillage practices will, in a large measure, determine the quantity of residues any crop contributes.

In summing up the results of 40 years' experiments on the Jordan Fertility Plots of Pennsylvania on which a 4-year rotation of corn, oats, wheat, and hay (clover and timothy) has been practiced, one of the reports notes the following:

> It is exceedingly difficult to increase the content of organic matter and N by crop residues in most well drained cropped soils. Ordinarily, crop residues that decompose rapidly when incorporated into soils add but little to the total content of soil organic matter. When a slow accumulation does occur, measurable quantities of increase can be detected by chemical analysis only after a period of years.
>
> As a result of increased quantities of crop residues that result from improved methods and rational fertilization, crop yields may be increased, but the quantity of organic matter may remain fairly constant.

Cover Crops and Green Manure Crops

A cover crop is one which covers the land during the autumn, winter, and spring (and sometimes during the summer). There is no sharp line of distinction between a cover and green manure crop. With a green manure crop, the emphasis is on the supply of organic matter and the improvement of the physical properties of the soil. With a cover crop, the emphasis is on keeping the land from idling, protecting it against erosion and preventing losses of nutrients by leaching (the cover crop utilizing whatever nutrients become available).

A green manure crop is one which is turned under, whether planted for that purpose or not. Green manuring is an ancient practice. Greek chronicles, as early as four centuries B.C., tell about the uses and beneficia effects of green manuring.

Generally, a cover crop is harvested, as in the case of winter grai crops, or utilized for pasture or hay during the spring and early summer It may be followed by a cultivated crop, if the season is long enough, or b a grass crop, usually a legume, for pasture or hay. Like any other crop, a cover crop furnishes organic residues, stubble and roots.

In selecting a cover crop, the first consideration should be economy and suitability for the particular locality. The Agricultural Experiment Stations, competent agronomists, the County Agricultural Agents, and progressive farmers of the locality should be consulted for reliable information.

Market gardeners have been confronted with the problem of organic matter ever since mechanization of agriculture displaced animal power on the farm and motor vehicles drove the horse from the city. The trainloads of manure rolling from the cities to the rural districts along the Atlantic seaboard, a common sight on railroad tracks in the beginning of the present century, are no more. When horses and mules disappeared from farms and cities, large areas of hayland were plowed up, thus decreasing the land area in sod and exhausting the organic matter of the soil more rapidly. Green manure became a substitute for the vanishing sources of soil organic matter.

Legumes are the most desirable green manure or cover crop. They supply not only organic matter, but also appreciable quantities of N. Alfalfa is a better green manure crop than any of the clovers, and the latter are better than the shallow-rooted soybeans, or cowpeas. Among the non-legumes, domestic ryegrass is better than rye; combinations of a legume and non-legumes, such as winter vetch with ryegrass, or winter wheat with clover as a catch crop, are better than either rye or ryegrass. Very often the choice of a green manure crop is determined by local conditions.

Beneficial Effects of Green Manures. — One of the frequently referred to benefits of green manure crops is the supply of nutrients. This contention may be questioned inasmuch as the nutrients of the green manure crop come from no other source than the soil. In other words, there is no additional increment of nutrients, except in the case of a legume when some N is added. The actual benefit of green manure crops, as far as nutrients are concerned, is that they retard the loss of nutrients by leaching and some of these are picked up and returned to the soil for the cash crop.

Another would-be benefit of green manure cropping is the supply of organic matter to the soil. Whereas the physical condition of the soil is improved whenever organic matter is wisely added, there is this to be remembered: the quantity of dry matter added by the average green manure crop is of minor significance. There are, however, other beneficial effects of green manuring.

Green manure crops, if plowed under in *the early stages of growth*, deliver to the soil readily available nutrients in a balanced form. They also gather and supply the known and unknown minor elements. Young plants are also rich in vitamins and other vital substances that are an asset to the succeeding crop.

One may draw an analogy between young green plants and spring chicken, squab, or the tender steak of a young steer. The meat of a spring chicken, or of a squab differs little in composition from that of an old rooster or pigeon; insignificant too are the differences in the composition of steaks of a steer from those of an old bull. And yet, we all know the specific taste, flavor, and many undefined properties of the spring chicken, squab, or the tender steak of a young steer. It is this unknown "spring chicken quality" that is distinctive in the young green plant.

A reasonable conclusion, based on the views expressed, is that the stage of growth of the green manure crop is of important consideration. Plowing under a mature or a near mature green manure crop may be dangerous, as pointed out earlier. In most soils, except for the real sands, the better way of handling green manure crops is to plow them under young. A rye or wheat crop should not be higher than 12 inches. In sandy soils where oxidation, and hence decomposition, is very effective and rapid, a more mature green crop may be used, and even then one should make adjustments for the disturbed balance of nutrients.

In the arid and semiarid regions where dry farming (See Ch. VIII) is practiced, plowing under an alfalfa sod in the spring has been shown to cause the succeeding crop to "fire". The reduction in moisture supply, brought about by the decomposition of the organic matter, is responsible for the firing.

Summary Statement. — In closing the subject of green manure, the following quotation from the paper by A. J. Pieters and Roland McKee[4] may be appropriate:

> No very large addition to the soil organic matter can be expected from turning under a single green-manure crop. If a crop of vetch that will yield a ton of dry matter per acre is turned under, about one half will quickly be lost as carbon dioxide or in other ways, and the balance, or about 1,000 pounds per acre, will become in a limited time a part of the humus. If a soil contains 2 per cent organic matter in the surface soil, the organic matter will weigh approximately 40,000 pounds per acre. By adding 1,000 pounds a year, 40 years would be required to double the organic matter in the surface soil, if it were all permanently retained. This illustration, while a rough one, is introduced to point out that in the main, the object of green manuring must be to maintain rather than to increase the quantity of organic matter in soils.
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> The New Jersey Agricultural Experiment Station concluded that turning under green-manure crops ratarded the loss of soil organic matter, but did not increase the

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[4] Soils and Men, Yearbook of Agriculture, 1938. U. S. Dept. of Agric., Washington, D. C., pp. 431-444.

amount, while grass sod, down for 2 years, increased the humus content by 1,340 pounds per acre.

Loss of organic matter begins with cultivation, when decay of the sod and roots sets in, nitrogen and minerals are set free for the use of the cultivated crop, and, by a process of oxidation, the carbon dioxide is released and organic matter lost.

This loss of organic matter is not to be altogether deplored, as the decrease is in large part merely the necessary accompaniment of making the soil organic matter available to crop plants. The fact must be recognized, however, that cultivation is necessarily accompanied by a loss of organic matter, and that if this is allowed to go too far, declining crop yields will result (not necessarily: J).

The amounts of organic matter, and, in the case of legumes, nitrogen, are not the sole factors determining the crop to be used for green manuring or the time to turn it under.

Cover and green manure crops should be used when they least interfere with the regular cash crops. In the South, winter cover crops fit into the farm program most effectively. In the North, catch crops following grain crops or planted with them can often be used to advantage. In trucking areas, catch crops frequently can be utilized, and legume crops in the regular rotation serve in effect as green manure. It is generally considered that giving over the entire crop season exclusively to a green manure crop is seldom profitable, but it is perhaps justifiable when the succeeding crop is more or less permanent and the establishment and good growth of the seedlings or young plants are of prime importance. Preceding permanent orchard plantings, a full year or more given over to green manure crops might be justified, and where fall seeding of lawns is practiced, a summer green manure crop of soybeans, cowpeas, or some other legume can well be used to prepare the land for the grass seeding.

In the South. when a legume is plowed down in early fall, it should be followed with rye or some other winter-growing crop to prevent leaching of the plant food released in the decaying of the turned-under crop and to stop erosion. If it is not to be followed by such a winter crop, the summer green manure should not be plowed under green, but should be cut or disked in the fall and allowed to remain on the surface as a mulch or lightly worked into the soil so as to delay decay and prevent loss during the winter months by both leaching and erosion.

In northern latitudes, there is relatively little leaching during the winter period, and it is seldom profitable to grow a crop merely to prevent this small loss. A regular winter small-grain or similar crop, however, will greatly reduce loss by erosion.

In the case of abandoned or worn-out lands, a cover crop should be sown to occupy the land more or less permanently, using a legume when possible. In certain parts of the south, annual lespedeza and crotalaria can be used in this way. Sometimes, a green manure crop can be used in this way. Sometimes a green manure crop can be planted in late spring or midsummer following an early cash crop, such as wheat, oats or some truck crop. Whether a crop thus grown can best be used exclusively for green manure or in part for forage, and in part for green manure, will have to be determined by the probable cash value of the succeeding crops and the value of the forage that might be obtained. In this connection, it should be mentioned that the use of a legume in rotation as one of the regular cash crops is a very economical way of maintaining soil fertility and crop production. The roots and stubble of the legume return to the soil considerable organic matter high in nitrogen at practically no cost.

It should be made clear to every user of green manure crops that when large quantities of green organic matter are turned under, or otherwise incorporated into the soil, some time must be allowed to elapse before planting a succeeding crop, in order to avoid injury, by decomposition products, to the seedlings of the crop to be planted. In the South, a green manure crop should be turned under about 2 weeks before planting corn and 3 weeks before planting cotton.

When cover crops are planted in orchards, the season of growth of the trees and the time and manner of incorporating the crop into the soil become matters of importance. It is necessary, with an annual crop, to plant at such time as to interfere as little as possible with tree growth and fruit development, but some attention must be given to the harvesting operations. The incorporating of any crop with the soil should be done, if possible, when the tree roots are not in active growth, and if this is not possible, the green manure should be lightly worked into the soil or left on the surface as mulch. The best method for one section, and for a given crop will not be the same for all sections and all crops, but the important fact to remember is that the decay of the green manure or cover crop should occur at the time when it will best serve as fertilizer for the crop it is to benfit.

Animal Manure

Manure, farm manure, barnyard manure, stable manure are interchangeable terms in agricultural literature and parlance; they refer to animal excrements mixed with bedding. Generally, however, the term "manure" is reserved for the natural excrements, solids and urine.

If all the manure of the livestock on farms in the United States could be collected and used on the farmland in crops and pasture, each acre would receive annually about one ton. About 900,000,000 tons of manure is voided by animals on the farm, but not all of it gets to the land, and the part that does is not efficiently utilized. It has been suggested that one-half of the manure from farm animals is dropped on pastures, where it is poorly distributed and a large share of it is, therefore, wasted. An indeterminate amount of manure is dropped on the cow paths. Large quantities of manure, especially of the liquid portion, are lost in handling (see Chapter XII).

From table 4, it is obvious that if animal excrements were collected under ideal conditions, a ton of *fresh manure* (the average of horse, cow, sheep and pig manure) would carry about 460 pounds of dry matter. Actually, the moisture content of *stable manure* is lower than that of fresh manure and the quantity of dry matter is, therefore higher. Assuming the average farm manure to contain about 60 to 70 per cent water, the quantity of dry matter per ton would be from 600 to 800 pounds. An application of 10 tons of manure per acre supplies 6,000 pounds of organic matter, a 15 to 20 per cent increase for a soil containing 2 per cent organic matter.

In truck gardening areas where stable manure is still available, applications of 15 to 20 or even 40 tons per acre annually are not uncommon. Under such practices, the organic matter content of the soil may be increased and the level maintained. However, if such heavy applications of manure should be discontinued, the organic matter content of the soil would drop to its normal pre-manured level within a year or two, even though the favorable effects may last for many years.

From the standpoint of organic matter supply, one would expect fresh stable manure of straw or sawdust litter, the latter containing as much as 30 per cent lignin, to yield a large quantity of humus. Any farmer who knows his business (but knows very little about lignin) will be reluctant

TABLE 4

*Daily production (per 1000 pounds live weight) of manure and partial composition**

Animal	Feces	Urine	Manure plus bedding	Dry matter in fresh		Organic matter in a ton of stable manure, dry basis**
				Feces	Urine	
	pounds	*pounds*	*pounds*	*per cent*	*per cent*	*pounds*
Horse	39	10	65	24.3	9.9	482
Cow	52	22	82	16.2	6.2	388
Sheep	23	11	53	34.5	12.8	650
Pig	50	33	99	18.0	3.3	376
Hen	.1			35.0		700

*From Ohio Agr. Expt. Sta. Bulletin No. 605 (1939) and other sources.

**The figures seem to be too low, unless the figures for the dry matter in fresh feces are too high. Thus, if we accept 34.5 per cent of dry matter for feces of sheep, the organic matter content without bedding should be at least 690 pounds. In general, data of this kind are close approximations which serve as a guide in various calculations pertaining to manure.

to accept such manure for immediate use. He would rather keep such manure in the pile until it has rotted well. Not that the farmer objects to the lignin, but he is aware of the injurious effects of fresh manure made up of such common forms of litter as straw, wood shavings, or sawdust.

State of Manuring. — The state of manuring of a soil, i. e., whether the manure effects are still operating, may be determined by making a count of thermophilic bacteria (those that can withstand high temperatures) in the soil. Manure carries the thermophiles and, as long as they can be found in the soil, it is a good indication of the state of manuring. No thermophiles are found in sod, but in heavily manured soils the Ap horizon may show as many as 150 to 300 per gram of soil. The thermophiles are also found in the layer below the Ap.

The citric acid soluble phosphates may also be used as an index of the state of manuring of the soil. The presence of manure in the soil increases the citrate soluble phosphates.

Animal Versus Other Types of Manure. — Besides supplying organic matter, animal manures contribute some unknown substances, the specific benefits of which are still not known. Green manures may supply the quantity of organic matter and nutrients contained in manure; still farmers tell us that green manures cannot compare in effectiveness with stable manure.

In recent years, stable manure has been credited with the supply of sex and other hormones which are of great importance in human physiology; they react effectively in very minute quantities. Some of the sex hormones have been used in an experimental way on plants, but no definite evidence of their potency has as yet been established.

The author has observed that the European farmers, especially the peasants of Eastern Europe try to manure as many fields as possible, be it even by a small quantity. When first introduced, mineral fertilizers have been used as a supplement to and not as a substitute for stable manure.[5] Acid phosphate serves now the function of a manure supplement. Reinforcing manure with acid phosphate, about 50 pounds to the ton, is a common practice. It serves two purposes; first, the excess acid of the acid phosphate takes up the NH_3 of the manure and preserves it; second, manure is low in P and the addition of acid phosphate enhances greatly the value of the manure, since a deficit of one element impedes the utilization of the others.

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[5] With the disappearance of manure on the farm, due to mechanization and specialization, mineral fertilizers gradually replaced it. The passing generation of farmers has not learned how to farm without manure. The newer knowledge on soil productivity is rapidly being acquired by the young generation, and farming without stable manure is the order of the day.

Stable manure and green manure have one common property, namely, they supply organic matter. They vary, however, in many other respects and their positive and negative qualities should be evaluated.

1. As a waste product of digestion, animal manure contains large quantities of indigestible substances which are not readily attacked by microorganisms and are, therefore, not a good source of immediately available nutrients.

2. The litter of stable manure, as a rule, contains compounds of a high C:N ratio which is not a desirable characteristic, as pointed out earlier.

Against these neagtive features of stable manure, green manures and cover crops, when properly handled, offer positive qualities. They are a source of organic matter which is readily attacked by microorganisms, thus making the nutrients quickly available. Such crops concentrate the minor elements and whatever else young vigorous growth may accumulate. Upon decomposition, all of these beneficial elements and substances are made available in balanced form to the succeeding crop.

There are, however, positive qualities of stable manure which the green manures do not have.

1. In the process of digestion, some metabolic products of the animal body come with the manure.

2. The urine adds readily available N and K, and what is also important, the sex and other hormones mentioned earlier.

3. With manure, billions of microbes are introduced into the soil. About 20 per cent of the dry weight of manure consists of microbial cells. The high protein and ash content of these cells, when introduced into the soil, give readily available N, P, and K.

Caution in the Use of Manure and Green Manure. — The practices of green manuring and, or, applications of fresh stable manure are of doubtful value, if not injurious, when the soils are wet because of poor drainage of one kind or another.

The decomposition of organic matter in the soil calls for a huge supply of oxygen. Even though there is a blanket of air *over* the soil, there is always the danger of depleting the supply of oyxgen *in* soils of the humid regions. This, of course, is more true for poorly drained soils. By adding organic matter, a condition of poor aeration is not improved; on the contrary, the little O of the soil air is utilized in the process of decomposition. An example of an O supply problem will illustrate the aforesaid.

It has been estimated that the average rye green manure crop under conditions of central New Jersey supplies, in tops and roots, about 5 tons of green weight or about 1 ton of dry matter. Assuming that the dry matter contains 50 per cent C, it would take 2666 pounds of O_2 to convert the 1000 pounds of C to CO_2.

An acre of land to a depth of 12 inches, with 50 per cent pore space, may hold, theoretically, 21,780 cubic feet of air. At optimum moisture, however, the available pore space will be only about half the total, namely 10,890 cubic feet. Inasmuch as about 20 per cent of the air is O, the total content of the soil, at optimum moisture, is 10,890x20/100 cubic feet, equivalent to 61,700 liters. Since 22.4 liters of O, at standard conditions of temperature and pressure, weigh 32 grams—one gram molecular weight —the total O available in one acre of land to a depth of 12 inches is: $32 \times (61{,}700 \div 22.4) = 194$ pounds. With 2666 pounds of O required to mineralize a 5-ton green-manure crop, it is easy to see that about 14 changes of air would be necessary to oxidize the 1000 pounds of C of the green manure crop.

There are no exact figures on the diffusion of gases through soils, and it is difficult to evaluate how much O may be available at any time. Rarely do we get a complete change of air. It takes place only in well drained soils after heavy rains when the non-capillary pore space is relieved of the water by gravitational forces and fresh air rushes in.

One should keep in mind that a certain amount of O is necessary for other reactions, such as plant root respiration, microbial metabolism, and oxidation of mineral materials. It is thus safe to assume that in the humid regions, for example in the Eastern States, the danger of a lack of O is real. And one more point: whenever the diffusion of air from the atmosphere above into the soil is impeded, root activity may cause the accumulation of CO_2, which in itself is an undesirable condition.

Heavy sod, mature green manure crops, fresh stable manure, or an kind of organic matter, when plowed under, increase the moisture holdin capacity of the soil and thereby reduce its O content. Generally speaking, therefore, it is not advisable to use organic materials, especially gree manure crops, in poorly drained soils. The only valid reason for th use of a green manure crop on these soils is the prevention of erosio (usually not a serious factor in poorly drained soils) and losses of nutrients. In such cases, the crop should be plowed under as early as co ditions will permit, leaving the soil in the rough for better drainage an aeration. Such soils are usually late and can not be used for early sprin crop plantings. Poorly drained land should be plowed in the fall and le in the rough.

If the land is not too wet, and a cover crop is to be used, it shou be a cash crop, to be harvested late in spring or early summer, such grain, or a grass crop that makes luxuriant and rapid growth. In th way, huge quantities of water are pumped out (on the average, 500 pounds of water are used for every pound of dry matter produced). Fertilizer applications in the early spring to stimulate vegetative growth of the cover crop will work in the direction of draining the soil. *Under such conditions, the crop should be removed from the land instead of being plowed under.* In general, it should be remembered that the roots rather than the tops supply stable organic matter to the soil.

Only well-rotted manure should be used for poorly drained soils. One may very often detect a strong sewage smell emanating from wet soils in which fresh manure has been added or a cover crop has been turned under in the spring. Such cases have been encountered by the author time and again. This condition may be the cause of many crop failures. In wet soils, it is better practice to disc the manure in, instead of plowing it under. This method will reduce the danger of depleting the oxygen of the soil.

Composts. — Compost is a mixture of any plant or animal refuse and mineral soil material subjected to the reactions of the soil microbial flora. As a rule, the compost is made up in a pile formed of alternate layers of soil and organic matter varying in depth from 4 to 10 inches, the total depth of the pile being about 6 feet. For a compost with a 15 to 20 per cent organic matter content, one has to start with 50 per cent of organic matter. Of course, the quantity of organic residues in the composts depends on the kind of organic matter with which the compost heap is started. Fresh plant materials leave little residue; peat, straw, or woody materials persist for a long time. In composts, additions of lime, some fertilizer, and manure are helpful. For every ton of the pile, the following may be added: 25 to 50 pounds of dolomitic limestone, 10 to 15 pounds of N in the form of nitrate of soda (about 70 to 100 pounds) or $(NH_4)_2SO_4$ (about 50 to 75 pounds), 75 to 100 pounds of acid phosphate, 15 to 25 pounds of muriate of potash, and 150 to 200 pounds of fresh manure.

The sides of a compost are made nearly vertical. A shoulder is made at the edge of the top of the pile, the top layer consisting of soil. The shoulder retains the rainwater and keeps the pile wet. Three to four times during the year, the compost is turned. As a rule, the compost is used after the first year.

In some parts of the world, such as China, India, sections of Japan, Eastern and Southeastern Europe, the compost heap is the recipient of organic wastes, including kitchen garbage and human feces. The compost heap for the peoples of these parts of the world is not only the chief source of organic matter supply, but also of fertilizer.

In the more advanced parts of the world, where the nutrients are supplied in the form of mineral fertilizers, composts are used primarily as a soil conditioner in the greenhouse and home garden, or as a top-dressing material on golf courses, lawns, flowerbeds, etc.

Artificial Manure. — Composting vegetable and other organic remains without mineral soil, has been known for a long time, but only since stable manure began to disappear from the farm has this kind of composting been undertaken with a view of producing artificial manure. It has been shown that good grades of manure can be produced by composting such materials as straw, corn stalks, leaves, or similar materials. To each ton of such organic residues, the mixture of limestone and fertilizer, as specified for soil composts, is added. It is good practice to mix several hundred pounds of stable manure with the artificial manure. A ton of dry wheat straw may give, after 6 to 8 months, as much as 3 tons of artificial manure.

Other Sources of Organic Matter. — Sewage sludge not contaminated with industrial waste poisonous to plants, when used in the same manner as stable mannre, is a good source of organic matter.

Peat and muck, if limed to a pH between 5.8 and 6.6, may be used as a source of supply of organic matter. Unless composted, these materials are of little value in the soil during the first year, except as a mechanical soil conditioner, especially in heavy soils. In soil, with a favorable pH, the peat gradually becomes available.

The organic materials that come with the mixed fertilizers (either as sources of plant nutrients, like dried blood and tankage, or as a conditioner, like ground tobacco and banana stems) add some organic matter to the soils, but only to a small extent.

APPENDIX

Carbohydrates

The substances which have the characteristics of sugars or resemble them ir structure and chemical behavior are classified as *carbohydrates.* For convenience these are separated into three groups: 1, monosaccharides, sometimes referred to a monoses or monosaccharoses; 2, sugar-like polysaccharides, or polysaccharoses o polyoses; and 3, polysaccharides which are unlike the sugars.

Monosaccharides. — They are represented by the simple sugars, such as glucos and fructose, which are very widespread in nature. Their fundamental compositio or empirical formula, is $C_6H_{12}O_6$. The glucose, of which grape sugar is the prom inent representative, is also known as dextrose. In general, sweet fruits are ric in it. Fructose, or fruit sugar, is found in most plants, particularly in ripe fruits an honey. The monosaccharides are neutral compounds, readily soluble in water, an difficultly soluble in alcohol. They are the building stones of the polysaccharides.

Among the less known simple sugars are the pentoses. Their fundamental con position, or empirical formula, is $C_5H_{10}O_5$. Examples of these are *arabinose,* whic occurs in large quantities in cherry-tree gum, and *xylose* (wood sugar). The pe toses are important from the point of view of soil organic matter, inasmuch as th are products of the hydrolysis of pentosans which are associated with the pol saccharides of group 3, found in large quantities in wood, in straw. in many kin of resins, in seed-cases, in lichens, and in molds.

Sugar-Like Polysaccharides. — These carbohydrates resemble closely the mon saccharides in solubility, taste, and chemical properties. To this group belong t well known cane sugar (*sucrose, saccharose*), malt sugar (*maltose*), milk sugar (*lactose*), and the less known *melibiose*, classified as disaccharides. The name "disaccharides" refers to their makeup, consisting of two molecules of glucose (as in maltose) or of one glucose and one fructose (as in sucrose), minus H_2O. In other words, two molecules of a monosaccharide may be considered as combining to form one molecule of disaccharide and one molecule of water, as indicated in the following equation:

$$2C_6H_{12}O_6 \rightarrow C_{12}H_{22}O_{11} + H_2O$$

The trisaccharides, of which *raffinose* is a representative, are made up of three molecules of $C_6H_{12}O_6$ minus two molecules of water:

$$3C_6H_{12}O_6 \rightarrow C_{18}H_{32}O_{16} + 2H_2O$$

Sugar of commerce is obtained from sugar cane and sugar beets which are very rich in sucrose, up to 20 and 17 per cent respectively. Most plants contain some sucrose.

Maltose is formed from starch by the action of the diastatic ferments. Since the latter occur in abundance in germinating barley or malt, the sugar has received the name malt sugar. Maltose is undoubtedly present in many plants. It has been demonstrated in soybeans.

Lactose, or milk sugar, is present in the milk of mammals to the extent of 5 to 6 per cent. Its presence in plants has not been demonstrated. However, lactic acid produced by microbes in milk from lactose may also be produced by many soil bacteria from other sugars.

Raffinose is the most important of the trisaccharides. It is found in small quantities in many plants, such as barley and sugar beets. It is also found in cottonseed, and in large quantities in eucalyptus manna; it occurs as an impurity in refined sugar.

Polysaccharides Not Resembling Sugars. — This group takes in two types of compounds. One is represented by starch and inulin which serve as reserve food; the other is represented by the celluloses which serve as skeletal substances. When treated with mineral acid, the compounds of this group break down into monosaccharides. The empirical formula showing the fundamental composition of the starch group of substances is $(C_6H_{10}O_5)n$.

Starch is the most important carbohydrate reserve of plants. Some plants, such as potatoes, contain as much as 85 per cent starch. It is soluble in cold water, but at 60° C. it swells, forming a colloidal solution. As stated earlier, starch is acted upon by diastase and gives rise to maltose.

Very close to starch is glycogen, found particularly in the liver of animals, in muscle tissue, and in other cells. It is also encountered in fungi.

Inulin is found in many plants, especially the *compositae* which retain it in their subterranean organs. It is usually obtained from Dahlia tubers or artichokes. Inulin is not affected by the diastatic enzymes.

Cellulose is the most characteristic and in many cases the prevailing substance of the cell walls of plants. The woody portions of conifers and deciduous trees are rich in cellulose, 50 to 60 per cent of the dry weight. Leaves, needles, residues of grasses, such as straw or hay, may contain from 20 to 40, and not less than 15 to 10 per cent cellulose. Of all organic compounds occurring in nature, cellulose is the most prevalent. It is estimated that 2,420 billion pounds of CO_2 is locked up in the cellulose of the plant world, an amount equal to about half of the weight of CO_2 in the atmosphere.

Upon hydrolysis with mineral acids, cellulose is converted into glucose. It is stable in dilute acids and alkalies, and insoluble in water.

Hemicelluloses are closely associated with cellulose. On the average, plant residues contain from 15 to 30 per cent hemicelluloses. They are less stable than cellulose in dilute acid. When heated in such acid solution, they hydrolyze and form pentoses and hexoses (glucose forms of sugar). Hemicellulose may have 5 or 6 carbon atoms in its empirical formula. The pentosans have the formula $(C_5H_8O_4)n$ and give rise to the pentose sugar *xylose*. The woody portion of fir contains 8.8 to 9.2 per cent xylose, of beach—23 to 33 per cent, and of birch—25 per cent; jute contains 14.9 per cent xylose. They are hemicelluloses which should be looked upon as mixtures of derivatives of pentoses and hexoses, as represented by the formula $(C_5H_8O_4.C_6H_{10}O_5)n$.

Other associates of cellulose are the *pectins.* Under this name are included gelatinizing substances which are found in abundance in the fleshy part of fruits, in currants, grapes, peelings of apples, and in roots of many plants. In small quantities, pectins are also found in leaves and green portions of stems.

Substances Other Than Carbohydrates

Lignin. — Next in importance to the carbohydrates is a substance or a group of substances known as lignin. It seems to impregnate the living cells of the woody portion of the plants and becomes lodged in them. Lignin is associated with the cellulose and hemicellulose portions of the plant. It is of interest to know that a gain in lignin in the living plant almost equals the loss of pectins.

The nature of lignin is not yet clear, although it has been known for more than one hundred years. One of the difficulties in studying this subtance lies in the fact that material of different plants, upon extraction with the same reagent, does not yield lignin of the same fundamental composition. Lignins from various sources are reported as varying in composition from 57 to 69 per cent carbon, 5 to 6.5 per cent hydrogen, and 26 to 35 per cent oxygen. Generally, the empirical formula is given as $C_{45}H_{48}O_{16}$. The woody portion of plants contains as much as 30 per cent lignin. A similar quantity of lignin is found in the plant residues which make up the forest floor; rye straw contains as much as 14 per cent lignin; grasses, however, contain only about 10 per cent.

Fats and Oils.—Similar to starch, these substances serve as storage material. They are, as a rule, concentrated in the seeds and fruits of plants. Very little fat is found in the vegetative parts of plants. The lower forms of plants, the algae, fungi, and bacteria do contain appreciable quantities of fatty substances.

The elementary composition of fat fluctuates from 76 to 79 per cent C, 11 to 13 per cent H, and 10 to 12 per cent O. The solid oily substances, such as palmitic and stearic acids, have the empirical formula $C_{16}H_{32}O_2$ and $C_{18}H_{36}O_2$ respectively. The soft oils, such as linololenic acid—the drying oil of linseed—has an empirical formula $C_{18}H_{30}O_2$. Fats and oils are rich sources of energy, furnishing gram for gram about two and one half times as much as the carbohydrates.

Waxes are very closely related to the fatty plant substances and are found as coating materials on leaves and fruits of plants.

Tannins. — These substances are generally known for their property of converting skins into leather. They are found in various parts of many plants, but are concentrated in the bark. The bark of the chestnut contains as much as 27 per cent of tannin; pine, spruce, willow, and oak contain from 5 to 18 per cent. The monocotyledonous grasses, as well as the lower plant forms, contain very little tannin.

Upon the death of plants, the tannins oxidize and become dark brown in color and for this reason have been identified with certain acids associated with humus.

Minor Plant Substances. — The resins, gums, and mucilages, alkaloids, chlorophyll, and enzymes are complex compounds of C, H, and O. Chlorophyll and the alkaloids also contain some N. Being minor in quantity, these plant substances contribute little to the organic matter of the soil.

Proteins.—These compounds are an indispensable part of plant life. The foundations of living matter, protoplasm itself and cell nuclei, are primarily made up of proteins. They are unequally distributed in plants. Because of their association with living matter, it is natural to find a concentration of protein in green leaves, buds, cambium layers, and seeds. The percentages of protein in a variety of plants and their parts are given in table 5.

The fundamental composition of most proteins varies only within narrow limits: 50 to 55 per cent C, 6.5 to 7.3 per cent H, 20 to 24 per cent O, 15 to 18 per cent N, 0.3 to 2.4 per cent S, 0.0 to 0.8 per cent P, and some ash.

The constitution of protein is very complex. When broken down, chemically or biologically, the building stones of the protein molecule are set free. They are known as amino-acids, or aminocarboxylic acids, containing the amino group, NH_2, and the carboxyl group, COOH. About 25 of these building stones have thus far been isolated. Examples of these are tyrosine, asparagine, glycocol, and arginine.

Most of the proteins are insoluble in water. Some proteins, such as globulins, are soluble in salt solutions. Many, such as the albumins, form colloidal solutions.

As a matter of fact, all proteins are colloidal (see next chapter) in nature and are subject to the effects of coagulation and peptization. After having been coagulated by heat, some proteins, such as albumin, can not go back to their original state when cooled. These colloids are spoken of as *irreversible.* In the arid, semiarid, and subhumid climate, the proteins, because of the frequent droughts, become irreversible, and are, therefore, not attacked so readily by microbes. The result is that the N content of the organic matter in the soils of arid regions is higher than that in the soils of humid regions.

TABLE 5

Protein content of a few plants

Name of plant*	Per cent protein
Wood of common trees	0.6 — 1.0
Needles and leaves	3.5 — 9.2
Fungi	11.0 — 51.0
Bacteria	49.0 — 80.00
Mosses	4.5 — 8.0
Straw of grains	3.5 — 4.7
Meadow hay	9.5
Clover hay	12.6
Alfalfa hay	14.8

*See table 2 (Ch. 5) for N content of a number of plants. Multiplying the N figures by the factor 6.25, the proximate protein content of the plants enumerated may be calculated.

CHAPTER VII

COLLOIDAL BEHAVIOR OF SOILS AND SOIL ACIDITY

Introduction. — In the year 1861, the Scotch chemist, Thomas Graham, also the Master of the London Mint, discovered that gelatin in aqueous solution does not diffuse through animal parchment. From the Greek words *kolla,* meaning glue, and *eidos,* meaning like, he coined the word *colloid* to mean the glue-like substances that possessed this property of non-diffusibility. The process by which substances diffuse through a membrane Graham termed *dialysis,* the Greek expression for "dissolve through." During the next eight years Graham went on to discover other fundamental properties of colloids; and at the time of his death, in 1869, he had already laid the foundation of the science of colloid chemistry.

Through the years, colloid chemistry has moved far beyond those few properties which Thomas Graham so painstakingly recorded. A tremendous number of materials, many of them very different from Graham's glue-like substances, have been found to possess colloidal properties, and many new principles have been uncovered. Today, complex natural phenomena which long defied explanation are understood in terms of colloidal behavior.

Properties of Colloids. —The modern definition of colloid greatly transcends the initial concept of glue-like substance. As a matter of fact, Graham himself early recognized that the difference between colloids and crystalloids (substances which diffuse through parchment) lies in their physical state. We now know that *any material which has a sufficiently large surface area in comparison to its volume takes on the colloidal state.* In order to achieve this very large ratio of area to volume, it is necessary that the substance be sufficiently small in at least one dimension. This colloid state may be considered as an intermediate condition somewhere between true solution and visible suspension. In terms of approximate size, colloidal particles are from 5 to 200 $m\mu$ (millimicron) in diameter.

We meet with many examples of colloids in everyday life. Gelatin, glue, casein, silical gel, egg-albumin, and clay are commonly recognized colloids. Clouds and fogs are caused by moisture particles, colloidal-in-size, distributed in air. The color of the iris of the eyes and the red color of ruby glass are due to colloidal phenomena. The blue of the sky, rainbows, and the thrilling beauty of sunsets are nothing more than the luminosity caused by the reflection of light passing through space and encountering in its path colloidal particles, such as dust, crystals of salt, or droplets of water. This phenomenon of light scattering is known as Tyndal effect. In the laboratory this effect may be observed with the ultramicroscope when a strong beam of light is passed through a medium containing a colloid. The same effect may be noted when a bright ray of light enters a darkened room through a slit and strikes dust particles in the air.

Substances in colloidal state distributed in a liquid medium are known as *colloidal solutions*. They differ from true solutions inasmuch as in the latter the solute is of molecular magnitude, whereas in a colloidal solution the solute consists of an aggregation of molecules. When the aggregates increase in size and stay dispersed (colloid systems of this nature are called suspensions) the colloidal solution becomes opaque. The colloid is then a chain of molecular aggregates and is said to be in the *sol* state. When the aggregates increase in size still more, a network of colloidal particles becomes tied up in the solution which turns into the consistency of jelly. The colloid is then said to be in the *gel* state.

In any colloid system there are two phases: the *dispersed phase* and the *dispersion medium*. In the case of clouds, minute water droplets are dispersed in air. The beautiful color of ruby glass is due to the dispersion of very finely divided metallic gold in glass. In milk, the fine globules of fat are the dispersed phase. When fine clay is suspended in water, the latter is the dispersion medium. Generally speaking, the dispersed phase is discrete, each particle being separate from the other. The dispersion medium, on the other hand, is continuous. The dispersion media may be solid, liquid, or gaseous, water being the most important medium in nature.

Dispersion of Colloids. — Dispersion represents the distribution of finely comminuted particles in a medium. This phenomenon was recognized very early in the history of man. Hauser, in his book *Colloidal Phenomena* points out that "the dispersive action of straw extracts on clay slips was apparently known to Jewish masons prior to their exodus from Egypt." The Egyptians used gum-arabic to keep the coloring material of ink in suspension. The Chinese used gelatin for the same purpose. In 1827, Robert Brown, the English botanist, discovered that dispersed particles, due to molecular bombardment, exhibit a peculiar zigzag movement when viewed through the microscope. This is known as Brownian movement.

As materials approach colloidal dimensions, the number of particles and the total surface of the disperse phase increase tremendously. This is strikingly illustrated in table 6, which indicates what happens when a cube of 1 cm. edge is repeatedly subdivided. Depending on the degree of dispersion, clay particles range in size from 0.002 mm. and smaller in diameter. The surface of a glassful of clay particles may equal to several acres. As the particle size in clay decreases, its total surface and reactivity increase, as shown in table 7. This brings out another angle on the manifold role of clay in soil reactions.

The relative stability of a colloidal system is expressed by the degree of dispersion. Materials or factors that act to keep colloidal particles apart are known as peptizing agents, and the process as *peptization* or *deflocculation*. Thus, the gum-arabic and gelatin used in ancient ink manufacture served as peptizing agents.

TABLE 6

Increase of surface of a 1 cm. cube due to fractionation.

Length of size of cube	Number of cubes	Total surface
1 cm.	1	6 sq. cm.
1 mm. = 1000μ	10^3	60 sq. cm.
100μ	10^6	600 sq. cm.
10μ	10^9	6000 sq. cm.
1μ	10^{12}	60000 sq. cm. = 6 sq. meters
0.1μ	10^{15}	600000 sq. cm. = 60 sq. meters
0.01μ	10^{18}	6000000 sq. cm. = 600 sq. meters

TABLE 7

Decomposition of hydrogen peroxide by the mechanical fractions of a loam.

Diameter of fractions (mm.)	.002	.002-.01	.01-.05	.05-0.1	.1-.5	.5-1.0
Per cent H_2O_2 decomposed in 2 hours by 5 gms. of the respective fractions; 20 cc. H_2O_2 used.	96	24	22	12	2	0

Coagulation of Colloids. — Coagulation is the opposite of peptization; it is flocculation and connotes a decrease in degree of dispersion or an increase in aggregation of colloidal particles. The mechanism of coagulation is in a large measure controlled by the electrical charges carried or by the colloid and the medium.

The electrical charge of colloids is either positive or negative. Hydrated Fe and Al oxides, for example, are positively charged; arseniou sulfide, humus, silica gel, and clay have a negative charge. If a direc current is passed through a colloid solution in a U tube equipped with positive electrode in one arm and a negative electrode in the other, th positive colloid will move toward the negative pole (cathode) while th negatively charged colloid to the positive pole (anode). When the particles reach the respective poles, their charges are neutralized, causing th colloid to coagulate and precipitate out. We can thus see that colloids of opposite charges when mixed are mutually discharged and precipitated.

Highly ionized electrolytes are strong flocculating agents. Sodium chloride solution added to a colloidal suspension of gold causes the particles to agglomerate and settle out. As a rule, the higher the valence of an ion the more effective it is as a coagulating agent. Thus, for negative colloids ferric ion is a better precipitating agent than Ca, whereas Ca is superior to Na. By the same token, phosphate is more effective than sulfate which is, in turn, more active than chloride. In addition, in the case of cations, coagulation power increases generally with increasing ionic weight.

Colloids may also be coagulated by drying, heating, and freezing. The coagulation effects of these factors may be permanent or temporary. For example, a glue upon heating ceases to be coagulated. Various colloid precipitates, such as silver chloride, barium sulfate, iron hydroxide, and egg-albumin, become coagulated upon heating and remain so even upon cooling. Such colloids are known as irreversible. Some of these coagulates can be redispersed by the addition of a peptizing agent, such as NaOH. Fired clay bricks can not be redispersed even with peptizing agents.

Sorption. — At one time, the reaction of *adsorption* was considered a physical phenomenon, such as the accumulation of a gas, liquid, or dissolved substance at an interface; and the reaction of *absorption,* a chemical phenomenon where a substance penetrates a liquid or solid producing an intimate union with the adsorbing liquid or solid. It has been established since that there is no sharp line of demarcation between the two concepts, and to avoid confusion the term *sorption* was coined.

Colloids have an outer layer of molecules which differ from the interior molecules in that on the exposed side the intermolecular forces apparently are not active. Hence, these molecules have a tendency to the sorption of cations or anions, depending on the charge of the colloid. Positively charged colloids adsorb (sorb) anions and negatively charged colloids adsorb cations.

SOIL COLLOIDS

The clay and clay-like minerals constitute the bulk of soil colloids. Humus and organic matter, in general, constitute another large colloid fraction; and hydrated oxides of Al, Fe, and Mn, and sometimes silicic acid make up most of what remains. The SiO_2, clay, and organic colloids bear a negative charge, whereas the sesquioxides are positive; and, because of the predominance of clay and organic colloids, they impart to the soil a negative charge.

The Clay Separate. —The chemical composition of the clay separate varies in diffeernt areas; this variation is due principally to the variations in climate and, to some extent, parent material. The data in table 8 illustrate this. In considering the soil as a medium for plant growth, the colloidal behavior of the clay separate is of paramount importance.

The clay separate in the soil may become dispersed in one of two ways: 1, by the sorption of Na and to some extent of K ions; and 2, by the washing out of free electrolytes. Na ions are effective in causing soil dispersion because they carry with them relatively large quantities of water of hydration. When enough hydrated Na ions are adsorbed by the clay particles, the latter take on a hydrophilic[1] character and tend to become dispersed when in contact with water. This is the most frequent cause of dispersed soils and is characteristic of certain areas in the arid and semi-arid regions (see Chapter IX). It may occur also when irrigation water contains excessive quantities of Na salts, or when $NaNO_3$ is used excessively in fertilization.

Since electrolytes, especially polyvalent ones, such as Ca, Mg, Al, and Mn salts, act to coagulate colloids, the washing out of electrolytes will tend to bring about the opposite effect, dispersion. In the humid temperature regions, this condition prevails during the winter and early spring seasons.

Dispersion of the clay separate has a deleterious effect on the physical condition of the soil. For one thing, the dispersed clay tends to clog up the pore space in the soil, causing waterlogging and poor aeration. In addition, valuable clay colloids holding large amounts of plant nutrients are washed away by surface runoff. Dispersed clay also prevents water from entering the soil, causing at times surface swamping.

Any highly dispersed material is difficult to moisten because of the existence of a tightly held film of air around the individual particles. This can easily be demonstrated by sprinkling water on dust. The drops of water, instead of coating the dust particles, become coated with dust. The cushion prevents the easy access of the water to the dust particles (highly dispersed clay and humus). For the same reason, dust scattered over a water surface will not immediately become wet because of the air cushion.

To overcome the adverse effects of dispersion, coagulating agents are added to the soil. In the humid regions, these are usually liming materials in combination with gypsum (see Ch. XI). In the arid and semi-arid regions, gypsum or sulfur is used. The latter is oxidized by soil

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[1] Colloids may be loosely divided into two classes: hydrophilic (water loving) and hydorphobic (water hating). Hydrophilic colloids show a marked affinity for water and hence form relatively stable dispersions; they tend to deflocculate. Hydrophobic colloids show no such affinity for water and hence do not form stable dispersions, i. e. they tend to flocculate.

TABLE 8

Composition of the colloid (clay) fraction of soils, per cent of total*

Soil designation	Horizon	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	TiO_2	P_2O_5	SO_3
Chester series	A	36.5	31.7	13.8	0.51	1.65	1.02	0.12	0.71	0.42	0.28
	B	38.8	30.0	14.7	0.44	1.28	1.04	0.09	0.75	0.25	0.17
	C	38.1	32.3	13.2	0.33	0.93	.89	0.09	0.52	0.54	0.35
Cecil series	A	37.5	36.4	10.5	0.21	0.44	0.71	0.05	0.94	0.21	0.13
	B	35.6	36.7	12.0	0.16	0.32	0.35	0.07	0.78	0.07	0.15
	C	36.4	35.4	13.2	0.14	0.27	0.49	0.07	0.92	0.21	0.17
Miami series	A	49.8	25.3	9.4	0.76	2.09	2.67	0.23	0.75	0.29	0.20
	B	47.9	25.1	11.4	0.74	2.62	3.42	0.15	0.65	0.17	0.15
	C	46.3	23.3	10.4	3.14	3.16	4.47	0.24	0.61	0.19	0.13
Nipe series (Cuba)		10.2	15.8	62.5	0.23	0.05	Tr.	Tr.	0.20		

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*The data are compiled from the work published by Holmes and Edington in U.S.D.A. Tech. Bul. 229, 1930; also in Jour. Agr. Res., vol. 28 (1929), p. 567

microbes to sulfuric acid which in turn reacts with Ca (and other) carbonate and forms gypsum.

Organic Colloids. — Complex organic substances are generally colloidal in nature because of their high molecular weight and their tendency to form aggregates. Soil organic matter is an important example of a natural organic colloid.

Quantitatively (and, from the standpoint of activity, qualitatively), humus is the most prominent fraction of the soil organic matter. Its colloidal properties are in general similar to those of clay, both being negatively charged.

One of the very important functions of organic colloids is the stability which they impart to soil structure. Excesses of sorbed Na and, to a lesser degree, K tend to dissolve the organic envelope around the structural units, causing the clay bound particles to slake and leading to the undesirable effects of dispersion, as pointed out earlier (See Ch. V). The dissolved organic matter imparts a black color to the soil, and it is this reaction that is responsible for the black alkali soils in the arid regions where the Na salts are apt to cause a partial saturation of the soil colloids with Na.

The property of sorption is developed to a much higher degree in the organic than in the inorganic (clay) colloids. By virtue of this property, the negatively charged soil colloids retain the Ca, Mg, Mn, K, and NH_4 ions. These nutrients are obtained by the plant roots by the mechanism of ion exchange, as shown presently.

Another important attribute of organic colloids is their ability to facilitate the movement of Fe and Al. Because of the positive charge carried by these colloids and the overall negative charge of the soil, the Fe and Al would become discharged as they appear in the soil solution. However, the organic colloids in solution discharge the positive charges of the Fe and Al and the new particle by virtue of the protective coating of the organic colloid, moves freely downward. When these particles reach the B horizon, the concentration of electrolytes coagulates them and stops their further movement. In this manner Fe and Al accumulates in the B horizon.

Soil Colloids and Hardpan. — The sesquioxides, silica gel, and humus serve as cementing agents. Sometimes they bind together sand grains and soil particles to form hard stone-like lumps, known as *concretions.* They are scattered here and there in the profile, usually in B horizon. *Orterde* or *ortsand,* the former in heavy and the latter in light soils, are the other names for concretions. Cementation is sometimes continuous and takes on the form of a uniform stone-like layer at a certain depth of the B horizon. This formation is known as *hardpan* or *ortstein* (see Pl. 7, Ch. VIII).

Hardpan, as a rule, is encountered in poorly drained sandy soils. Sometimes, hardpan is encountered in well drained soils. However, this hardpan formed at an earlier period when the area was poorly drained. It is also found in the saline soils of the arid-semiarid grasslands. The dispersed cementing agents move through the uniformly large pore space of the sandy soil, or the gravel, fill the interstices, glue the particles, and give rise to a stone-like layer. In soils suffering from excessive alkalinity, due to sorbed Na, hardpan may occur also in heavier than sandy types of soils.

In heavy soils of the forest zone, water *filters* through the A horizon, i. e., it moves uniformly through the non-capillary pore space resulting from the crumbly structure of this horizon. Water reaching the compacted B horizon can not filter easily; the bulk of the water must, therefore, move horizontally and follow channels made by roots, burrows of earthworms, grubs, passageways of rodents, cracks, and other types of openings. The colloids as they move through the channels may cause the cementation of sand grains, silt, clay and other constituents forming scattered *concretions.* Thus, heavy soils occasionally have concretions and may exhibit very extensive and tough compaction which at times appears to behave like hardpan.

Hardpan hinders the penetration and extension of roots into the B horizon. An examination of deep rooting plants, especially trees, in soils having a hardpan reveals a flattening out of the roots in a plane parallel to the hardpan. This phenomenon has been observed time and again by the author in the pine forests of the Coastal Plain.

Planting orchards in soils afflicted with hardpan is dangerous. The initial results may be deceptive, since trees may make rapid progress until the root system extends to the hardpan and then they begin to suffer. Dynamiting rather than digging holes for planting trees is a wise procedure to follow whenever hardpan is encountered. Simultaneously, the soil should be limed with ground dolomitic limestone and gypsum (see Ch. XI) to a depth of 18 to 24 inches. Such soil management practices will permit the penetration of the fruit-tree roots into the C horizon, thus increasing the feeding area and water supply of the trees.

In combating hardpan, the killifer or any other type of pan-breaking plow may be used to advantage. These operations are, however, useless and often injurious when natural compaction is mistaken for hardpan. It should be remembered: *Hardpan is a cemented material, stone-like in nature, which will not slake or melt away when in contact with water.* Compaction, on the other hand, is a compression of the material in the B horizon as a result of the penetration of fine particles into the pore spaces between the larger particles; a compacted soil will slake when in contact with water.

A compacted condition may be ameliorated by improving the structure of the B horizon. The best method of attaining this is to increase the calcium content of this horizon by applying limestone and, from time to time, some gypsum or acid phosphate containing gypsum. Deeper plowing is another means of improving the structure of the B horizon.

In sandy soils, hardpan can be advantageous because the concrete-like layer serves as a storage tank for the soil above it. The famous celery-growing section of Sanford, Florida, is simply a sandy soil with an ideally located hardpan and a supply of good water. The open structure of the sand and the consequent copious pore space facilitate the aeration of the water reservoir retained by the hardpan. Aeration is also enhanced by the low temperature of the irrigation water, since oxygen is more soluble in cold water. Under such conditions, plant roots actually bathe in a favorable nutrient solution.

Ion Exchange. — Lucretius, the Roman poet and philosopher, records observations that sea water becomes fresh and palatable when passed through a layer of soil. Lord Bacon is credited with the method of making sea water fresh by passing the water through a column of clay. This is essentially the method used today for softening hard water.

If one liter of a KCl solution, containing five milliequivalents of the salt (5 x 74.6 mg. KCl), is passed through a column of 100 gms. of soil and the leachings poured back several times, most of the K is retained by the soil. All, or practically all of the Cl, however, may be accounted for in the leachings.

The ability of the soil to take Na (the Lucretius' "bitter principle") out of sea water, or the retention of the K as described, is due primarily to the sorptive power of clay and organic colloids for cations. Gram for gram, the sorptive capacity of organic colloids is four to ten times that of inorganic colloids.

Should a soil, saturated with adsorbed K be leached with a solution of a Ca salt, there will be a tendency for the Ca to replace the K. If leached long enough all of the K will be removed and a stoichiometric quantity of Ca will be sorbed by the soil. In simple words, there has been an exchange of ions, and the process is called ion exchange. When cations, such as Ca, Mg, H, and K are involved in this reaction, it is known as ***cation exchange;*** when anions, such as sulfates, hydroxides, nitrates, and phosphates are involved, the reaction is known as ***anion exchange.***

The most important source of exchangeable cations is the soil body itself. As rocks and minerals weather, bases are released. In the process of humification and mineralization, another array of bases and hydrogen is released. Similarly, an equivalent quantity of anions get into circulation. These ions are picked up by the soil sorption complex (the term *complex* is used because the mechanism of sorption in relation to the soil colloids is extremely complicated and not too well understood) and placed at the disposal of plants. In a way, the ionic exchange is a part of a cyclic process, inasmuch as the bases and other ions are originally gotten from the soil. A large share of the K, Ca, Mg, NH_4, Na, Mn, Cu, and of many other cations that are naturally available or added to the soil in the form of fertilizers, liming and spray materials, and minor elements, is stored for the most part in the exchange complex. These cations are made available to plants by ion exchange, primarily with the aid of the H ion.

The exchange of ions takes place in two ways. First, organic matter, upon decomposition, furnishes a supply of carbonic acid, organic acids, some nitric, and sulfuric acid. These acids are the source of H ions in the soil solution which, in contact with the sorbed ions on the surace of the exchange complex, enter into exchange reactions. Second, roots give off carbonic acid, and hence H ions may be sorbed on their surface. As a rootlet comes in contact with the surface of a soil colloid the H ion on the rootlet exchanges positions with any of the cations on the colloid. This process is known as *contact exchange*. It is claimed by some students of ion exchange that both mechanisms described above are fundamentally one and the same.

Clays are endowed with the property of sorption. Being negatively charged, clays absorb cations, the quantity differing with the type of clay minerals. Thus, the kaolinite types adsorb less cations than the montmorillonitic types. It is clear that the higher the clay and organic matter content of a soil, the higher is the cation exchange capacity and, hence, the greater are the potential resources of available nutrients. On a quantitative basis, soils of lighter texture possess a lower exchange capacity than heavier soils. Thus, the range varies from not much more than 1 milliequivalent[2] of exchangeable cations per 100 grams of sandy soils to 30 to 40

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[2] A milliequivalent represents 1/1000 of an equivalent weight. The equivalent weight of an element or radical is the weight in grams of the element or radical required to displace or to unite with one atomic weight of H or to combine with one atomic weight of Cl, or of any other univalent element. The equivalent weight of H is 1.008 and that of Cl is 35.46, since their respective atomic weights are 1.008 and 35.46. The equivalent weight of K is 39.1, because it takes one atomic weight of K to combine with one atomic weight of Cl to form KCl. The equivalent weight of the ammonium radical, NH_4, is 18, the compound NH_4Cl requiring 18 grams of NH to combine with 35.46 gms. of Cl which is one atomic weight of Cl. The equivalent weight of Al is 9, because it takes 3 atomic weights of Cl for *one atomic* weight of Al, which is 27, to make up the compound $AlCl_3$. The equivalent weight of Ca is 20, because it takes two atomic weights of Cl for one atomic weight of Ca, which is 40, to make up the compound $CaCl_2$.

Example. — 100 grams of soil, when treated with NH_4CH_3COO, gave up the following cations: 8.064 mgs. of H; 60 mgs. of Ca; 8 mgs. of Mg; and 78.2 mgs of K. In terms of milliequivalents per 100 grams of soil, each cation may be calculated as follows:

$8.064 \div 1.008 = 8$ milliequivalents for H; $60 \div (40 \div 2) = 3$ for Ca; $8 \div (24 \div 2) = 0.67$ for Mg; $78.2 \div 39.1 = 2$ for K. The total cation exchange capacity for the particular soil will thus be $8+3+0.67+2=13.67$ milliequivalents per 100 gms. of soil.

in heavy soils. Peat or muck soils may have as much as 60 to 100 milliequivalents of exchangeable cations per 100 grams of material.

SOIL ACIDITY

Acidity is caused by the presence of H ions. In general, acidity is defined by two factors: *strength* and *quantity* of acid available. The strength of an acid is determined by the *degree to which it ionizes.* For example, HCl which dissociates (ionizes) almost completely in dilute solutions is a strong acid. Acetic acid, on the other hand, ionizes to an extent of less than 1 per cent and, hence, is a weak acid. The *quantity* of acid, irrespective of its ionization, represents the potential supply of H ions when all are ionized. The quantity of acids, as well as of other chemical substances in solution, is measured in terms of normal or molar concentration.

A molar solution contains one mole (gram-molecular weight or formula-weight) of the solute in one liter of solution. A normal solution is one containing one gram-equivalent of a solute (in the case under discussion—an acid) in a liter of solution. Thus, 36.5 grams of HCl or 60 grams of CH_3COOH (gram-equivalents of hydrochloric and acetic acid respectively) in 1000 cc. of solution are acid solutions of the equivalent concentration. One tenth of a gram-equivalent of acid in 1000 cc. of water is a dilute acid solution. Acids found in the soil are for the most part weak and extremely dilute.

Soil acidity is most prevalent in the soils of the humid regions. It is caused by leaching of bases from the profile to the ground waters. Also, in cultivated areas large quantities are removed by harvested crops. Acidity is also accentuated by acid carrying fertilizer salts, such as $(NH_4)_2SO_4$ and NH_4NO_3, and by the acids formed by spray materials, such as sulfur. Soil acidity is no problem is the soils of arid, semiarid, and subhumid regions.

Acid in the Soil. — Two types of acids, inorganic and organic, supply the H ions to the exchange complex of the soil. Among the inorganic acids we have the following: nitric acid HNO_3, supplied by the nutrification process; sulfuric acid H_2SO_4, resulting from the oxidation of sulfur compounds, also released in the decay of organic matter; and the most abundant of all acids, carbonic acid H_2CO_3, produced from CO_2 realeased in the decay of organic matter and augmented by the CO_2 dissolved in rainwater and that excreted by roots.

Of the organic acids, all of which are intermediate products in the decay of organic matter, mention may be made of the following: acetic acid CH_3COOH, commonly associated with fermentation; oxalic acid

$(COOH)_2 2H_2O$, produced by various microorganisms, especially fungi, and also found in plants; citric acid $COOH.CH_2COHCOOH.CH_2COOH$, produced by fungi and found in many plants. A host of other organic acids also form in the soil. These include malic, propionic, butyric, benzoic, and carbolic.

Exchange Acidity. — The A_0 layer and the A_1 horizon are a vast source of H ions in the soil. There ions constantly bombard the bases of the minerals and colloids, replace them and send them into solution. In regions of high rainfall, much of the bases are leached downward and lost in the ground waters.

Soils poor in bases may have as much as 80 to 90 per cent of their exchange capacity filled with hydrogen. Such soils are spoken of as being 80 to 90 per cent *unsaturated,* the term *saturated* being used for the base content of the exchange complex. The higher the per cent unsaturation, the greater the acidity.

Acidity in Solution. — Acids produced in the soil, first go into solution. Once in contact with the soil, the H ions are quickly removed from solution by the process of exchange. Free acids are, therefore, a rare phenomenon in the soil solutions. When present, they are designated by the term *active acidity.* The acid retained by the exchange complex are termed *potential acidity.* In the final analysis, it is the potential acidity of the exchange complex, where more than 90 per cent of the total acids reside, that must be considered in the study of soil acidity.

pH. — From the foregoing, it is apparent that some means of measuring acidity is necessary, especially in considering ameliorative measures for soil acidity. To get the total quantity of acidity, one has to replace the sorbed H by prolonged leaching with a neutral salt and titrate the leachate. This is a cumbersome procedure and gives no inkling as to the other factor of acidity, namely its strength. For this purpose, the pH scale is admirably suited.

It was pointed out above that acidity in water solutions is caused by H ions. Basicity (or alkalinity), the opposite of acidity, is caused by hydroxyl ions. All aqueous solutions contain both H^+ and OH^- ions. When there are more H^+ than OH^- ions, the solution is acid. When OH^- ions are in excess, the solution is basic. When equal amounts of each ion are present, the solution is said to be neutral. pH is a scale for measuring acidity (and also basicity) over a very wide range.

Mathematically,[3] the relation between the H ion concentration and the pH value of a solution may be expressed as follows:

$$pH = -\ log\ (H^+),\ or\ pH = log \frac{1}{(H^+)}\ (the\ common\ base\ 10\ is\ used)$$

where (H^+) means hydrogen ion activity in mols per liter. If the (H^+) of a solution is known, the value is merely substituted in the above equation and the pH is readily calculated. For example, 0.01*N* HCl (containing 0.365 grams HCl per liter of solution) which is practically all ionized (and we can, therefore, speak of H^+ concentration as well as activity) may be presented as follows:

$$\begin{aligned} (H^+) &= .01 = 10^{-2}, \text{ and} \\ pH &= -\log 10^{-2} \\ &= -(-2), \text{ since } \log 10^{-2} = -2 \\ &= 2 \end{aligned}$$

Now, consider 0.0001N HCl (containing 0.00365 grams HCl per liter of solution):

$$\begin{aligned} (H^+) &= .0001 = 10^{-4}, \text{ and} \\ pH &= -\log 10^{-4} \\ &= -(-4) \\ &= 4 \end{aligned}$$

Iit is important to note the following: (a) As the acid concentration *decreases,* the pH value *increase;* in other words, the higher the pH the lower the acidity. (b) Comparison shows that the solution of pH 2 is 100 times more acid than the solution of pH 4. It is apparent then *that a small difference in pH means a large difference in actual acidity.* (e) In general, a difference in *one* pH means a difference of *ten* times in H ion concentration. A difference of two pH units means a difference of 10^2 or 100 times in *H* ion concentration. Similarly, a difference of 0.5 *pH* units means a concentration difference of 10.5 or 3.16 times. Specifically, a soil of pH 5.5 is about 3.16 times as acid as one at pH 6.0.

The product of the (H^+) and (OH^-) in an aqueous solution at a fixed temperature is always constant. That is:

$$(H^+)\ (OH^-) = Kw = 10^{-14} \ldots \text{ at } 25°C.$$

If $(H^+) = 10^{-7}$, calculation shows that $pH = 7$. Furthermore, substituting this in the above equation

$$10^{-7}\ (OH^-) = 10^{-14}, \text{ or}$$

$$(OH^-) = \frac{10^{-14}}{10^{-7}} = 10^{-7}$$

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[3] Literally pH may be looked upon as an abbreviation, *p* meaning the electrical potential resulting from the positive charges carried by the *H* ions of the acid. According to present theories of electrolysis, the mathematical expression given is an approximation only.

It is evident, then, that at pH 7 the concentration of H^+ and OH^- are equal, and the solution is neutral.

It should be understood that pH, a measure of activity, gives the intensity of the H ion concentration; whereas normality, a measure of total acidity, gives the total quantity of H ions the acid is capable of delivering. As in a thermometer, the scale shows the intensity or degree of heat, but tells nothing about the calories or quantity of heat units. The pH of a 0.001 N acid may be 3.0 or higher, depending on the percentage of ionization. Thus, pH 1.0 and 1.0 N are two distinct chemical expressions, quite far apart in meaning and significance.

pH is the most important single property identifying the chemical character of a soil. It controls the sorption and distribution of the various cations by soil colloids. The pH of a soil is instrumental in controlling the release of bases from the exchange complex. The solubility of many soil constituents are sensitive to pH, since the various minerals of the soil dissolve at different pH levels.

In acid soils, the pH may drop to a point where the clay minerals are attacked. This may result in the release of Fe and Al, both of which are toxic to plants.[4] In addition, hydrated oxides of Fe and Al serve as cementing materials for hardpan and concretion formation. Generally speaking, a soil with a pH below 5.5 may be regarded as a potential carrier of soluble Fe and Al. Of course, if a soil has a high exchange capacity, the bulk of the H ions are kept in an adsorbed state and are not likely to attack the clay nuclei and release Al. This is the reason why soils with a high organic matter content, such as peats and mucks, can stand a low pH and not be toxic; they have a great adsorptive capacity for H ions. They are, so to speak, buffered; that is, they can take up appreciable quantities of H ions and still retain essentially the same pH.

A *buffer* solution is a mixture of either a weak acid and one of its salts, or a weak base and one of its salts. The term buffer is used because such solutions resist a change in H^+ ion (or OH^-) concentration upon addition of small amounts of acids or bases. A mixture of acetic acid and sodium acetate, for instance, maintains essentially the same pH when a small quantity of NaOH is added. The reason for this is that as soon as the OH^- ions react with the free H^+ to form water, a practically equivalent quantity of previously undissociated acetic acid ionizes and replaces the H^+ so removed. If, on the other hand, a small quantity of HCl is added,

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[4] Even though Fe is an essential element, its concentration in the soil solution need not be very high to satisfy the requirements of the plant. A concentration of Fe above that necessary for plant growth is injurious. An excess of soluble Mn is also injurious. Both of these elements are just as toxic as Al which alone is usually blamed for toxicity.

the H^+ ions unite with the acetate ions (from the sodium acetate) to form undissociated acetic acid which does not contribute materially to the *active* acidity, which is what pH measures.

Phosphoric acid and its salts are good examples of buffered systems, their action having been discovered in 1900. In the titration of H_3PO_4 with NaOH, the course of the reaction is illustrated by the following equations:

$$
\begin{aligned}
&1.\quad H_3PO_4 + NaOH = NaH_2PO_4 + H_2O\\
&2.\quad NaH_2PO_4 + NaOH = Na_2HPO_4 + H_2O\\
&3.\quad Na_2HPO_4 + NaOH = Na_3PO_4 + H_2O
\end{aligned}
$$

It is important to note that each one of the sodium phosphates has a pH of its own. When the first few drops of NaOH are added to a H_3PO_4 solution, the pH does not change much until a large quantity of NaH_2PO_4 is formed. Then the pH rises to the value for NaH_2PO_4. When more NaOH is added to form Na_2HPO_4, the pH of the NaH_2PO_4 prevails until enough disodium salt is formed to change it. When more NaOH is added, the pH of the Na_2HPO_4 persists for a while until large quantities of Na_3PO_4 are formed. Then the pH rises to the value for Na_3PO_4.

The soil also is a buffered system. Were it not for its tremendous buffering capacity, the soil would be too sensitive to change when acid or alkaline residues form. Any sudden pH drop is to be looked on as a danger signal. It means a high acidity, a possible breakdown of the buffer effect, and hence a threat to the normal functioning of plants.

In parts of the arid and semiarid regions, some soils contain appreciable quantities of Na in the exchange complex. This may result in a pH value of 9.0 and even higher. Such a high pH is just as injurious to plant growth as a low pH. In addition, it is much more difficult to control. In normal soils of the regions under discussion, Ca and Mg are retained in the B horizon because of the low rainfall and hence paucity of leaching. The pH of such soils is from 7.0 to 8.0. Under such favorable conditions, the soils are flocculated and open in structure, and plant roots penetrate all through the soil profile and into the subsoil. There are cases on record where alfalfa roots in such soils have penetrated to a depth of 30 to 40 feet. This is unusual. In general, one should not expect roots to penetrate to such depths.

A low or extremely high pH of the soil is injurious to the activities of friendly microorganisms. Thus, the group of nitrogen fixing microbes, for example, is adversely affected by low pH. The type of soil flora is controlled by the pH; at the pH values 6.0 to 8.2, bacteria predominate. At low pHs, bacteria are inhibited and fungi predominate. The number of microbes in the soil also depends in a large measure on the pH. The higher the pH (not above 8.2), the greater the number; and the lower the pH, the smaller the number of microbes in the soil.

pH Tolerance by Plants. — Plants are able to adjust their metabolic activities over a considerable range of pH values. Most plants do not tolerate a low pH, though there are exceptions such as the rhododendron, azalea, holly, cranberry, and blueberry. Rhododendron and holly are, as a matter of fact, said to be affected adversely by the addition of lime which raises the pH of the soil. They even require the addition of raw acid humus, alum, or sulfur, which keep the soil at a low pH. (The wisdom of this practice has been questioned in recent years). There are others, such as the desert plants which can stand a very high pH. It has not been conclusively demonstrated that these plants would be affected favorably or unfavorably by lowering the pH. From the evidence available, it is safe to follow the rule: neither a high pH, above 8.4, nor a low pH, below 5.0, is favorable for maximum yields of the standard agricultural crops. Soils which are acid must therefore be limed to raise the pH.

For potatoes and tobacco in the acid soils of the humid temperate regions, the pH is kept within the range of 5.0 to 5.5, at which *actinomyces scabies,* the organism causing scab on potatoes, and the organism causing root rot of tobacco are dormant. In soils free of these organisms, a higher pH may be used to the advantage of the tobacco and potato crops. The author has examined lime marl soils of Lithuania, Latvia, and Estonia (on the Baltic coast) with pH values ranging from 7.2 to 7.6 in which 350 to 400 bushels per acre of scab free potatoes have been produced time and again. The merits of keeping the soil at a low pH for growing potatoes have been questioned in recent years.

The pH range for any one crop grown under various conditions (such as climate, nutrient supply, drainage, and deficiency or excess of trace elements in the soil) has not been worked out as yet. As a matter of fact, even under controlled conditions in solution or sand culture the pH range for most crops has not yet been established.

Approximate pH ranges have been established at which certain crop groups may be grown successfully. In Michigan Agricultural Experiment Station Special Bulletin No. 306 (1941), Spurway lists the pH ranges for close to 1700 types of plants.

CHAPTER VIII

CLIMATOGENIC SOILS

A basic principle of pedology states that soils, as they appear in nature, are essentially the result of climate.[1] Any permanent change in climate is reflected in the appearance and constitutional makeup of the soil. Hence, *the soils of the world, as we see them in their geographic distribution, are the result of the present day climate.* One may construct a soil map of the world from climatological data without examining the soils. As a matter of fact, this was accomplished some 50 years ago by Sibirtzev, the closest collaborator of Dokuchaev. The concept of *climatogenic soils* owes its origin to the genetic relationship between climate and formation of soil types.

The geographic distribution of the major soil groups of the world coincides with the belts or zones of temperature and precipitation, i.e., the climatic zones. The continuity of the climatogenic soil zones is occasionally broken by soil types whose origins are due to some local factors or conditions, such as topography, ground water level, and distinctive composition of parent material. These factors and conditions either modify the constitutional makeup of the climatogenic soils or introduce new types within the boundaries of the zonal soils. These modified or new types of soils are called *climatogenically subdued or intrazonal* (see Ch. IX).

There are six distinctive climatogenic types of soil formation: 1, desert and semidesert; 2, arid and semiarid steppe; 3, semiarid and subhumid steppe; 4, humid temperate; 5, tundra; 6, humid tropical and subtropical. Each type of soil formation gives rise to a soil zone and imparts to the body specific zonal features.

The color of the A horizon is used in naming five of the six soil zones: 1, the gray and red soil zone of the semidesert; 2, the brown and chestnut brown soil zone of the arid-semiarid steppe; 3, the chernozem zone of the semiarid-subhumid steppe; 4, the podzolized gray-brown *forest* soils; and 5, the red colored soils (laterites) of the tropics and subtropics.

DESERT AND SEMIDESERT TYPE OF SOIL FORMATION

Strictly speaking, there can be no desert type of soil formation. The desert climate has negligible precipitation and a high evaporation rate. Under true desert conditions the shifting sands do the work of destruction or burial of soils of earlier times. Indeed, in many of the present day

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[1] For a brief discussion of the *Elements of Climate*, see Appendix at the end of the chapter.

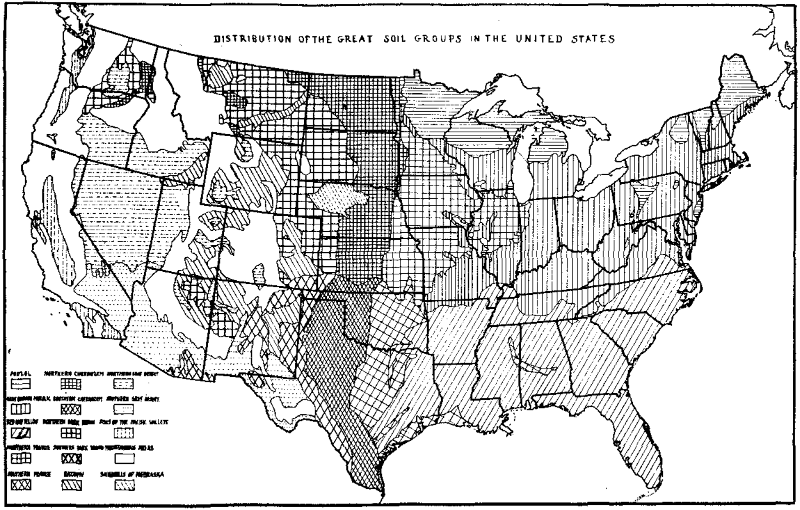

PLATE 3
(After Marbut)

deserts, buried soils are uncovered, thus revealing that another climate prevailed in the region at the time of their formation.

Desert Pavement. — An outstanding feature of the desert and semi-desert soils is the desert pavement or crust. As the name implies, desert pavement represents a hard rock-like formation. Its contours depend on the type of materials which make them up; they are level on fine grained substances and irregular on gravels. Its surface may be rough or highly polished, depending on the fineness of the sand and dust which the winds carry over the surface of these crusts.

Several types of desert pavement have been recognized: limestone, gypsum, sand and gravel, and mixtures of these. The "protective brown crust" referred to by explorers of the desert is undoubtedly represented by the types enumerated. The brown crust appears to be more prevalent in the more desolate sections of the desert. The lower the rainfall and the poorer the vegetation, the more pronounced is the crust. Whereas the color of the crust is generally given as brown, other colors are mentioned yellow, black, and a reddish tinge. The color of the crust is independent of the underlying materials. Black crusts of iron oxide, known as desert varnish, form coatings on pebbles and rocks of the hot desert.

The depth of many of the desert pavement formations may extend to three or more feet. In certain parts of the desert of Morocco, the natives dig their underground dwellings in the sand layers beneath the desert pavement crusts.

The *caliche*, found in Nevada, Arizona, and other sections of the deserts of the South-West, is another form of desert pavement. It is primarily a calcareous formation sometimes referred to as hardpan, extending in places to depths of several feet.

The origin of the desert pavement is not well known. One theory ascribes its formation to the upward movement and accumulation of $CaCO_3$, gypsum, NaCl, and Na_2SO_4 with small quantities of Fe,Mn, and other elements. Another theory on the origin of desert pavement is that it is nothing more than an exposed B horizon; it is the remnant of a soil that lost its A horizon by wind erosion. Indeed, the lime and gypsum crusts remind one of the horizon of illuviation of the arid steppe type of soil formation.

Marbut, in the "Atlas of American Agriculture, Soils of the United States," states:

> The typical desert profile, such as that of the well-developed Mohave soils, consists of a desert pavement at the surface. This consists of a layer of gravel and small stones, lying practically bare and kept bare of fine material by the wind which usually forms a rather firm crust capable of bearing some weight, but in most places it is not sufficiently strong to bear the weight of a man. In walking over it, the crust breaks and the gravels forming it sink half an inch or more, making a well-

defined track in the pavement. The gravels of the pavement are embedded in a gray, almost white, fine-grained material which is usually extremely porous or vesicular. When removed, however, the material is so delicate that it falls to pieces easily in the hand. This material lies in the lower part of the desert pavement and extends downward for an inch or two. It constitutes the material into which the pavement is pressed when trod upon. It contains within it some gravel material also. This layer is underlain by a firm structureless brown or reddish-brown layer, forming the important part of the soil, the horizon in which lie most of the plant roots. This layer ranges from 5 to 8 inches in thickness and may contain some pores and in extreme cases may be firmly cemented. It is underlain by the zone of calcium-carbonate accumulation when the soil is well developed, or by alluvial-fan material if immature.

It is not difficult to recognize the B horizon formation in the Marbut description.

Process of Soil Formation. — In the true desert, rainfall is very low and erratic, i.e., some years none and other years copious. There is no definite periodicity of precipitation. Under such conditions, the processes of soil formation are not active.

In the semidesert of the intermediate (temperate) climate, such as in Turkestan, Mongolia, Nevada, and Utah, the 5 to 12 inches of precipitation come with greater regularity than in the desert. There is frequently enough moisture to cause percolation and, therefore, movement and translocation of soil constituents, with consequent possibilities for limited horizon differentiation. There is not sufficient moisture to support a uniform grass cover. There is no sward, the vegetation assuming the habit of growing in tufts or bunches, hence the name of *bunch grass.*

Because of the scant vegetation, the A_0 layer is poorly developed or lacking. The A horizon is low in organic matter, 0.5 to 1.5 per cent in cultivated soils. The quantity of organic and inorganic acids and other reagents, generally supplied by the biochemical reactions in the A horizon, is limited. Kaolinization is subdued and, therefore, there is little difference in the clay content of the various horizons, i.e., the mechanical composition of the soil is about the same throughout the profile. The latter is, therefore, generally not very well developed.

In the reactions of weathering and soil formation, Na and K are the first to be split off from the silicates and the first to be eluviated from the A horizon. These elements are not retained in the B horizon, but translocated into the subsoil. From there, more Na and less K is lost into the ground waters, (whenever there is sufficient rainfall to leach the soluble salts), because more of the latter is taken up by plants and returned to the soil upon their death. Besides, K has a tendency to become fixed in the soil. Na, save for minor exceptions, is taken up by plants in only small quantities, and very little is, therefore, returned to the soil.

Ca and Mg also enter into the profile circulation, and some of them are retained by the B horizon and sometimes even in the lower part of the A horizon in the form of carbonates. Besides, gypsum is formed in the B horizon. *Gypsum accumulation is specific for the semidesert type of soil formation* and is not, as a rule, encountered in the normal profile of any other type of soil formation.

With the prevailing alkaline environment of the soils in the gray soil zone, Fe, Al, and Mn do not split off from the silicates and do not circulate in the profile.

The water table in these regions is, as a rule, located very deep. In a few localities, it is just a few feet below the surface. Under such conditions, appreciable quantities of salts (depending on the mineral content of the ground waters) may rise to the surface as a result of the upward movement of water and its evaporation. This usually leads to the formation of saline soils (see next chapter).

SEROZEM AND RED SEMIDESERT SOILS

The color of the soils in the semidesert is generally gray, hence the name *zone of gray soils,* or *serozem.*[2] In soil literature, the name *gray-earths* is also used.

Profile of Gray Soils. — The typical profile of a loam possesses the following characteristics:

A_0: Seldom present, and shallow if present, the parched dead vegetation is blown away.

A_1: 3 to 4 inches deep; gray, with a straw colored tinge; scaly or laminated structure; mellow; $CaCO_3$ frequently found; organic matter content 0.5 to 1.5 per cent; P and K content is generally higher than in the other horizons.

A_2: 4 to 8 inches deep; similar in structure to A_1; lighter in color; perforated by tracks of insects, worms, and higher animals; $CaCO_3$ and even gypsum sometimes found.

B: 8 to 16 inches deep; somewhat more compact; gray with white specks, veins, and layers of $CaCO_3$; entire depth effervesces; gypsum is almost always present in the lower depth of this horizon.

C: Type of material depends on geologic deposits.

Because of poor kaolinization, the gray soils are generally low in clay and high in silt. They are, therefore, not plastic and do not puddle much

Geographic Location. — In the United States, the gray soils are found in the intermountain desert plains and plateaus of the Great Basin and Snake and Columbia River Basin, in Nevada, Utah, Idaho, Oregon

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[2] Russian term, sometime erroneously spelled *sierozem,* meaning gray earth.

and Washington. The Portneuf, Sagemoor, Wheeler, and associated soil series[3] make up the soils of this zone.

In the semidesert, *red soils* are found in addition to the gray soils. Their color may be the result of an earlier more humid tropical or subtropical climate where the weathering of rocks releases hydrated oxides of Fe. The profile constitution of the red soils is similar to that of the gray soils. The red soils are more prevalent in the hot semideserts of the subtropics and tropics: North Africa, Arabia, Israel, Syria, Asia Minor, and other regions. In the United States, they are found in the hot arid southwest, from Texas to southeastern California. They are represented by the Mohave, Reeves, Anthony, and associated soil series.

Agricultural Features. — The soils of the semidesert, frequently referred to as arid, are not important agriculturally. However, under irrigation they are highly productive. Under natural conditions, the land is utilized for grazing, mostly sheep, but its carrying capacity is low.

With irrigation, these lands become exposed to the dangers of salinization. In some areas, salts are found in the subsoil. Whenever irrigation waters establish contact with the salts they move upward and enter the rhizosphere. If there is not enough irrigation water to wash the salts out they accumulate in the profile. The failure of many irrigation projects in arid regions may be traced to the type of salinization just described. Salinization may also result directly from the use of water rich in soluble salts.

In managing semidesert soils, a few points are to be remembered. K and P are fixed in the surface layer. With irrigation, some of the K may be released; however, P remains unavailable because of the large excess of Ca in the soil. In intensive agriculture, soluble phosphates must therefore be supplied. In some sections of the gray and red soils of the semidesert, N fixation is high and little mineral N is needed for fertilization.

In regions where erosion is not a problem, clean winter fallow is a practical expedient. The land is plowed in the fall and left in the rough, so that the waters of rain and snow can penetrate deep into the subsoil, wash out soluble salts from the rhizosphere, and augment water storage capacity of the soil for the next crop.

Under intensive irrigation, these soils lose their structure. Expedients used in facilitating structure (see p. 57) should be practised. A natural ally in facilitating the structure of the soils in this zone is an arid climate, whereby the agencies of heat and desiccation tend to stabilize the structure.

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[3] For meaning of soil series see Chapter XV. For a description of the soil series named in this and other books, consult: *Soils and Men. Yearbook of Agriculture for 1938.* U. S. Department of Agriculture.

THE STEPPE TYPE OF SOIL FORMATION

The steppe (the Russian word for grassland) originates in the semidesert and terminates in the forest zone. Geographically, it covers the arid, semiarid, and semiarid-subhumid regions of the intermediate (temperate) climate. Treeless areas in the tropics and subtropics are also referred to as steppe. The flora of the steppe consists primarily of short grasses in the arid and semiarid regions, and of tall grasses in the semiarid-subhumid regions.

Related to the steppe country are the savannas. They are located north of the tropical rainy areas. The savanna is grass country wherein are found scattered clumps of trees. It is a formation representing the transition between the forest and grasslands of the warm latitudes.

The Arid and Semiarid Steppe. — The precipitation in the steppe area of the United States is from 10 to 15 inches in the northern section and 15 to 20 inches in the southern section. In either section, precipitation is higher in the eastern portions. The bulk of the precipitation comes in the summer season, often in downpours. The quantity of moisture available for percolation is about the same in the two sections; the higher rainfall effects in the southern section are offset by the increase in evaporation because of the higher temperatures.

Short grass, with grama and buffalo grass predominating, is the native vegetation of this type of soils in the United States. In some sections, like the Rio Grande plain of southern Texas, curly mesquite and grama are the principal grasses found, with some shrubs scattered here and there. In other parts of the world, the grama grass predominates, such as *Stipa lessingiana, Poa bulbosa, Vivipara, Festuca sulcata.*

Process of Soil Formation. — The development of a normal profile is assured under the climatic and biosphere conditions of this region. There is enough precipitation to induce percolation and the downward movement of constituents. Sufficient decomposition of the organic matter takes place to furnish reagents necessary for the process of eluviation.

In the steppe country, rodents are a disturbing element in the formation of the soil profile. Crotovinas (abandoned nests and passageways of rodents) are a typical phenomenon in many profiles.

The leachings of the percolating waters carry soluble organic compounds, Na, K, Ca, and Mg. Some of the bases are gathered up by the plants whose roots extend through the profile. With the death of plants, the bases are returned to the soil. Some of the alkaline earths are retained at the bottom of the A and all through the B horizon as carbonates, mostly Ca. As a rule, there is no accumulation of gypsum. It is found occasionally at the C horizon in the soils of the areas bordering the semidesert.

In areas where the water table is a few feet below the surface, soluble salts, usually NaCl and Na_2SO_4, may come to the surface. Whenever there is not enough water for percolation, or the soil conditions preclude washing out the salts, they accumulate and give rise to salinized soils.

The reaction of the soils in the arid and semiarid steppe is alkaline, because of the uniform grass cover and consequent return of large quantities of bases. None of the sesquioxides (R_2O_3), such as Al_2O_3, Mn_2O_3 and Fe_2O_3, therefore, enter into the circulation of the profile of these soils.

Local Action Phenomena. — The question may be raised, how do plants obtain Fe or Mn from the soil in the steppe at the neutral or more usually alkaline reaction prevailing in the soils of the steppe? The answer is fairly simple. In speaking of the pH of any soil, what is meant is the average pH of the various constituents of the soil mass. However, the pH of the soil may vary from point to point, because the soil mass represents a heterogenous system in contrast to a homogenous system where the pH is uniform throughout. At the rhizosphere, where CO_2 is given off, the local pH is much lower than the overall pH of the soil. It is still lower at points where HNO_3 and H_2SO_4 are formed as a result of nitrification and sulfur oxidation. At these local points the pH may drop to 1.0 or lower and dissolve the Fe, Mn, P, and other ions that plants need. These reactions are known under the name of *local action.*

ZONE OF BROWN AND CHESTNUT BROWN SOILS

In general, the soils of the arid and semiarid steppe are brown or chestnut brown in color. At the border of the semidesert, brown soils predominate. At the edge of the climatic belt where the short grasses are interspersed with tall grasses, the color of the soil is chestnut brown.

The color difference in the brown and chestnut brown soils is due chiefly to differences in organic matter content. In the brown, it may come to 2.5 per cent and in the chestnut brown to 4-4.5 per cent. The quantity of organic matter in the profile decreases gradually with depth: in the first 2-3 inches, 2.0 per cent; the next 4-5 inches, 1.4 per cent; at a depth of 14-18 inches it still has 0.5 per cent.

Profile of Brown Soils. — A typical profile of a loam possesses the following morphologic characteristics:

A_0: About 0.5 inch deep; a mat of dead grasses of the sod.

A_1: 4 to 6 inches deep; brown to grayish brown in color; somewhat laminated in structure; mellow, with fine porosity; no effervescence (if tested with acid).

A_2: 4 to 5 inches deep; distinct brown color; slightly compacted; columnar-like and lumpy structure, with cracks between the structural units; no effervescence.

A_3: About 8 inches deep; lighter brown with darker brown streaks; slightly compacted; lumpy to nutty structure; cracks between structural units and abundance of insect and other animal borings; effervescence appears at this point, indicating the accumulation of carbonates.

B: About 12 inches deep; pale straw color, with white spots and veins of lime carbonate concretions; porous and slightly prismatic in structure.

C: The parent material of a large area of this type of soil is loess.

Profile of Chestnut Brown Soils. — The chestnut brown or dark brown soils, as they are known in the United States, differ little in their profile characteristics from the brown soils. They are found in the less arid regions of the arid steppe. A typical profile of a loam is as follows:

A_0: About 0.5 inch deep; a mat of dead grasses of the sod.

A_1: 5 to 7 inches deep; grayish chestnut brown; somewhat laminated in structure; mellow at the surface; lumpy to granular and slightly compact at the bottom; no effervescence.

A_2: 6 to 8 inches deep; lighter in color than A_1; lumpy structure; more compact than A_1, cracks along structural units; as a rule, no effervescence.

A_3: 10 to 12 inches deep; light brown, with darker brown streaks on the lumpy prismatic structural units; some cracks; tracks of worms and rodents are found; effervescence is distinct.

B: 12 to 15 inches deep; straw-colored to grayish in color; white spots of lime concretions or veins; tendency to prismatic structure.

C: Lighter in color than the horizon above; parent material exhibits its geologic characteristics, that is, it may be loess, granite, basalt, shale, or any other mellowed rock.

The upward movement of salts from the ground waters is more marked in the brown and chestnut brown soils than in the other types of soil of the grass country. The unequal depth of the ground waters and microrelief features cause a spotty condition of the soil cover. In lower places, where more water is available for percolation, slight variations are to be expected in profile development. Here and there, one may find small areas of chernozem. Where the water table is higher, more salts come to the surface, giving rise to stretches upon stretches of saline soils (see next chapter). Salinized soils are alkaline in reaction because of the absorption of Na by the clay and humus fractions. The soil loses its structure, becomes powdery, when dry, and is subject to blowing. The condition of the dust bowl in the Plains regions of the United States may be traced to such circumstances.

Because of the possibilities for variations in the soil cover, some areas of the brown and chestnut brown soils are not uniform in character. Within one and the same area one may find spots of brown, chestnut brown, saline, and chernozem soils. Such a soil area is, therefore, named a *soil complex* or soil *catena*. The latter term denotes specific differences in the soil caused by drainage or topography in areas of otherwise normal soils.

Geographic Location. — In the United States, vast areas of brown soils are found in the western parts of the Great Plains and smaller areas in the intermountain country of the far West. Specifically, these soils are located in southwestern Kansas, southeastern Colorado, northeastern New Mexico, the western tip of the Oklahoma Panhandle, the northwestern corner of the Texas Panhandle, the plateaus of New Mexico, northeastern Arizona, extending into Utah and Colorado, Montana, Wyoming, the Columbia plateau of Washington and Oregon, and in some sections of Idaho. The Bach, Prowers, Capulin, Tucumacari, Joplin, Ritzville, Weld, Fort Collins, Maverick, Uvalde, Reagan, and associated soil series make up the soils of this zone.

In the warmer sections of the temperate climate, as from the southwestern part of Texas to southern Arizona, the brown soils, in addition to their normal characteristics, have a reddish hue.

The chestnut brown soils adjoin the brown soils and extend eastward to the semiarid-subhumid region where the chernozem soil zone begins. The Hyrum, Bingham, Avon, Rosebud, Keith, Bridgeport, Walla Walla, Williams, Morton, Amarillo, Duval, Greensburg, Pullman, Miles, Vernon, and associated soil series are representative of the chestnut brown soils.

Agricultural Features.—The vast areas of brown and chestnut brown soils are of greater agricultural value than those of the gray soil zone. In these areas, especially in the case of the chestnut brown soils, dry arming is an outstanding characteristic. Large areas of the brown soils are devoted to grazing. With irrigation, all kinds of crops and fruits may be grown. With irrigation, the chestnut brown soils yield small grains, principally spring wheat. In the southern section of the chestnut brown soils, grain sorghum and cotton are grown in addition to wheat.

DRY FARMING

A system of farming in the arid regions whereby the land is kept allow for one season and planted the next season is known as *dry farmng.* Grain crops, particularly winter wheat, have been outstandingly successful under conditions of fallow. They have outyielded the year in year cut growing of grain.

Fallowing land is an old practice. During the fallow year moisture accumulates in the deeper layers of the soil and subsoil. An expedient in getting the moisture into the soil is to plow in the fall and keep it in the rough during the rainy period. The soil is prepared for seeding at the appropriate time. Under conditions of rolling topography, the method for increasing the moisture reserve of the soil is to prevent surface runoff by contour cultivation, terracing, and other soil erosion control measures.

Fallowing is not practical on sandy soils and on very heavy soils. In both cases, the loss of moisture by percolation (sandy soil) or by inability to penetrate deep into the lower layers (clay soil) is responsible for inadequacy of fallowing. In other words, under these conditions moisture can not accumulate in the soil and subsoil during the fallow year.

Where the spring and early summer rains bring out heavy weed growth, cultivation is essential. This operation pulverizes the soil and in regions of wind erosion the damage done by blowing is greater than the benefits of fallowing. No plowing is, therefore, advisable under such conditions. The land should be left in stubble and cultivated with a duckfoot cultivator or similar implement which destroys weeds without turning under the stubble. (See *Stubble Mulching, Ch.* XIII).

The quantity of water which may be stored in fallowed land depends on the seasonal distribution of the rainfall. In the Great Plains, where the precipitation comes during the season of high evaporation and low humidity, only 20 to 25 per cent of it may be stored up by fallowing. In the intermountain regions on the other hand, where much of the precipitation occurs in the late fall or winter, a larger proportion may be stored.

The Semiarid-Subhumid Steppe. — The general features of the climate of the semiarid-subhumid steppe are as follows: continentality, a deficiency of precipitation, low humidity, hot summers, cold winters, and a summer concentration of rainfall, 40 to 50 per cent of the total, accompanied by frequent downpours. However, the total precipitation, which amounts to 16 to 20 inches,[4] is higher than in the arid-semiarid steppe. The average temperature is 2 to 5°C (36 to 41°F). In this region, tall grasses make their appearance, with forests sometimes making inroads in the sections of higher precipitation.

CHERNOZEM

Process of Soil Formation. — Under the climatic conditions of the semiarid-subhumid steppe, a large share of the summer rains is not effective for percolation. There is, however, sufficient moisture during the late spring and early summer to carry the native grasses through their

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[4] The rainfall and temperature figures are averages for Europe and Asia; for the United States see p. 131.

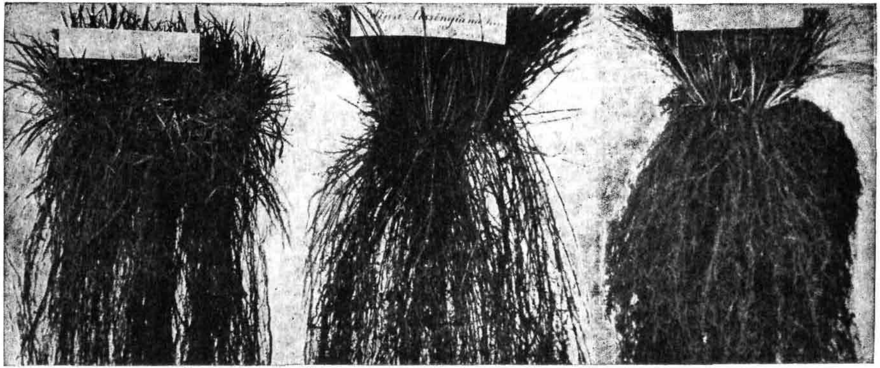

PLATE 4

Root development in chernozem

(After Kossovich)

short life cycle. When hot summer weather sets in, the landscape becomes a bleak wilted brown. Occasionally, after heavy showers, the steppe greens up for a short while. As the surface of the A horizon begins to dry out, the roots of the steppe vegetation become more extensive and penetrate deeper and deeper, as shown in plate 4.

As the summer advances and droughts set in, the A horizon becomes desiccated to a considerable depth. Microbial activities and humification are subdued. After the late summer rains, when life starts anew in the steppe, microbes have at their disposal fresh and juicy plant residues. The old, tough, and leathery organic matter remains relatively intact and accumulates in the A horizon.

During the spring, late summer, and early fall, the moisture and temperature conditions in the semiarid-subhumid steppe are favorable for the process of humification. Large quantities of organic and inorganic acids and other reagents are released. As the soluble organic compounds move through the A horizon, they permeate the mineral aggregates (see Ch. V). Subjected to the desiccating summer heat and the frost of the winters, these aggregates become stabilized, imparting to the soil a lasting granular structure. This exclusive characteristic makes the soils well aerated, and water may easily enter the soil profile. There develops a deep A horizon containing from 3.5 to 15 per cent (and more) organic matter.

Calcium humates are an important contributing factor in structure formation. Freshly formed, these humates are soluble. Upon desiccation they become insoluble, rendering the organic coatings of chernozem granules so stable that they do not slake readily in contact with water.

The color of the soil is dark-brown to black and, because of the color, it has been named *chernozem*, a Russian word meaning black-earth. Chernozem, however, stands for more than just black soil; it is a definite process of soil formation. Peats, mucks, and poorly drained soils are rich in organic matter and black in color, yet they are not chernozems.

Inasmuch as chernozem is rich in organic matter, its N content is high, from 0.15 per cent to as much as 0.5 per cent. For the same reason, the P_2O_5 content of the A horizon is also high, from 0.1 to 0.3 per cent. This is another outstanding characteristic of chernozem. The gradual diminution of organic matter from the upper to the lower layer of the A horizon is also characteristic of chernozem. Table 9 illustrates this point.

Aided by the reagents resulting from humification and mineralization, the process of kaolinization proceeds favorably during the late summer fall, and spring. In this climatic belt montmorillonitic type of clay is produced. This clay possesses a high exchange and moisture holding capacity.

TABLE 9

Distribution of organic matter in the chernozem profile
(After Glinka)

Depth	Leached or degraded chernozem	Deep chernozem	Ordinary chernozem	Southern chernozem
cm	*per cent*	*per cent*	*per cent*	*per cent*
1-5	8.0	10.5	7.0	4.5
20-25	6.5	9.0	5.5	3.0
40-45	5.0	7.5	4.0	1.5
60-65	3.5	6.0	2.5	1.0
80-85	2.0	4.5	1.0	0.5
110-120	0.5	1.5	0.5	—

In the process of mineralization of the organic matter and mineral breakdown, both Na and K are released. Percolating waters carry the Na and part of the K to the ground waters. A share of the K, because of the intense desiccating effects, is retained and fixed in the A horizon. Consequently, K accumulates in this horizon. The accumulation of K constitutes another characteristic feature of chernozem soils.

Water soluble Ca and Mg salts are eluviated from the A horizon. With few exceptions, no Ca or other carbonates appear in this horizon. In some cases, carbonates are found at the junction of the A and B horizons. Despite the removal of soluble bases, the A horizon is generally not acid. This is due to the high ash content of the grass vegetation which brings large quantities of the bases back into circulation, as pointed out earlier. The overall pH of chernozem ranges from close to 7.0 up to 8.2, lower in the A and higher in the B horizon.

Ca and some Mg carbonates accumulate in the B horizon in the form of white spots, veins, and occasionally layers. These accumulations may extend through a depth of several feet.

The neutral to alkaline reaction of chernozem soils precludes the splitting off of Fe, Al, and Mn from the minerals. Except for traces of these elements that go into solution through local action for plant nutrition, very little appears in the circulation of the profile.

Chernozem in the United States. — In the United States, the chernozem type of soil formation extends from north to south, in regions with an average precipitation of 17.0 inches and an average temperature of 3.5°C (38.8°F) as in North Dakota, and in regions with about 30.0 inches

TABLE 10

Composition of typical chernozem

I. Oxbow series, Alberta, Canada

(After Joel, Proceed. & Papers First Int. Congress Soil Sci. 4 (1928) pp. 200-222)

Horizon[1]	Depth	Organic matter	N	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	P
	inches	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*
A_1	0-4	10.9	0.546	69.93	9.93	2.58	1.57	0.80	0.075
A_2	4-10	4.32	0.216	70.78	12.52	3.26	1.64	1.25	0.062
B_1	10-26	1.98	0.099	64.60	10.54	3.23	7.97	2.32	0.050
B_2	26+	0.90	0.045	63.14	11.08	3.43	6.82	2.92	0.047

II. Barnes Loam, Cass County, N. Dakota

(After Hopper, Nesbitt, and Pinckney (1931), Exp. Sta. Tech. Bul. 246)

Horizon[1]	Depth	Organic[2] matter	N	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	P_2O_6	SO_3
	inches	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*
A_1	0-7	7.45	0.356	72.7	10.0	3.0	1.78	0.92	1.81	0.147	0.193
A_3	7-20	3.12	0.162	73.3	9.4	3.3	3.04	1.31	1.67	0.109	0.527
B	20-40	1.02	0.060	62.7	7.8	3.3	9.10	2.82	1.46	0.105	1.25

[1] The horizon designations were not given in the original papers and were made up by the author from the data on "depth." Whereas the horizon designations might not correspond with the actual conditions in the field, they do seem to illustrate the properties of the chernozem profile.

[2] The organic matter content was calculated from the data on organic carbon by multiplying the figures by the factor 1.724.

of precipitation and 18°C (about 65°F) as in eastern Texas. Nonetheless, the quantity of water available for percolation is the same in the northern and southern sections of the chernozem zone. The higher precipitation in the south is offset by the increase in evaporation because of higher temperatures.

Whereas the fundamental profile features of the chernozem soils are the same throughout their vast geographic distribution, some specific features are characteristic for definite sections.

✓In the northern regions of the chernozem belt in the United States, the organic matter content is higher than in the southern regions. Midway between the semiarid and subhumid climate (from west to east) the organic matter content is highest. The depth at which lime accumulates in the profile varies with the change from the semiarid to the subhumid—deeper in the latter. The profile is also deeper in the northern regions. The color from north to south changes from black to a dark brown.

✓ On the basis of these differences, a number of chernozem subtypes have been recognized, such as the northern chernozem, southern chernozem, and deep chernozem. Some subtypes are associated with a specific area or locality, such as the Azov chernozem, located near the Azov sea in European Russia. All chernozem subtypes, however, have the same fundamental characteristics.

✓*Profile of Chernozem.* — A typical chernozem profile possesses the following morphological characteristics:

A_0: A mat of dead grasses and stems associated with the surface of the sod, generally 0.5 to 1.0 inch thick.

A_1: Dark brown to black, the color being more pronounced when wet; 12 to 24 inches and more in depth; organic matter content is high, from 4 to 15 per cent, *decreasing gradually,* with depth; the structure ranges from granular to crumbly; *the aggregates are very stable and do not slake even when subjected to heavy rains;* aeration and water intake are ideal under these structural conditions.

A_2: Similar to A_1 in color and depth; the organic matter content is still appreciable, even at the bottom of this horizon; the structure is granular to nutty in the upper layer and clumpy to cloddy in the lower one; in some soils, especially in the regions close to the chestnut-brown soils, this horizon frequently contains free lime and effervesces when tested with acid.

B: Pale straw color; 15 to 25 (and more) inches deep; structure, not well defined, may vary from lumpy to powdery; Ca and sometimes Mg carbonates, in the form of specks, veins, and even layers, are abundant; in places, the carbonates appear as fine webs resembling fungus mycelium;

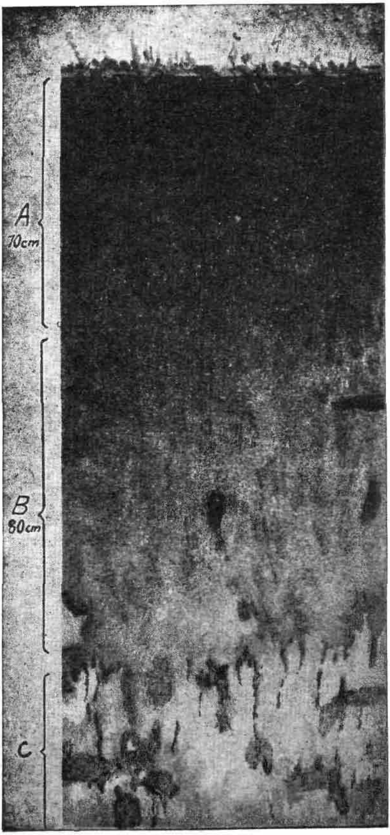

PLATE 5
A chernozem on a heavy loess-like loam
(After Kassatkin and Krasyuk)

in some soils, lime spots are apparent; these are designated by the Russians as beloglazki, white eyespots; in the southern variety of chernozem of Russia, gypsum is sometimes found in the lower layer of this horizon.

C:Loess[5] is the usual parent material of chernozem. This fact does not exclude the formation of chernozem on other parent materials, such as granites, basalts, limestones, and other rocks. There is, however, *one condition that parent material must fulfill before it can form chernozem, namely it must contain some Ca.* Sandstone parent material, poor or lacking in Ca does not form chernozem, even in the midst of the chernozem zone.

Geographic Distribution. — In Europe, a belt of chernozem runs southwest to northwest, from northern Bulgaria, through Hungary, Galicia, Romania, and Russia. This belt continues in Asia east of the Ural Mountains through Siberia up to tbe Amur Province. There are chernozem soils in Manchuria, at the border of Inner Mongolia, and adjacent provinces of China. The Manchurian chernozem is probably an extension of the black soils in the Amur Province which are not true chernozems. They resemhle greatly the prairie soils of the United States. In South America, some of the pampas of Argentina are very much like the chernozem. The annual high rainfall of the pampas—about 30 to 35 inches—is offset by the high average temperature, 16 to 17°C. Chernozem may also be found in other parts of South America, in Chile and Peru.

United States. — Chernozems are distributed in the central part of the country, on the tall-grass plains where precipitation ranges from 18 to 28 inches annually. Specifically, these soils occupy about three-fourths of North Dakota, one-half of South Dakota and Nebraska, more than half of Kansas, one-half of Oklahoma, and a large portion of Texas. Other areas of chernozem are in southeastern Washington, northeastern Oregon, and northern Idaho. The total area occupied by chernozem soils are 280,200 square miles.

The western boundaries of the chernozem zone adjoin the chestnut

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[5] Loess is a fine calcareous silt with some clay, the bulk consisting of particles 0.05 to 0.01 mm. in diameter, poor in organic matter, yellowish or buff in color, mellow and yet strongly coherent. When cut by stream action, it is found to stand with vertical walls, sometimes hundreds of feet high. Ordinarily loess contains concretions and snail shells.

The largest area of loess, about 300,000 square miles, is found in the drainage basin of the Hoang-Ho River, China. In the United States loess is situated in the drainage basin of the Mississippi River.

The oldest theory on the origin of loess is the aeolian. As the wind blown material settled over the grass, the stems moulded tubules which are characteristic of loess deposits. According to the views of some geologists, the deposition of loess had occurred during Post-Glacial time under conditions of aridity. In recent years opposition to the aeolian theory has resulted in advancing the alluvial origin of loess. The material was carried and deposited hy glacial waters in Post-Glacial time.

brown soils and the eastern borders adjoin the prairie country. The Boyd, Holt, Barnes (one of the most representative types), Parnell, Fargo, Bearden, Hays, Holdrege, Hall, Moody, Palouse (in Washington, Oregon and Idaho), and associated soil series are representatives of chernozem.

Agricultural Features. — Chernozem soils are known the world over for their productivity. They contain large quantities of organic matter and abundant supplies of mineral nutrients; they have a high absorption capacity for bases; they possess an ideal structure; they have, as a rule, a favorable mechanical composition, with few sandy soil areas and not too many excessively heavy soils; they are neutral to slightly alkaline in reaction. All of the foregoing properties make chernozem the richest of all soils. They have, however, one handicap: they often suffer from lack of moisture.

Methods of conserving and storing water in these soils have been investigated for a long time. Summer fallow, plowing in the fall for spring planting, and allowing the land to remain in the rough are expedients that tend to allow more water into the soil profile. Forest strips at various intervals in the steppe region serve as wind breaks, and thus reduce the evaporation of soil moisture in the areas between the strips. As wind breaks, these strips obviate snow drifts and facilitate an even distribution of snow on the ground.

Constant vigilance against prolific weed growth is a chore in conserving moisture. In combating weeds, the common methods of cultivation and crop rotations are at times supplemented by turning a furrow slice 180° to a depth of 15 to 20 inches. Most weed seeds, when buried at such depths, do not come up.

Wheat and other small grains are the principal crops in all parts of the chernozem belt. In the United States, corn is the prevailing crop in the eastern section of this belt. In most sections stock farming is developed, with alfalfa and sweet clover as some of the best hay crops produced. Because of the natural richness in these soils, very little fertilizer is used.

✓ DEGRADED CHERNOZEM

At the eastern edge of the chernozem belt, the *grassland climate* begins to give way to the *forest climate*. The grasslands are invaded by forest species and taken over by forests. From time to time, the forests disappear and fail to reestablish themselves. This happens after fires or after a cycle of dry years. Once more the grasses take over the land to be pushed out by forests after a number of years. This struggle between the forest and grass vegetation may engulf an area several hundred miles wide. It is generally referred to as the forest steppe area. The newly acquired properties resulting from the change in climate—primarily increased precipitation—and biosphere introduce some specific changes in the profile characteristics of the chernozem soils. Prominent among the changes is the shift of the lime accumulation deeper into the profile (this is known as the point of effervescence, as shown by the HCl test) until it disappears altogether. The A horizon begins to show signs of acidity. Some Fe and Al split off and enter into circulation as hydrated oxides, in combination with some organic colloids. As they reach the more alkaline medium of the B horizon, they precipitate and thereby impart a reddish-brown coloration to this horizon. At the same time, SiO_2 remains behind in the A horizon. The white specks of SiO_2 on the black background of this horizon give it a "salt and pepper effect." The soil profile still resembles typical chernozem in color, organic matter content, granular structure, sorption capacity for cations, and accumulation of K and P in the A horizon. However, the additional attributes mentioned above indicate that the chernozem has degraded and for that reason the subdivision is known as *degraded chernozem*.

The eastern limits of the true chernozem in Siberia and in the United States border and merge into an extensive belt of dark colored soils which have the characteristics of degraded chernozem but are not identical with the forest steppe soils. They are known as the prairie soils, identified only in the United States and in the Amur Province of Siberia.

PRAIRIE SOILS

Origin. — According to ecologists, the soil and climate of the prairie region are favorable for tree growth. Nevertheless, no forests have ever covered this region. Many reasons have been proposed to explain this treeless state. Extensive grazing by buffalo, sweeping prairie fires, and unfavorable conditions for germination at critical periods when forest seedlings try to gain a foothold are among those advanced. It is claimed that germination of tree seeds is inhibited by the high, though temporary, Ca content prevailing in this soil type during the fall, by the desiccated condition of the soil in the late summer and early fall, and by the lack of snow cover, the presence of which protects plants against winter injury.

The explanations offered bring out the "why" of grass vegetation in the prairie, but tell nothing on the origin of the prairie soils. However, many distinguishing features of degraded chernozem are characteristic of the prairie soils. It is very probable, that during some period of Wisconsin Post-Glacial time the climate of the prairie region was conducive to the formation of chernozem. Since that time the climate has changed to a more humid one, and the chernozem has been undergoing a degradation process.

Geographic Distribution. — The prairie soils in the United States cover an area of 283,500 square miles; they occupy southeastern Minnesota, practically all of Iowa, three quarters of Illinois, the eastern half of Missouri, parts of eastern Kansas, the eastern half of Oklahoma, and a large strip in Central Texas. Some small areas of soils similar to those of the prairie are found in California, Idaho, Washington, and Oregon.

The representative soils series in the prairie of the northwest are: Altamont, Los, Osos, Cayucos, Nez Perce, Alical, and associated series. The soil series in the prairie region proper are: Carrington, Clyde, Clarion, Cherokee, Webster, Florence, Crawford, Summit, Newtonia, Bates, Oswego, Tama, Marshall, Grundy, Zaneis, Renfrow, and associated series. The last two series are representatives of the southern section of the prairie where the soils begin to show reddish coloration.

Agricultural Features. — The largest acreage of the corn belt is located in the prairie region. No other soils in the United States can compare with the prairie in growing the small grains, hay, and forage crops. Stock-raising and dairying are a natural complement to the crops in the prairie country.

The natural feritility of these soils is comparable to that of the true chernozem. Grain crops may be grown year after year without commercial fertilizer. In the eastern edge of the prairie, the soils become more acid and they respond to liming and fertilization. The experience and practices of good farmers and the advice of Experiment Stations should be followed for successful farming.

Northern Versus Southern Sections of the Steppe Country

The steppe type of soil formation in the United States extends in belts from north to south, as shown in plate 3. Since rainfall and temperature increase progressively from north to south, it is plausible to assume that the character of the soil profile will be influenced by its particular geographic location. Indeed, Marbut did divide the brown, chestnut (dark brown), true chernozem, and prairie soils into northern and southern belts. These belts have been further characterized by the workers of the United States Department of Agriculture (*Soils and Men, United States Department of Agriculture Yearbook for* 1938) on the basis of color. Thus, the southern belt of the brown zonal soils, because of some reddish coloration in many areas, has been named "reddish brown" soils. Until a better set of properties have been found to characterize these soils, the above classification may be accepted. The northern belt of the dark brown soils has been named "chestnut" soils; and the southern belt of the dark-brown (chestnut) soils has been named "reddish chestnut" soils. The reddish prairie soils formed on limestone, like the Houston series, are known as Rendzina (see next chapter).

The reddish color of the soils in the southern portions of the steppe country is undoubtedly not the result of the present day climate, but of an earlier subtropical, perhaps tropical, climate (see: Joffe, J. S., Climatic sequences of the Post-Wisconsin glacial age as revealed in the soil profile. *Proc. Soil Sci. Soc. America* (1941) 6:368-372).

HUMID TEMPERATE TYPE OF SOIL FORMATION: THE PROCESS OF PODZOLIZATION

The humid temperate climate coincides with the zone of forests. In Europe and Asia, this zone is bounded by the tundra (see p. 149) in the north, and by the steppe in the south. In North America, the forests terminate in the north, also in the tundra, but along the Atlantic seaboard in the south they merge into forests of the subtropical climate. The reason for the difference is that in Europe and Asia the temperature increases and the rainfall decreases from north to south, whereas in North America, east of the Rockies, the rainfall increases from north to south and decreases from east to west. In this vast climatic belt, the annual precipitation varies from 20 to 50 inches and the average temperature from 3 to 10°C. The precipitation is, as a rule, uniformly distributed throughout the year.

More than 800,000,000 of a total of 1,900,000,000 acres of land area of the United States were in forest when white men set foot on the New World. The primeval forests of the northern and southern portions of North America were a theme in the sagas of the Vikings; and 500 years later, of the followers of Columbus, Don Ferdinando de Soto with his "roving company of gallant freebooters" and their followers.

In eastern United States, hardwoods and softwoods are widely distributed. The western forests are rich in varieties of softwoods, but poor in important hardwoods.

Process of Soil Formation. — The conditions responsible for the accumulation of organic matter in the grasslands are absent in the forest zone. The A horizon and, more so, the A_0 layer of soils in the forest zone never dry out as much as those of the grasslands, thus making the environment very favorable for microorganisms to attack organic matter. Nor are the soils in the forest zone subjected to desiccating effects, so essential in fixing organic matter, as are the soils in the grasslands. The aforementioned conditions bring about a low organic matter content in the soils of the forest zone. (For details on the variation in organic matter content in the forests and grasslands the reader is referred to chapter VI).

The climate, the attendant forest vegetation, and intensive decomposition of organic matter result in the liberation of large quantities of acids oxides, humus, and silicic acid serve as cements, to form concretions and hardpan (see Ch. IV and VIII).

The process of soil formation, as outlined, is known as podzolization. This word originates from the Russian *podzol,* meaning ash-like. The forest zone of the humid temperate climate, where this process of soil formation prevails, is known as the *zone of podzolization.* Be it noted, however, that the *degree* of *podzolization* is not the same all through the vast geographic extent of this type of soil formation. The degree of podzolization is weak at the boundary of the chernozem zone. In the southeastern section of the United States, the process of podzolization is subdued by the subtropical climate where a new type of soil formation—laterization (see p. 151)—takes place. The highest degree of podzolization is encountered in the central and northern sections of the humid temperate climate. The soils in these sections have the bleached ash-gray A_2 horizon and are designated as *perfect or mature podzols.* Depending on the degree of podzolization, soils are described as *weakly podzolic, medium podzolic,* and *strongly podzolic.*

If the parent material of the soil in the zone of podzolization is rich in limestone or any other calcareous material, the process of podzolization is impeded, and time enters as a factor in moulding the characteristics of the profile. The bases present in the C and lower B horizons rise towards the A horizon and counteract acidity. These bases also delay the appearance of Fe, Al, and Mn in the circulation of the soil body.

In poorly drained areas, the A_0 layer is deep. It is, therefore, a rich source for the formation of acids. Moreover, since mineralization is impeded because of the prevailing anaerobic conditions, the release of bases is low. These factors combine to accelerate the process of podzolization, and poorly drained soils are, as a rule, very acid.

Swedish foresters have noted that soils showing strong podzolic effects, when planted to beech, tend to revert to a medium or a weakly podzolic condition after several decades. The color of the A_2 horizon begins to exhibit a brownish tinge, indicating that not all of the Fe and Al that enters the horizon is washed out from it. This condition is reflected by an increase in the pH of the horizon. On the other hand, soils showing weak podzolic effects, when planted to conifers, begin to become more strongly podzolic. The color of the A_2 horizon tends to lose its brownish color and becomes more gray; the pH drops.

The figures on the ash and base content of the two forest species explain their differential effect on the process of podzolization. The beech may have as much as 7 to 8 per cent ash, most of which is salts of Ca, Mg, and K. These bases are mobilized by the beech from the lower horizons and returned to the surface of the soil by way of the leaf fall and dead trees. Upon entering into circulation, these bases reduce soil acidity and retard podzolization. Conifers, on the other hand, contain only 1.5 to 3.0 per cent ash; acids form in excess of bases and podzolization is enhanced.

Profile of Podzols and Podzolic Soils. — A typical well drained loam soil profile possesses the following morphological and related characteristics:

A_0: 0.5 to 2.5 inches thick; consists of an accumulation of undecomposed or partly decomposed plant residues—leaves or needles, or both (depending on forest species), twigs, branches, and trunks of trees, mosses, ferns, and various types of herbaceous vegetation. The mat of forest litter which makes up the A_0 layer is named by foresters either *duff* or *mull.* The latter is usually found under hardwoods and the former is found under conifers. The thickness of the A_0 layer varies with the climate, decreasing from north to south in Europe and Asia, and from north-east to south-west in North America. In very sandy soils, the A_0 is sometimes lacking, especially on the more elevated portions of the landscape.

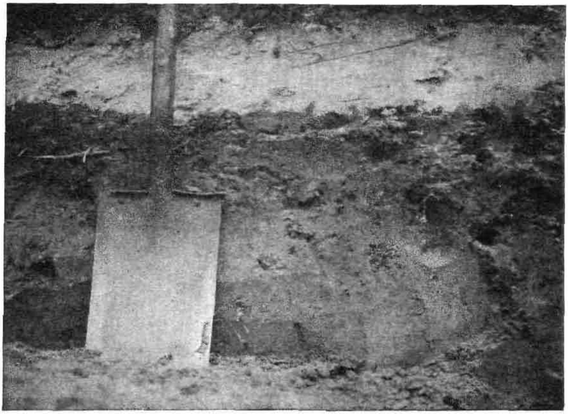

PLATE 6

A typical podzol in New Jersey on sandy parent material

The more advanced the stage of podzolization, the more acid is the A_0 layer. The peak of the acidity is reached in the late winter and early spring; the lowest point of acidity occurs in the fall when the new fallen leaves give up their bases.

A_1: 6 to 8 inches deep; impregnated with dead and living roots and humus; the organic matter content diminishes rapidly with depth; gray to brown in color, often of a straw colored tinge; no well defined structure; silty, mellow, and of loose consistency; the organic matter content varies with the climate, following the pattern described for the A_0 layer.

A_2: 6 to 8 inches deep; lighter in color than the A_1 horizon; in a mature podzol, the color is ash-gray to white, giving the soil a sandy appearance; its structure is powdery, changing to laminated (platy) at the bottom. In a sandy soil, the A_2 horizon may extend almost to the surface, leaving but an inch or two of the A_1 horizon.

B_1: 6 to 10 inches deep; heavier in texture than the A horizon; brown to dark brown or reddish brown; with veins of dark brown humus and tongue-like projections of lighter colored material from the A_2 horizon; laminated structure in the top portion, becoming nutty to lumpy with depth.

B_2: 6 to 8 inches deep; brown to reddish brown in color; lumpy to cloddy in structure; compact in constitution, becoming more open at the bottom; lighter texture.

The B horizon is easily detected by its compactness. Digging with downward gentle strokes (using a hand scoop or garden trowel) along the exposed profile, one soon feels that more force has to be applied. This is the beginning of the B horizon. The compactness increases with depth and at the bottom of this horizon it decreases. Darker colored concretions may be encountered in this horizon. In poorly drained sandy soils, these concretions often form a layer of coffee-brown colored hardpan, made up of grains of sand and some silt and clay, cemented with sesquioxides and organic substances.

The compacted B horizon, upon drying, becomes extremely hard; it is then often designated erroneously as hardpan. When saturated with water, the dense mass of the B horizon becomes putty-like, smeary, and plastic; its permeability is thereby reduced. Even after a moderate rain, water backs up to the surface, indicating poor drainage. Anaerobic conditions set in and crops suffer. As a rule, acidity increases; the situation then becomes still more aggravated by the appearance of gels of Al, Fe, and Mn. Permeability is reduced to a minimum and surface swamping, with all its evils, ensues. At this stage, the soil has to be treated with mixtures of limestone and gypsum.

The B horizon is also the recipient of bases and other nutrients, such as P and S, washed down from the A horizon. Were it not for the acidity and toxicity, these nutrients would be utilized by the plants.

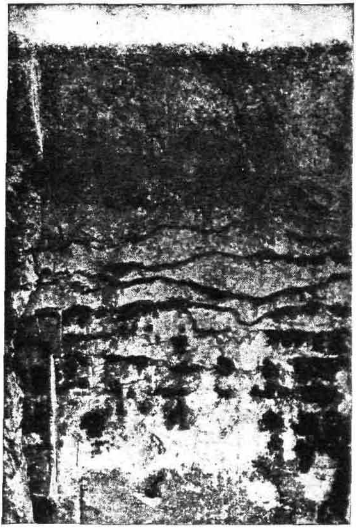

PLATE 7
Ortstein veins in a podzol soil
(After Krasyuk)

C: This horizon, composed of true parent material, is more mellow in constitution and lighter in texture than the B horizon. The fact that the composition of the C horizon remains constant for considerable depth indicates that the reagents percolating this horizon do not react with the soil material.

In table 11 analyses of typical profiles are presented. The data clearly illustrate how the translocation and distribution of soil constituents take place under conditions of podzolization.

SUBTYPES OF PODZOLIZED SOILS

The normal mature podzols and soils in various stages of podzolization described earlier are not all alike in their morphological, physical, and

Analyses of podzolized soils

1. A sandy loam (Brassua series) in New Hampshire (After Brown and Byers, U. S. Dept. of Agriculture)

Horizon	Depth	SiO_2	Fe_2O_3	Al_2O_3	MgO	CaO	K_2O	Na_2O	TiO_2	MnO	P_2O_5	SO_3	Org. matter	N	Reaction
	in.	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*pH*
A_0	5-0	3.0	0.18	0.79	0.08	0.15	0.04	0.05	0.07	0.000	40.09	0.26	88.5	1.05	3.1
A_2	0-3	86.7	1.36	5.92	0.14	0.70	1.04	1.34	1.18	0.02	0.04	0.08	1.25	0.04	3.6
B_1	3-4	62.2	4.77	9.64	0.28	1.11	0.98	1.88	.92	0.04	0.07	0.07	16.4	0.25	3.7
B_2	4-9	67.1	3.44	14.5	0.43	1.47	1.40	2.32	.74	0.05	0.09	0.14	5.5	0.07	4.5
B_3	9-19	75.7	2.50	11.6	0.57	1.68	1.58	2.74	1.42	0.05	0.08	0.09	1.4	0.02	4.6
C	19⁺	77.1	2.72	10.5	0.64	1.90	1.52	2.70	1.22	0.10	0.14	0.09	0.43	0.01	5.4
Rock	—	71.4	4.84	14.1	1.62	1.46	2.39	2.25	0.61	0.08	0.19	—	—	—	—

2. A podzolized loam (Chester series) in New Jersey

Horizon	Depth	SiO_2	Fe	Al	Ca	Mg	Mn	N	P	Reaction	Cation exchange capacity	Unsaturation (H)
	cm.	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*pH*	*m.e.*	*per cent*
A_1	12	71.5	4.5	5.7	0.50	0.40	0.16	0.07	0.04	5.5	7.2	63.5
A_2	16	72.6	5.0	5.2	0.53	0.44	0.20	0.04	0.04	5.4	6.3	54.8
B_1	15	68.4	6.5	5.6	0.42	0.46	0.25	0.03	0.05	5.2	6.8	66.0
B_2	43	63.3	10.2	5.9	0.26	0.16	0.21	0.01	0.05	5.2	6.6	50.5
C	—	68.9	5.3	5.8	0.40	0.18	0.24	—	0.03	5.4	5.3	45.0

Notes: Profile 1 is a dwarf podzol, formed on a sloping topography.

Profile 2 has no morphologically pronounced bleached A_2 horizon, but the chemical data show the podzolization effects.

chemical properties. To identify the variations, a number of subtypes has been established. They are soils which, in addition to the general podzolization features, exhibit some specific characteristics. Thus, meadow and peat podzols give rise to a specific type of A horizon, and soils subject to a fluctuating water table exhibit some specific characteristics in the lower part of the A and in the B horizon.

a) *Meadow Podzols.* — These soils, for reasons as yet *unknown*, are occupied by grass vegetation in the midst of the forests. They are located generally along water courses, near lakes and ponds and are somewhat poorly drained. The humus accumulative A_0 layer consists of a mat of dead grass containing bitumens. The A_1 horizon, 6 to 10 inches deep, is almost black when wet, and dark gray and somewhat granulated when dry. The A_2 horizon, 6 to 8 inches, is not uniform in color, generally a dirty gray, with humus streaks. At bottom, some concretions are frequently encountered. The B horizon is usually compact, mottled, gray to yellowish gray and sometime greenish, with veins and streaks of red along root paths; concretions and hardpan may be encountered. As a rule, meadow podzols are acid, unless the materials draining into these low areas carry bases. These soils are a transition to the swamp meadows which are frequently submerged and, therefore, contain a layer of organic matter a foot or more deep.

b) *Peat Podzols.* — These soils represent areas adjoining swamps gradually rising from submergence to become dry land. The more elevated edges of peat bogs manifest the characteristics of peat podzols. The A_0 layer may extend to a depth of a foot or more. It is underlain with a dirty-gray horizon resembling the A_2 of mature podzols. As in the case of meadow podzols which they resemble greatly, peat podzols suffer from poor drainage.

c) *Glei.* — Soils in the zone of podzolization subjected to a rising and falling water table acquire a gray colored layer either in the lower part of the A, in the B, or in the upper part of the C horizon. This new layer is known as *glei* horizon and is designated by the letter G. Throughout its depth, this horizon is mottled, with greenish-bluish streaks and tinges, and occasional veins of brown. The color shades are due to reduction reactions. If the ground waters contain Fe (in the ferrous state), it is carried to the G horizon. When the level of the water table drops, the Fe in the G horizon oxidizes and precipitates. At the same time, the Fe released from the A horizon moves downward and precipitates at the G horizon where some of the bases, especially Mg, are retained. The net effect of the upward and downward movement of Fe is an accumulation of an ochreous deposit resembling hardpan. The higher the Fe content of the ground waters, the faster the accumulation of this deposit. Many bog iron formations may be traced to the process just described. Typical examples have been examined by the author in the Chatsworth area of New Jersey. The Fe content of these may run from 10 to 30 per cent. Abandoned foundries and ore piles in that area of New Jersey are evidence that this bog iron was being mined at one time.

PODZOL ZONE IN THE UNITED STATES

Area of Podzolization. — The zone of podzolization covers probably the largest habitable area of the earth's land surface. In the United States, 614,400 of a total of 3 million square miles are in this zone. Of these, 149,100 are mature podzols and 465,300 square miles are strong, medium, and weak podzolic soils. If some of the transition soils (those adjoining the zone of podzolization to the south and west) were added to this zone, they would cover a third of the area of the United States. Almost half of the area of the Soviet Union is in the zone of podzolization.

The soils of the podzol zone in the United States are grouped, on the basis of degree of podzolization, into: 1, *mature podzols;* 2, *brown podzolic;* and 3, *gray-brown podzolic.*

1. There are *mature podzols* with different subtypes within their boundaries; these soils possess a well developed ash-gray A_2 horizon and *occupy an extensive area in the northern part of the Great Lakes region* and in the New England States. Many sandy soils of New York, New Jersey, and even of the more southerly sections along the coast are mature podzols.

The following soil series are typical representatives of this group: The Berkshire, Worthington, Greensboro, Calais, Peru, and Danby soils in Vermont, New Hampshire, and Western Massachusetts; the Caribou (famous potato soils) in Maine, Dekalb and Leetonia in the Appalachian plateaus and Appalachian ridges of Virginia, Pennsylvania, and New York; the Hermon, Colton, and associated series in Maine, New Hampshire, and New York; the Iron River, Milaca, Hiawatha, Baraga, Stambaugh, Vilas, and associated soil series around the Great Lakes, primarily Lake Superior; the Lackawanna, Culvers, and associated soils in New York and Pennsylvania; and the Lakewood, Duke, some Sassafras sand, Lakewood sand, Portsmouth sand, and associated soils along the coast from Southern Delaware to Cape Cod.

2. *Brown podzolic* soils are a group found only in the Northeastern States. The greater part occurs south of the region of the mature podzols, mostly in the hilly sections. These soils (separated as an independent group by the soil survey, U.S.D.A.) may be characterized as imperfectly developed podzols, the A_2 *horizon being shallow and not thoroughly*

bleached. They constitute a transition type (not an independent group) between the mature podzols and the gray-brown podzolic soils.

The following soil series are representative of this group: Gloucester, Plymouth, Merrimac, Carver, Charlton, Paxton, Woodbridge, Sutton, Colrain, Shelburne, Wethersfield, Cheshire, Manchester, Hartford, Chicopee, Windsor, Suffield, Agawam, Hadley, and associated soils. These are found in New England, New York, and New Jersey.

3. *Gray-brown podzolic soils* have developed under deciduous forests and include strong, medium, and weak podzolic soils. They have a gray-brown to a brown A_2 horizon. A chemical analysis of these soils (see table 11) shows the essential chemical properties of podzolization, namely: the highest acidity in the A_2 horizon, the greatest loss of bases and sesquioxides from this horizon, an accumulation of the latter in the B horizon and of SiO_2 in the A_2 horizon. These soils are encountered in the eastern and midwestern part of the United States. In the Pacific Northwest similar soils have developed under coniferous forests (see plate 3).

The large number of soil series in this vast region is grouped into areas bearing the names of representative series: Clinton-Boone-Lindley and associated series (along the valley slopes of the Mississippi River and along some of its tributaries, in Wis., Minn., Ill., Iowa, and Mo.); Chester-Manor and associated series (northern Piedmont in Pa., N. J., Del., Md., and Va.); Dutchess-Cossayuna-Nassau and associated series (in the Slate Belt which averages 50 miles in width, from northwestern N. J. to western Vt.); Everett-Alderwood and associated series (mainly in Puget Sound Basin); Fairmount-Lowell and associated series (northern Ky., southeastern Ind., and southwestern Ohio); Hagerstown-Frederick and associated series (mostly in Va., Md., Pa., and Tenn.; some in Mo., Ky., Ind., W. Va., and N. J.); Helmer-Santa Benewah and associated series (mainly in northern Idaho, Western Mont., Wyo., Colo., and in the Sierra Nevada in California); Lordstown-Volusia and associated series (southern N. Y. and northern Pa. on the northern end of the Appalachian Plateau); Miami-Crosby-Brookston and associated series (little corn Belt of Ind. and Ohio); Miami-Kewaunee and associated series (part of the glacial region of the Lake States); Muskingum-Wellston-Zanesville and associated series (Ky., W. Va., Pa., Ohio, and Ind.); Ontario-Honeoye-Pittsfield and associated series (N. Y., Mass., Conn., and Vt.); Olympic-Melbourne and associated series (mountainous areas in Wash., Oreg., and Calif.); Porters-Ashe and associated series (Blue Ridge and Great Smoky Mountain areas of Va., N. C., S. C., Tenn., and Ga.); Plainfield-Coloma and associated series (sandy soils in western Great Lakes region); Penn-Lansdale and associated series (Piedmont region in Va., Md., Pa., and N. J.); Rayne-Gilpin and associated series (rolling and hilly Allegheny Mountains and Kanawha section of the Appalachian Plateau in west-central Pa.); Sassafras-Collington and associated series (on coastal Plains of Va., Md., Del., N. J. and Pa.); Spencer and associated series (central Wis.); Williamette-Amity-Dayton and associated series (Williamette Valley in Oreg. and Wash.); Wooster-Mahoning and associated series (north-eastern Ohio, northwestern Pa. and western N. Y.); Westmoreland and associated series (Western Pa., north-western W. Pa., and east-central Ohio).

Agricultural Features. — General agriculture finds its highest development in this zone, the soils and climate being adapted to a great variety of crops. There is practically no branch of agriculture that can not be successfully pursued, despite the difficulties encountered in the management of soils in this zone.

The soils in the zone of podzolization require heavy fertilization because they are constantly leached. These soils are, as a rule, acid (except for the young soils on calcareous parent material) and have to be limed. They are also low in organic matter, possess poor structure, are subject to poor aeration, and easy prey to erosion.

The geographic area of this zone is probably the most populated in the world, except for some regions of the tropics. An array of natural factors have contributed to the lure of this zone for close settlements: the climate is healthy and invigorating; the meteorologic elements are relatively dependable for the growing of crops; storms of devastating nature or other natural disasters are not common in this zone. There is always an abundance of potable water for man and beast; rivers offer means of communication; and in the forests, man finds game to hunt, lumber for fuel and shelter, and furs for protection against the severities of climate.

The advantages of living conditions on the one hand, and the difficulties in managing the soils of this zone on the other hand, have challenged the ingenuity of man. The struggle to master the soils in the zone of podzolization has indeed been a long one. Only after science and technology had made their entry, in the 19th century, did agriculture embark on the road of progress.

TUNDRA TYPE OF SOIL FORMATION

The tundra (from the Finnish ***tunturi,*** a flat, barren plateau) is a vast treeless plain in the Arctic region protruding deeply in places into the forest zone, making a rather sinuous and irregular border line. In almost all of its vast extent, the tundra region is underlain by a perpetually frozen layer (permafrost) which does not thaw, save during the short summer—and even then only to a depth of several feet. The estimated area of perennially frozen ground in North America is 2 million square miles.

The perpetually frozen layer varies in thickness, diminishing from north to south. Coal prospectors in Spitzbergen have found the ground frozen more than a 1000 feet deep. In Yakutsk, on the Lena River in Siberia, the bottom of the frozen layer had not been reached at a depth of 382 feet. At this depth the temperature was about 26°F. Throughout the year, the temperature remained constant beginning with the 50-foot depth. Whereas this constancy has been maintained, the numerical constant decreased, i.e., the temperature increased with each succeeding depth, although it still remained below freezing at the 382 feet level. It has been reported that drilling a well on Mount Washington, N. H., was abandoned because a permanently frozen layer was encountered.

The treeless condition of the tundra is the result of low temperatures, very short summers, and the drying winter winds blowing with great force over the unprotected plain. The winds desiccate the soil and interfere with transpiration of the trees. In areas shielded against the desiccating winds, fairly large trees develop. In such areas, the accumulated snow forms a protective cover and permits deeper thawing. Alpine vegetation and some forests become established and the permanently frozen layer drops to a lower level.

Rivers with headwaters in a warm climate flowing towards the Arctic Ocean through the tundra carry tremendous quantities of heat, thus mitigating the local climate. Within the boundaries of the watershed in the tundra, the depth of the layer of underground ice (permafrost) decreases. Forests appear, and these may extend into the far north, almost to the coast of the Arctic Ocean. Forest soils form under these conditions.

The climate of the tundra is characterized by long winters and very short summers (about 8 weeks) during which most of the 8 to 12 inches of precipitation falls. On some summer days, the temperature may rise as high as 90°F, and on others may drop to 32°F. There is practically no fall season, winter following hard upon summer, the temperature dropping suddenly to -60°F and even lower. It is this quick freezing that preserves and retains the food value of the vegetation. This type of climate is nature's way of providing reindeer and other animal life with nutritious feed during the trying winter months of the Arctic. Of the cultivated crops, berries, leafy vegetables, and potatoes (grown from sprouts) may be raised in this region. In the more protected areas, hay and some small grains may be grown. Settlers forced to live in these regions may even carry on some dairying.

The soil profile in the tundra is shallow, with little horizon differentiation. Weathering is primarily physical in nature. Since vegetation is scant and microbial activity is greatly hindered, very few chemical reagents are available for the processes of soil formation. In general, the soils are not acid; they have the same pH as that of the parent material. In many areas, soils suffer from droughts, even during the short summer season.

In the protected areas, where alpine vegetation and some forests gain a foothold, the soils thaw deeper and some podzolization takes place; the profile, however, remains dwarfed.

TROPICAL AND SUBTROPICAL TYPE OF SOIL FORMATION

The outstanding characteristic feature of soils in the tropics and subtropics is the red color. In 1807 Buchanan, an Englishman, named these soils *laterites,* from the Latin word *later* meaning brick. The brick-red color is due to the accumulation of Fe_2O_3 (in various degrees of hydration) in the profile. The iron content is generally very high; some Cuban laterites, for instance, contain 72 per cent Fe_2O_3. Indeed, there are records of laterites which contain 86 per cent Fe_2O_3. Such materials have been surfaced-mined as iron ore in Cuba.

Laterites also accumulate oxides of Al, Mn, and Ti. Many laterites originate from parent material high in Al and low in Fe. Still, most laterites are red in color. It takes small quantities of the colloidal oxide of iron to coat large quantities of material. Intensity of color of laterites is, therefore, not an index of a high Fe_2O_3 content.

The Process of Laterization

The process of soil formation in the tropics and subtropics is known as *laterization.* Like that of podzolization, it has several degrees of development. Where the soils have reached the highest degree of laterization, they are designated as *laterites.* Where the soils have reached certain degrees of laterization, they are known as *strongly, medium,* or *weakly lateritic.* True laterites are found in the equatorial region. They are more pronounced in the tropical rain-forest, less so in the savanna, and still less in the highland type of tropical climate; they are also found in the tropical steppe country, perhaps as the remains of an earlier, more humid climate. Lateritic soils are found in the humid subtropics and in the Mediterranean region.

Laterite. — To illustrate graphically the process of laterization, analyses of a typical profile are presented in table 12. Two chemical features are outstanding: 1, the loss of SiO_2; and 2, the relative accumulation of sesquioxides, chiefly Fe and Al. It is clear that of an original 42 per cent SiO_2 in the parent material not more than 2 to 3 per cent remained in the laterite profile. On the other hand, of an original Fe_2O_3 content o 7.84 per cent in the parent material it increased to 71.12 per cent in th soil profile.

TABLE 12

*Laterite profile from Cuba**

Constituents	0-26 inches	26-40 inches	40-156 inches	156-192 inches	192 + inches
	per cent	*per cent*	*per cent*	*per cent*	*per cent*
SiO_2	3.28	2.25	1.83	1.55	41.93
TiO_2	0.80	0.26	0.80	0.80	0.05
Fe_2O_3	63.04	69.56	71.12	68.10	7.84
Al_2O_3	18.46	11.13	12.36	14.66	2.00
MnO	0.42	0.28	0.38	0.47	0.12
CaO	0.12	Trace	0.01	0.15	1.50
MgO	0.33	0.48	0.64	0.60	34.02
K_2O	0.06	0.08	0.02	0.05	0.08
Na_2O	0.49	0.30	0.48	0.39	0.36
P_2O_5	0.03	Trace	Trace	Trace	Trace
Ignition loss	12.74	12.38	12.33	12.74	11.75
Organic matter	1.02	—	0.37	—	—
Cr_2O_3	—	3.14	—	—	0.10

*The data are taken from the book: The Soils of Cuba, by H. H. Bennett and R. V. Allison. Tropical Plant Food Research Foundation, Washington, D. C.

Temperature and moisture conditions in the humid tropics and subtropics are ideal for the production of luxuriant vegetation, as well as fo the processes of humification and mineralization. The organic matter content of well drained laterites is, therefore, low. Simultaneously, with th rapid oxidation of the organic matter, the bases are released, and the supply of these and the absence of organic acids in circulation keep the pH of the soil high enough to precipitate Fe, Al, and Mn. That is why thes elements accumulate in the A horizon, as shown in the table. At th same time, conditions are favorable for the silicic acid that splits off t ionize sufficiently to stay in solution and to be washed out from the profile

Whereas the rapid circulation of bases is sufficient to cause the precipitation of sesquioxides, the heavy rainfall leaches the bases and th laterites are, therefore, slightly acid.[1]

Phosphates, as a rule, tend to accumulate in the upper layer of laterite soils. As the P from organic matter is mineralized, it combines with

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[1] Of more than 40 samples of Cuban laterite soils tested, only two have been reported having a pH slightly below 5.0; most of the samples approached the pH of 6.0 or higher. Of course, the sandy soils, like in any other soil zone, are as a rule more acid than the heavy soils.

the readily available Fe and Al, forming insoluble phosphates. And yet, there are laterites low in P_2O_5. It is probable that in these cases the A horizon had been eroded.

Heavy laterites are, as a rule, distinctive by their friability and open structure. They easily take in water and dry readily. A characteristic tillage feature of true laterites is that they can be plowed within several hours after heavy rains, without puddling. These soils do not swell when wet, or shrink much when dry. They, therefore, do not crack upon drying, even though they may become very hard. These properties are related to the low plasticity of these soils, brought about by heavy coatings of Fe and Al oxides on the clay particles. Like dry iron rust, these coatings are non-plastic and they reduce or mask completely the plastic and cohesive properties of clay.

The low organic matter content and the high sesquioxide content tend to decrease the negative electrical charge on the soils in the zone of laterization. This causes a decrease in the adsorption of bases by these soils and may even induce adsorption of anions, such as sulfates and nitrates.

Many of the laterites contain iron crusts, or concretions, with a cellular or slag-like structure. Some students of tropical soils name these *cellular laterite.* These formations resemble the stone-like hardpan. They are dark brown, reddish-brown or yellowish and are found in the surface horizons, extending to depths of several feet. In some areas red tubular crusts, filled with soft white silica, are encountered.[2] In Cuba these slag-like formations are known as *perdigon.* In Panama, the author examined many areas in the savannas, where cinder-like to buckshot-like iron oxide concretions made up the bulk of the soil mass several feet deep. It is very likely that in this case erosion had removed some of the A horizon exposing the hardpan-like B horizon.

In the tropics, the fauna as a biosphere element in soil formation is much more active than in the temperate climate. Insects, particularly termites and ants, are a major force in attacking and reducing dead organic matter. Gigantic trees are destroyed in very short order. Land clearing in tropical forest may be accomplished with the aid of termites. Trees are felled, leaving high stumps. The dry brush is set on fire and the rest is left to the termites. Such methods are not entirely advisable, however, for land so treated must face the menace of the insects which also ravage the crops.

A useful index of determining the degree of laterization in soils is the ratio of $SiO_2 : Al_2O_3$, known as the *ki* value. If the ratio is lower

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[2] Such tubular crusts have been found by the author in many of the profiles of the Colts Neck soils of New Jersey. These soils are a relic of a tropical climate that persisted in New Jersey sometimes within the last 25,000 years.

than 1.0 the soil is a genuine laterite; if the ratio is from 1.0 to 2.0, the soils are lateritic.

Lateritic Soils. — The two subdivisions of the subtropical climate, the dry and the humid, give rise to two types of lateritic soils: 1, the red earths, known as *terra rossa;* and 2, the *red loams.* The red earths are lateritic soils formed under conditions of the Mediterranean climate, while the red loams are formed under conditions of a humid subtropical climate, such as that of the southeastern part of the United States, south of Chesapeake Bay, or of the Western portion of the Black Sea coast in the Caucasus.

Red Earths

A characteristic of the Mediterranean climate, with which the red earths are associated, is a winter concentration of rainfall, with little or none during the summer. Besides the distribution factor, there is the quantity factor of rainfall. Over the large geographic area of the Mediterranean climate, the rainfall may vary from 40 to 20 inches and less per year. When it goes down to the 10 inch mark, the red soils of the semidesert assert themselves. It is natural that with the increase in rainfall the lateritic features become more pronounced. Simultaneously, the vegetation may change from a forest climate to savanna and steppe. These factors complicate the classification of the red earths.

The red soils in the Mediterranean region extend from southern Portugal, Spain and France through most of Italy, in parts of Greece, Jugoslavia, along the northwestern coast of Africa in the Mediterranean basin, in Asia Minor, Palestine, and Syria. In the region of the Mediterranean-like climate of our Pacific Coast such red soils are encountered.

In the more arid sections of the red earths, during the dry season, salts may rise by capillary movement and cause salinization (see next chapter). If Na salts prevail, the soil may become partly saturated with Na, giving rise to a high pH and dispersion of the soil, two chemical properties that are injurious to plant life. In many areas of the red earths, climatic conditions during the summer are conducive to such a rise of salts. In general, however, the red earths tend to be neutral or alkaline. As in any other soil zone, the sandy soils are less alkaline than the heavier types. Sandy soils in these regions can even be acid, unless the parent material is sandy lime marl.

At one time, it was thought that the *terra rossa* is specific for limestone parent material. Now, it has been definitely established that soils formed from any parent material, save those very low in Fe, or under anaerobic (reducing) conditions due to poor drainage, develop a distinctive red color. Data in table 13 illustrate clearly that either basalt or *limestone give rise to typical red earth. It is very probable that the red* earths are a remnant of an earlier more humid climate.

TABLE 13

Soils of Israel on limestone and basalt parent material
(After Reifenberg)

Constituents	Limestone profile		Basalt profile	
	Rock	Soil	Rock	Soil
	per cent	*per cent*	*per cent*	*per cent*
SiO_2	0.19	49.93	43.85	49.16
Al_2O_3	0.07	16.67	11.91	13.40
Fe_2O_3	0.24	10.35	6.43	11.34
FeO		1.05	7.44	3.41
Mn_3O_4		Tr	1.32	0.75
CaO	57.35	4.00	10.31	2.07
MgO	0.40	1.13	8.86	1.17
K_2O	Tr	0.78	1.76	0.98
Na_2O	Tr	0.68	4.41	1.67
P_2O_5	Tr	0.06	0.54	0.02
SO_3	Tr	0.12	Tr	0.09
CO_2	40.98	0.57	0.60	2.66
H_2O	0.15	16.20	1.23	13.31
N	—	0.06	—	0.09

In the red earths, well developed horizon differentiation appears to be the general rule. Very little descriptive material and analytical data are available. While on a visit to the Near East, the author observed many well developed profiles in the red earths of Greece, Syria, and Israel. In the sandy types of the red soils of Israel, hardpan, locally known as *nazzaz,* was observed. The predominant vegetation in the region of the red earths is forest, *mostly deciduous.* Savannas and grasslands are common in the more arid regions.

Red Loam

Soils of the humid subtropics which have a characteristic red color are known under this name. The term *loam* is a misnomer, since the red soils of the humid subtropics include other textural classes, such as sandy loams, loamy sands, and silt loams. The name has been retained to distinguish *red loam* from the *red earth* of the Mediterranean climate.

In the red loam region of the United States, south of Chesapeake Bay, and in the region of the Caucasus (where it is known under the name *krasnozem,* a Russian word for *red soil*), the forests consist of mixed and pure stands. The climatic elements differ sharply from those in the region of the red earths. Besides being humid instead of semiarid-arid, the climate is distinguished by a uniform distribution of the rainfall, with the summer rainfall somewhat higher than in any other season.

Due to the strong leaching effects and the dormant growing season, the laterization effects are not so strongly pronounced. There is a tendency for the intermediate products of decomposition, such as the organic acids, to persist. This superimposes the process of podzolization on the process of laterization. One can thus find in the analyses of the soils of the red loam regions, table 14, evidence of both of these processes.

Most of the red soils of the humid subtropics are slightly to strongly acid. Some soils are just as acid as those in the zone of podzols. As noted in the table, the quantity of bases is very small. There is not, however, the accumulation of sesquioxides one would expect, although there is a definite shift of silica from the upper horizons.

Morphologically, the profile of the soils of the southeastern United States has the following features: The A_0 is an inch or two thick, consisting of forest litter; the first few inches of the A horizon are red-gray to brownish-red-gray, merging into a pinkish to red layer of loose material, to a depth of 10 to 16 inches. The more compact red or brownish red B horizon is very distinct and extends to a depth of 16 to 24 inches or more. In many of the areas, the yellowish to light red color prevails in the A horizon of the profile. This region is, therefore, referred to sometimes as that of *red and yellow soils.*

Geographic Location. — Geographically, the lateritic red loams (the red and yellow soils) of the United States occupy an area of 466,100 square miles. These areas include also the red soils of the lower mountains and foothills of northern California and Western Oregon, which should be classified with the red earths, since the climate of this area is of the Mediterranean type. Representative soils of the Pacific northwest include the Aiken, Konokti, Sites, and associated series. They are the home for the highly specialized production of tree fruits, such as pears, apples, prunes, plums, and walnuts.

The typical red and yellow soils are represented by the following soil series: 'Baxter, Lebanon, and associated series in the southwestern part of the Ozark Mountains, in Missouri, Arkansas, and Oklahoma. Cecil, Appling, Durham, Davidson, Mecklenberg, Iredell, and associated series of the red-clay hill region of the South, in Virginia, Carolinas, Georgia, and Alabama. Caddo, Beauregard, Segno, Pheba, and associated series on the flatwoods of the Coastal Plain in Texas, Louisiana, and Arkansas. Clarksville and more Lebanon in central and southeastern Missouri, extending into northern Arkansas. Dickson, Baxter, and asso-

TABLE 14

Composition of lateritic soils
(From Marbut's *Soils of the United States*)

Iridell loam, North Carolina

Horizon	Depth	SiO_2	Fe_2O_3	Al_2O_3	TiO_2	MnO	CaO	MgO	K_2O	Na_2O	P_2O_5	SO_3	N
	inches	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*
A	0-5	63.3	12.5	9.3	1.29	0.36	3.11	4.75	0.13	0.31	0.04	0.05	0.04
B	5-25	45.8	10.9	24.7	0.61	0.12	1.97	3.96	0.11	1.16	Tr.	0.05	0.04
C	25+	44.3	10.3	19.3	0.39		7.62	12.2	0.20	0.64	Tr.	0.03	0.01

Davidson clay loam, North Carolina

A	0-9	70.5	6.1	12.5	1.8	0.22	0.75	0.45	0.58	0.72	0.00	0.24	0.11
B_1	9-36	52.7	10.6	22.9	1.4	0.07	0.51	0.40	0.45	0.00	0.10	0.12	0.02
B_2	36-60	50.5	14.9	23.1	1.5	0.08	0.27	0.58	0.45	0.00	0.12	0.12	0.01
C	60+	52.6	13.4	21.0	1.2	0.47	0.27	1.00	0.34	0.00	0.20	0.09	0.01

Note: The red loams show effects of podzolization. It is very likely that the parent material formed under conditions of a tropical climate that had prevailed for a period during the Post-Glacial epoch.

ciated series in Tennessee on the Highland River, extending in the north into Kentucky and south into northern Alabama. Decatur, Dewey, Colbert, Fullerton, and associated series in northeastern Tennessee, continuing southwest into Georgia and Alabama. Georgeville, Alamance, Herndon, Goldston, and associated series in the Slate Belt of the southern Piedmont, extending from eastern Georgia across South Carolina and North Carolina and into southern Virginia. Greenville, Magnolia, Blakely, Faceville, Orangeburg, Tifton, and associated series in the eastern Coastal Plain, southwestern Georgia, Florida, and Alabama. Hanceville, Conway, and associated series in west-central Arkansas, and eastern Oklahoma. Memphis, Grenada, and associated series in belts bordering the Mississippi River bottom lands. Maury, Hagerstown, and associated series in the central basin of Tennessee and the bluegrass section around Lexington, Kentucky. Norfolk, Blanton, Bladen, Hernando, Ruston, Cuthbert, Kirvin, Gainesville, and associated series in a belt of land along the Atlantic and Gulf Coastal Plain extending from Virginia all around the coast into the southwest corner of Oklahoma. The Norfolk and Blanton series of the lake region of Central Florida are the principal citrus fruit soils.

AGRICULTURAL FEATURES

Any discussion on the agricultural features of the soils in the zone of laterization must make a distinction between the genuine laterites and the lateritic soils.

Laterites. — The humid tropical climate with its high temperature and humidity is a greater deterrent to the development of the agricultural features of the land than some of the unfavorable conditions of the soils. In the heat and humidity of the tropics, one cannot hope to work as intensively as in the temperate zone. Agricultural pursuits that require constant vigilance and close attention, such as vegetable gardening, dairying, and poultry, are not suited for the tropics. This is one of the principal reasons why white settlers from the temperate climate have not been successful in colonizing the tropics.

Anyone visiting the humid tropics is impressed by the luxuriant vegetation. However, the difficulties involved in agriculture and the low efficiency of manpower do not encourage intensive specialized agriculture. For example, insects and diseases are more numerous and more virulent in the humid tropics than in any other part of the world. Local markets for the northern types of crops are limited. Exports of winter vegetables and fruits for the northern markets meet with transportation difficulties, packing and storage problems, tariff barriers, and quarantine regulations. Fertilizers are expensive in the tropics since very few areas are endowed with natural resources of raw materials for the manufacture of fertilizers, and they have to be imported.

The agriculture of the tropics is limited to crops which can not be grown elsewhere, such as bananas, pineapples, coffee, cocoa, rubber, agaves, (sisal is the most important member of this class of plants), and coconuts. Of course, other crops are raised, such as corn, millet, tobacco, some tubers, oil seed crops, cotton, hemp, and jute. In some regions, dairying is being developed; beef and other animal production, as well as poultry and other agricultural pursuits are in vogue, subject to the limitations mentioned above.

Most of the cultivated tropical trees and bushes are comparatively deep rooting. Whenever a heavy B horizon is encountered percolation is impeded, and internal swamping and poor aeration ensue, causing shallow rooting.

More difficult to ascertain and to remedy than the physical properties are the chemical properties of the laterites. From what has been said on the process of laterization, it is obvious that the high P content of laterites is due to Fe and Al. No sooner do the organic phosphates of the plant residues mineralize, than they are immobilized by the Fe, Al, and Mn and, therefore, rendered unavailable. This immobilization is frequently referred to as fixation. Some laterites and lateritic soils have been reported to have a fixation capacity for P amounting to, in terms of 20 per cent superphosphate, as much as 5 per cent of the total weight of the soil. This is equivalent to an application of 50 tons of 20 per cent acid phosphate per acre. The phenomenon of fixation explains why the laterites, in spite of a high total P content, respond so favorably to phosphates. Additions of dolomitic limestone tend to reduce the fixation power of laterites for P. The Ca and Mg ions, by virtue of mass concentration effect and increased pH, prevent the locking up of P by the Fe and Al which become more insoluble with an increase in pH.

The low adsorption capacity of laterites for Ca, Mg, and K calls for the addition of these elements. The rapid mineralization of the organic matter and the thorough percolation resulting from the high rainfall cause a deficiency of many other mineral nutrients. Because of these adverse conditions, large quantities of mineral fertilizers are required in tropical agriculture.

It is claimed by students of tropical agriculture that the stand and type of vegetation (ecology) is no index of soil fertility. This is in contrast to the prevailing opinion on the relation of ecology to soil fertility in the regions of the temperate climate. In the early colonization of Pennsylvania, for instance, settlers followed the rollings lands which supported good stands of oaks. In the same vein, a good stand of some legumes i a reliable ecologic index of the fertility of land in the temperate regions

Lateritic Soils. — The red earths and the red and yellow soils (re loams) extend from regions free from frost, with or without cool winte periods, to regions where temperatures fall to a few degrees below 32°F with or without a definite winter season. This wide temperature rang adapts these regions to a great variety of cultivated crops, a greater variet often than is possible in podzol or podzolic soils. Except for the area adjoining the tropics, most of the subtropics may grow, with few exceptions, the cereals, many of the industrial oil seed and fiber crops (such a peanuts, sesame, and cotton), practically all varieties of vegetables, an most fruits, including small fruits, that grow in the temperate zone.

In many areas of the Mediterranean red earths, summer crops ca not be grown without irrigation. In the more arid sections, the soils o some areas may suffer from salinization whenever the water table is hig Such soils, however, do not belong strictly to the climatogenic groups an their genesis and management are discussed in the following chapter.

Red and yellow soils, such as those of the South Atlantic States, ar heavily leached. They require lime, and respond to heavy fertilizatio In no region of the country, except perhaps in the specialized truck sections in the zone of podzolization, is fertilizer used in such large quantitie as in the regions of the humid subtropics of the United States.

Because of the heavy rainfall, the soils of humid subtropics are subject to erosion. To protect these soils during the winter they must b cover cropped, a measure which serves, incidentally, to prevent excessiv leaching of residual fertilizer.

Dark Colored Soils in Tropics and Subtropics

In some sections of the tropics and subtropics we find dark brown t black soils. Notable among these are 200,000 square miles of the *blac cotton soils* of India known locally under the name *regur,* and large area in Morocco under the local name *tirs.* Similar dark colored soils hav been examined by the author in Algeria and Israel. Regur-like soils hav also been reported in Australia and South Africa. These soils are generally very productive.

At one time, the regur of India was considered a type closely relate to chernozem. Indeed, the color, the somewhat granular structure, an the presence of limestone in the profile of regur bear a great resemblanc to chernozem. However, analyses of tropical black soils reveal a low organic matter content, seldom exceeding the 1-1.5 per cent mark.

By now it has been established that the dark colored soils of th tropics and subtropics are a remnant of an earlier waterlogged state. A that time, organic matter accumulated because of anaerobic conditions. With the gradual improvement of the natural drainage, the bulk of the organic matter had disappeared by biological and chemical oxidation. The residual organic matter seems to be of the humin and bitumen types, not easily decomposed and intensely dark in color. It takes little of the bitumens to color the ground mass black. It is of interest to note that at higher elevations in the areas of the dark colored soils, the normal red laterites and lateritic soils prevail.

PEDOCALS AND PEDALFERS

Curtis F. Marbut, late chief of the Division of Soil Survey, U. S. Department of Agriculture, and international authority in pedology, distinguished two major soil groups: *pedocals* and *pedalfers.*

Pedocals are soils which, as a result of the soil forming processes, have an accumulation of calcium carbonate in some horizon of the soil profile. The following climatogenic soil zones belong to this group: gray, brown and chestnut brown, and chernozem. These soils accumulate calcium carbonate in the B horizon, and sometimes in the lower portion of the A horizon. The prairie soils are the line of demarcation between the pedocals and pedalfers, since some do and others do not have $CaCO_3$ accumulation in the B horizon.

Pedalfers are soils which have an accumulation of Fe and Al at some point in the profile. There is no lime accumulation in these soils. To this major soil group belong the other climatogenic soil zones: podzols, tundra, and laterites. Podzols accumulate Fe and Al only in the B horizon; laterites show accumulation of these elements in both the A and B horizons. The tundra soils accumulate Fe and Al in the B horizon, but much less than the podzols.

The chief characteristics of the two major soil groups, pedocals and pedalfers, may be recognized in the spelling: *Pedo-Ca-ls,* soils having Ca accumulation in the profile; *Ped-Al-Fe-rs,* soils in which a shifting of Al and Fe take place.

APPENDIX

ELEMENTS OF CLIMATE

Climate represents the repetitious pattern of average meterologic conditions in any given region. *Meterology* is the science of the atmosphere and its phenomena. Atmospheric conditions, as they prevail at any given time, are referred to as *weather.* In dealing with climate, we must consider its two principal elements: *temperature* and *precipitation.*

Temperature

Temperature is the term used to express the intensity or degree of heat. Generally speaking, the temperature of the air is at a maximum at the equator and decreases gradually with the latitude toward the polar region. This distribution of temperature is determined by solar radiation, i.e., heating of the earth by direct radiation of the sun, known as insolation. The more nearly perpendicular the sun's rays, the greater the insolation. At the equator, the sun is near the zenith most of the year and in the zenith at the times of the equinoxes. Within the polar zones, the sun is below the horizon for at least 24 consecutive hours in winter and above for at least 24 hours in the summer. These differences in the elevation of the sun determine the insolation. There are, however, other factors which have an effect on the temperature.

As a consequence of the higher specific heat[1] of water, equal insolation causes a smaller rise in the temperature of water than of land. The converse is also true: water masses tend to cool off less rapidly than land masses. In the final analysis, more heat units are concentrated in a volume of water than in an equal volume of land. Bodies of water, therefore, retain a relatively more constant temperature than land areas. It is a commonly observed phenomenon that large bodies of water, because of their heat retentive power, exert a moderating effect on the temperature of contiguous land masses, especially during the winter months.

In recording the distribution of temperature, lines known as ***isothermal lines*** are drawn through points of equal temperatures as plotted on a geographic map, On maps of extensive areas with great differences in altitude, the mean temperatures are first reduced to sea level by using temperature drops of 2.75°F for each 1000 feet of drop in elevation. Changes in altitude lead to changes in temperature irrespectve of latitude. At higher altitudes insolation results in less heating because more heat is lost hy radiation through rarified atmosphere.

Ocean currents influence the temperature of continents. Equatorial heat is transferred poleward, causing the isotherms to bend northward. The effect of the Gulf Stream is a case in point. The warm current in the Pacific from Japan to Alaska is another example. On the other hand, polar cold is transferred equatorward. Cold ocean currents flow toward the west coasts of South America and Africa, bending the isotherms equatorward. Air currents also move large amounts of heat across latitudinal lines and modify the temperature.

Zones or Belts of Temperature

The earth is divided into temperature zones or belts according to the geographic position of the isotherms and not according to the parallels of latitude, as expounded by the classic system of solar climate classification. Isotherm positions are determined not only by latitude but also by altitude and other geomorphological features, direction of prevailing winds, Gulf Stream effects, and similar natural phenomena.

Hot Belt.—The geographic area inclosed by the mean annaul isotherm of 68°F., specifically the tropics and subtropics, is included in this belt. Its poleward boundaries represent the limit of the growth of palms.

Cold Caps.—The geographic area around the poles inclosed by the isotherm 50°F. for the warmest month includes this belt. This isotherm represents the limit of the growth of cereals and forest trees.

Temperate Belts.—The area between the hot belt and the cold caps represents the two temperate belts. The temperate belt of the northern hemisphere extends north of the arctic circle in Alaska and in Eurasia. In the southern hemisphere, the temperate belt reaches no farther south than latitude 55°.

The distribution of climatogenic soils and the geographic divisions of temperature zones exhibits a certain parallelism. This parallelism becomes complete when the distribution of precipitation is taken into consideration.

Precipitation

Precipitation includes any type of water that reaches the surface of the earth: rain, snow, sleet, hail, and dew. Of these, rain and snow are the chief sources of

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[1] The specific heat of a substance is the number of heat units (calories) required to heat one gram of the substance through 1°C. Water at 15°C has a heat capacity of 1.0. Thus, to say that the sp. heat of lead is 0.0314 means that 0.0314 calorie of heat is required to heat one gram of lead through 1°C; this quantity of heat would raise the temperature of 1 gm. of water through 0.0314°C.

ioisture supply and the most important from the standpoint of soil formation and op production.

Since soil profile characteristics depend on translocation and distribution of conituents, it is rainfall that assumes key significance in the processes of soil formaon. Nevertheless, snow is just as important a factor in soil formation in areas of ild winters. There, the moisture of the thawing snow may penetrate the soil prole. In areas of severe winters, most of the snow sublimes during the winter and the st runs off during spring thaws.

Under some circumstances, as in the semiarid and arid regions, dew and other ypes of moisture condensation, such as vapor moving from a warmer atmosphere nto the cooler soil air, may play an important part in augmenting the moisture sources of the soil.

The amonut of precipitation is measured in inches or millimeters. The standard ain-gauge used in recording precipitation is a cylinder which drains through a funel into a lower-placed cylinder with a cross-section area one tenth as large as the pper one. Thus, the lower cylinder registers one inch for every one tenth inch of ainfall. An inch of rain over an acre of land weighs about 113 tons.[2] The quanty of precipitation varies from an average of more than 40 feet per year to almost ero. In some years, Cherrapunji, India, receives more than 600 inches of rainll, while at the same time the desert of Atacama, South America, is rainless.

General Distribution of Precipitation.—As with temperature, precipitation is ighest in equatorial regions and shows an irregular tendency to decrease towards the oles. Since the chief source of supply of the moisture-laden air masses comes from he oceans, rainfall decreases toward the interior of continents. Ocean currents inuence distribution of rainfall, warm currents increasing it (as on the eastern coasts f the American continent) and cold currents decreasing it (typified by the west oasts of South America and of Africa). Mountains serve as wind barriers and revent air masses from climbing across them, causing deposition of moisture on nly one side of the mountain. Examples of these are the western slopes of the Sierras nd Cascades which are wet, whereas the eastern slopes are dry. Rainfall also is elated to the general wind systems and direction of wind.

On the basis of precipitation, land areas of the earth are divided as follows: (1) rid, from 0 to 10 inches; (2) semiarid, 10 to 20 inches; (3) subhumid, 20 to 40 nches; (4) humid, 40 to 80 inches; (5) wet, more than 80 inches per year.

Seasonal Variations.—In some areas of the equatorial regions, rainfall is heavy hroughout the year. In other areas of the tropics, there are alternate wet and dry easons. In the middle latitudes, the west coasts of continents have a winter conentration of precipitation and dry summers. In the interiors, there is a marked ummer maximum, largely of the thunderstorm type. On eastern coasts, there is fairly even distribution through the year.

PRECIPITATION IN THE UNITED STATES

There are five types of precipitation in the United States: Pacific, sub-Pacific, rizona, Plains, and Eastern.

Pacific Type.—Pacific coast states from Sierra Nevada and Cascade range, westard to the Pacific have winter concentration of precipitation, with dry summers. Vestern Washington, Oregon, and California get 40 to 60% (the further south, the igher is the winter concentration) of the total precipitation during December—ebruary. The spring (March-May) precipitation is one-half of the winter preipitation. The summer is practically rainless in California, except in the northern art where some rains occur in June. The summer precipitation in California is qual to 1% of the total and in Puget Sound to a maximum of 10%. The total preipitation varies from 10-15" in the south to 40-60" in the north. Dry farming and rrigation are characteristic of the region, especially in the south.

Sub-Pacific.—Eastern Washington and Oregon, Idaho, Nevada, and Utah have

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[2] The calculation is made as follows: $62.4 \times 43560 \times {}^1/_{12} = 113.26$ tons, where 2.4 = pounds of water per cubic foot; 43560 = square feet per acre; and $^1/_{12}$ = ne inch.

no winter precipitation concentration. The total precipitation is 15-20″. In general, the precipitation is fairly uniformly distributed, except during the summer when it is scant. Dry farming and irrigation are characteristic of the region.

Arizona Type.—Extreme Western Texas, New Mexico, Arizona, and portions of southern Utah and Nevada possess this type of precipitation. The characteristic feature of this type of precipitation distribution is the heavy rainfall during July and August, when about 35% of the annual precipitation occurs. April, May, June are the months of least rainfall. During the other months, the precipitation is distributed quite uniformly. The summer rains are primarily in the form of thunder showers during the warmer part of the day. Since the total precipitation is from 5-15″, irrigation farming must be employed.

Plains Type.—From the Rockies eastward to the Great Lakes and middle Mississippi river region and thence southward to Missouri and Oklahoma, the seasonal distribution of precipitation is as follows: winter—less than 10%, spring—25 to 30%, summer—40 to 50%, fall—15 to 20%. The precipitation occurs more frequently at night. In portions of Montana and over small areas in the Dakotas and Eastern Colorado, the total precipitation for the winter is less than one inch. Total precipitation is from 10 to 20″, in the western, and 20 to 40″ in the eastern section. This is the area of wheat and corn belt.

Eastern Type.—East of the Plains type to the Atlantic Coast, there is uniform distribution of precipitation (somewhat lighter in fall). Most precipitation (75%) occurs during the daytime. With total precipitation from 20 to 50″, this area is one of diversified farming.

The Florida rainfall and distribution is somewhat dfferent from the eastern type. The months of November to May are fairly dry, 2 to 3″ per month. The precipitation is heavy during the other 5 months, July, August and September being especially wet, and the total precipitation (state average) varies from 40 to 60 inches. Tropical disturbances greatly affect the precipitation.

Snowfall.—Snowfall is most abundant in the west side of the Sierra Nevada and Cascade ranges with 400 to 500″ annually (5 to 15″ of snow are equal to 1″ of rain). As much as 697″ per year has been reported and as much as 300 inches in one month. In the Rockies, the snowfall is not so heavy being 200 to 300″. East of the Rockies, the snowfall is lower. In the Plains region, one finds in central Texas 1″ and in north Kansas 20 to 30″. Heavy snowfall occurs in the Upper Peninsula of Michigan, about 120″; in the Adirondacks, 50″; in New Jersey, 25″.

CHAPTER IX

CLIMATOGENICALLY SUBDUED SOIL TYPES

Within the borders of the climatogenic soil types we encounter soils hat are not true to type. Other factors or conditions subordinate the ffects of the climate, and either a new soil type is formed, such as the ydrogenic and lithogenic soils (see below), or one that is outside of its atural geographic habitat. Thus, podzols may be encountered in the hernozem zone, chernozems in the brown and chestnut zones, gray-brown odzolic in the chernozem, etc. It is obvious that the new soil types or he geographically displaced zonal soil types are not the result of a climatogenic process of soil formation. These soils have, therefore, been amed *climatogenically subdued soil types.* These soils have also been esignated as *intrazonal* soils, since some of them have been encountered mong one or more of the zonal (climatogenic) soil types.

Four factors—moisture, topography, parent material, and river flood lains—are responsible for displacing the climate from its role as the chief gent of soil formation and for imparting to these soil types specific profile haracteristics. These soil types are known as: *hydrogenic* (moisture), *rogenic* (topography), *lithogenic* (parent material), and *fluviogenic* (river lood plains).

HYDROGENIC SOILS

These soils are the most widespread and extensive climatogenically ubdued new types. The specific condition responsible for their formation s, as the name implies, moisture. Hydrogenic soils are subdivided into *aline* and *peat* or *muck* lands.

Saline Soils. — Sometimes, because of insufficient precipitation, the alts of the ground waters rising by capillary action are not returned to he ground waters. The soluble salts accumulate on the surface of the oil or at any point in the profile. Such soils are generally located in the rid and semiarid regions in depressions and in areas of level topography long stream beds and river deltas. They are not, however, excluded from egions of rolling topography or even from mountains where local deression areas may occur. Under these conditions, salts of the ground aters are augmented with those moving by seepage from the surrounding igher elevations.

Soluble salts are also common in soils on old lake beds, like those of he Great Basin in the United States. There, the ancient lake Bonneville was reduced in area by evaporation to the present level of the Great Salt Lake, leaving behind large salt accumulations. Similar soil basins containing salts are found around the Caspian Sea in Russia, Turkestan, and other parts of the world.

The process of accumulation of salts in soils is known as *salinization*, and the soils thus formed are designated as *solonchak*, a name derived from the Russian word sol', meaning salt.

Whenever more water becomes available for percolation (by a change in climate), or the supply of salts from the water table diminishes, or the water table drops to deeper levels, the soil begins to lose salts. A process of ***desalinization*** ensues, whereby the bulk of the soluble salts in solonchak disappears and other salts take their place. Among the latter, the very active Na_2CO_3 is most prominent. A series of morphological, physical, and chemical changes in the profile take place because of the desalinization, and a new soil type, known as *solonetz,* makes its appearance.

If the desalinization process is carried further, to a point where the solonchak and solonetz lose their salts from the A and also partly or completely from the B horizons, the soil profile undergoes still greater changes. It loses the alkalinity which is typical of solonchak and solonetz and attains new properties, as described presently. The soil resulting from this process is known as *solodi,* the name having originated among the Russian peasants.

Saline soils is the group name for the soils that are subjected to the reactions of salinization and desalinization, giving rise to solonchak, solonetz, solodi, and subtypes and varieties of these.

Solonchak

During the dry season, the soluble salts of solonchak on the soil surface show efflorescence, a kind of a powdery crystalline salt layer. American investigators have named these *white alkali* soils, because of the white efflorescence. This name, however, is not as inclusive as solonchak, since it restricts the salinity to alkalies only and excludes the Na_2CO_3. As a matter of fact, there are some saline soils which contain besides the sulflates and chlorides of Na, which usually predominate, also Na_2CO_3, $MgCl_2$, $CaCl_2$, $MgSO_4$, and $CaSO_4$. The caustic Na_2CO_3 and in some degree $MgCl_2$ dissolve organic matter which permeates the surface soil with its dark brown to black color. Soils subjected to the effects of Na_2CO_3 have, therefore, been named ***black alkali*** soils.

Solonchak is most widespread in the gray soil zone. In some sections of this zone, the area of solonchak is larger than that of the normal gray or red semidesert soils. Because of this situation, pedologists have at one time considered the saline soils as the zonal type of the semidesert climate.

However, when the true nature of the processes of salinization and desalinization was discovered and the three standard types of saline soils—solonchak, solonetz, and solodi—were found scattered among other soil zones, they were classified as *intrazonal*.

As we leave the gray soil zone and enter the brown, then the chestnut brown, and finally the chernozem soil zones, solonchak becomes less prevalent. Increase in rainfall and decrease in evaporation bring about an accelerated leaching of salts. Still, even in the podzol zone, where leaching of salts is usually in excess of their upward movement, saline soils may be encountered. Indeed, solonchak has been found in Finland and in eastern Siberia as far north as the 62° latitude. Saline soils have been reported in the tundra zone, in areas where the thawing water contained large quantities of soluble salts. Any region may thus be subjected to salinization, if the concentration of salts in the ground waters is sufficiently high to cause an accumulation of soluble salts in the profile sometimes during the calendar year.

General Types of Solonchak. — In the semidesert region, we find soils with very little profile development. In these, the upward movement of salts is greater than the percolation effects of the scant rainfall. We also find, as pointed out, areas of old lake bottoms where salts had accumulated as a result of evaporation. These would-be soils are known as *primary solonchak*. Their characteristic features are a low organic matter content and no horizon differentiation.

A rising water table may bring about salinization of the profiles of any zonal soil. The salinization process is thus superimposed on the normal profile of the zonal types, and the soils are known as *secondary solonchak*. We can, therefore, have brown solonchak, chestnut-brown solonchak chernozem solonchak, laterite and lateritic solonchak, podzol solonchak, and tundra solonchak. In other words, these soils, in addition to maintaining most of their zonal features, acquire characteristics due to salinization.

Salts do not necessarily rise to the surface of the soil; they sometimes accumulate at the level reached by the capillary waters in the soil profile or subsoil. This level may be many feet below the surface, out of reach of the percolating effects of the natural precipitation. The salts are then neither washed out nor can they come to the surface of the soil. Such salinized soils are known as *hidden or disguised solonchak*.

Types of Solonchak Based on Salts Present. — The type of solonchak is often designated by the prevailing salts. The most prevalent type is the *chloride-sulfate Na solonchak*. Small quantities of salts of Mg, Ca, and K usually accompany this type of solonchak. Here and there, a *carbonate-*

chloride Na solonchak is found. As a rule, this type of solonchak is accompanied by appreciable quantities of sulfates.

There is also a *nitrate solonchak* in which 25 per cent and more of the total soluble salts are nitrates, associated with sulfates and chlorides of Na, Ca, Mg, and K. The nitrates seem to accumulate by seepage from the higher elevations where nitrification is intense.

In the early stages of solonchak formation, the chloride-nitrate type prevails. Within its area, a borate-nitrate-chloride subtype is infrequently found. The latter, as a rule, makes its appearance in regions where volcanic disturbances took place.

With age, solonchak gains sulfates, and the chloride-sulfate solonchak appears. The relatively insoluble gypsum accumulates and the chloride content decreases. This phenomenon is an indication of the initial stages of desalinization.

Salt Concentration. — At the height of the dry season, the maximum concentration of soluble salts in solonchak is at the surface. At the end of the rainy season, the highest concentration of salts is at the level in the profile reached by the percolating waters. In reporting salt concentrations at various depths in the soil, dry season conditions are taken as the reference point.

Desert pavement may be considered a bad case of solonchak, if the theory discussed in Ch. VIII is accepted, namely, that pavement is the result of ascending salts, it may have as much as 60 per cent soluble salts. Such salt concentrations were found in the semidesert regions of Turkestan in the beds of ponds produced by river flood waters, after the ponds had dried up. The first inch of soil in one of these pond-solonchak contained as much as 23 per cent soluble salts. At a depth of 20 inches, the salt concentration was about 0.5 per cent. The ground waters analyzed 0.12 grams of salt per liter, or 0.012 per cent.

A water extract of a nitrate solonchak in an old river bed in Central Asia showed 20 per cent soluble salts in the desert pavement, 7.5 per cent in the first two inches, and 2.3 per cent at 48 inches below the surface. The ground waters analyzed 14.3 grams of soluble salts per liter, or 1.43 per cent.

Some of the solonchak soils of Southern California, Arizona, Nevada, Utah, and Colorado contain as much as 10 per cent soluble salts in the surface inch or two, decreasing gradually to less than 1.0 per cent.

The concentration of salts in solonchak is never the same. In some regions, the salts are in a fluffy condition and are frequently blown away by winds. Heavy downpours, which are not uncommon in the arid regions, also carry away some salts by surface runoff. The concentration of salts in the ground waters also affects the final concentration of salts in the solonchak.

Measuring Salt Concentration. — Water soluble salt content of soils is an important index of the nutrient status of soils. In saline soils, the concentration of osmotically active salts reaches proportions which make these soils unsuitable for crop production.

The most direct quantitative method of determining soluble salts is to extract the soil with water in 1:5 ratio. The mixture is shaken for 30 minutes, filtered, an aliquot evaporated, the residue dried at 105°C, weighed, ignited (to destroy organic matter), and weighed again. The residue after ignition represents the water soluble salts.

To determine the relative concentrations of salts, the conductivity method is used. Electrical conductivity, specific conductance, or conductivity are the terms used in representing the reciprocal of the specific electrical resistance of a conductor, in this case of a solution. The *specific resistance,* defined as the resistance in ohms of a cube 1 cm. long and 1 sq. cm. in cross-section, is determined by means of the Kohlrausch conductivity apparatus. *Specific conductance,* recorded as reciprocal ohms (*mhos*) usually at 25°C, is numerically represented by some number times 10^{-5}. Normal, non-saline well fertilized loam to sandy loam soils have a reading (designated by some by the symbol Ks) of 20 to 50; that is 20×10^{-5} or 50×10^{-5} mhos. Loamy sand and sandy soils, when fertilized, may have a reading of 15 to 30. Values as high as 100 may not be injurious to plant growth in heavy soils or mucks if the salts are a mixture of different compounds.

Irrigation water with a reading of 200 or even 300 is still safe, as long as the salts are not exclusively Na compounds. Of course, the lower the reading of the irrigation water, the better it is (see also Ch. XIV).

For conductivity determinations, saline soils and non-saline mucks are extracted with a 1:5 ratio of soil to water. For heavily fertilized non-saline soils, ratios of 1:3 for heavy soils and 1:2 for light soils are used.

RECLAMATION OF SOLONCHAK

Solonchak may be reclaimed to normal productivity by washing out the soluble salts and removing the leachings from the profile by drainage. Thus, the crux of the problem of ameliorating saline soils is a source of good water and a well planned tile drain system.

In laying out a drainage system for solonchak, the guiding principle is to place the tile at or below the *critical level* of the ground waters, i.e., at a depth of the water table which will not allow the capillary rise of water to reach the rhizosphere or the soil surface. As long as the water table can be kept at this level, there can be no repetition of salinization.

From the data in table 15, it is clear that it took two years to remove the salts to the critical depth in the profile, and to reduce their concentration sufficiently to make possible normal crop production. It is to be noted that proper drainage removed the salts from the upper four feet of soil, thus allowing enough room for normal root development.

TABLE 15

The dynamics of salt removal from soil near Salt Lake City, Utah, by drainage; per cent of salt in soil

(After Harris)

Depth in feet	Sept. 1902	May 1903	Oct. 1903	Oct. 1904
1	1.7038	0.6238	0.1263	0.0475
2	1.9250	0.6125	0.2283	0.1600
3	2.2075	1.3325	0.4125	0.2650
4	2.4775	1.5813	0.7608	0.6250
Total	8.3138	4.3510	1.5284	1.0975
Average	2.0785	1.0875	0.3821	0.2744

Leaching of excessive salts from saline soils, or from soils under irrigation that tend to become salinized, should be carried out preferably in winter. First of all, there is less evaporation during the winter. Secondly, in many regions of saline soils winter is the rainy season, and the rainwater may be put to work in washing out the salts.

As a rule, the early rains barely moisten the soil that has dried to great depths during the rainless summers. As a matter of fact, these rains are not only wasted, but the shallow penetration of the water may even bring to the surface more salts. If it were possible to irrigate such areas prior to the arrival of the rains, the rainwater would flush the soils beyond the depth of penetration of the irrigation waters. The higher the rainfall, the more efficient can be the partnership between the rainwater and irrigation waters in the removal of the salts deep into the subsoil, out of the reach of the rhizosphere, or complete removal through a drainage system.

Plowing the soil before the rains come and keeping it in the rough (and, if necessary, an application of gypsum should be made to facilitate percolation) expedite the penetration of the rainwater which, in turn, leaches the salts deeper, either to the ground waters or to a drainage system.

Under some special conditions, such as in orchards or citrus groves, the loss of water by evaporation may be reduced by keeping a soil mulch which, if properly maintained, goes a long way towards saving moisture.

An alfalfa sod is an efficient expedient in keeping the salts at the critical level, since the deep rooting alfalfa with its high transpiration ratio is capable of intercepting the rising waters. It is to be remembered that alfalfa has a fairly high tolerance for salt. By itself, alfalfa will not desalinize a soil. For best results, irrigation and leaching have to be resorted to.

It may be of interest to note that alfalfa, grown on a soil with a high salt content, gives a low yield and does not produce much seed.

In table 16, the results of leaching a California saline soil are given. After the salt content had been reduced, alfalfa was planted in that soil. Yields of 11,217 pounds for the first year and 12,523 pounds for the second year were obtained.

TABLE 16

Soluble salts in a California solonchak, milliequivalents per 100 grams of soil

(After Shaw and Keller)

Depth in cm.	CO_3	HCO_3	Cl	SO_4	Ca	Mg	K	Na
				Before leaching				
0-12	0	0.35	80.2	11.7	26.0	14.0	2.4	50.8
12-24	0	0.40	20.8	4.1	4.7	4.3	1.6	14.7
24-26	0	0.32	11.7	3.2	2.8	2.1	1.3	9.0
36-48	0	0.42	8.4	3.4	1.8	1.9	1.0	7.5
				After leaching				
0-12	0	0.52	0.50	1.6	0.7	0.5	0.6	0.8
12-24	0	0.50	0.74	2.4	0.5	0.4	0.6	2.1
24-36	0.1	0.60	0.60	2.0	0.2	0.7	0.5	1.9
36-48	0.1	0.72	0.90	3.5	0.2	0.5	0.5	4.0

Large areas of solonchak have been reclaimed by irrigation and drainage in every part of the world. In the United States, the reclaimed area amounted to 1.5 million acres in 1920 and more than 3.5 million acres in 1930.

Solonetz

The salts of solonchak are removed in the process of desalinization totally or in part by natural forces in the following ways:

1. If the level of the water table drops, the scant rainfall usually prevailing in the regions of saline soils is often sufficient to leach and remove the salts.

2. Whenever a change in climate takes place towards a higher rainfall the salts may be removed.

Salts may be removed artificially by irrigation and drainage, as described in the section on *The Reclamation of Solonchak.*

In short, whenever the leaching effects are sufficient to keep the salts from coming back to the surface, the process of desalinization begins and it exerts far reaching influences on the morphology, chemical composition, physical makeup, and biological characteristics of the soil profile.

Formation of Solonetz. — The desalinization process consists of leaching the soil with a salt solution, primarily NaCl and Na_2SO_4, of a concentration prevailing in the solonchak. The result is that the bulk of the Ca, Mg, and K adsorbed by the colloids of the A horizon are exchanged by Na.[1]

When the soluble Na-salts are removed from the A horizon, some of the adsorbed Na ions are replaced by the available bases in solution and by the relatively few H ions resulting from the ionization of water. The Na ions combine with the OH ions of the water to form NaOH which in turn picks up CO_2 to form Na_2CO_3.

The replacement reactions described may be schematically presented in the following manner:

$$1.\ \left.\begin{array}{l}2\ Ca\\ 2\ Mg\\ 3\ K\end{array}\right\}\text{soil} + 5\ NaCl + 3\ Na_2SO_4 \longrightarrow \begin{array}{l}CaCl_2 + MgCl_2 + KCl +\\ CaSO_4 + MgSO_4 + K_2SO_4 + 11\ \text{Na-soil.}\end{array}$$

$$2.\ \text{Na-soil} + HOH \longrightarrow NaOH + \text{H-soil}$$

$$3.\ 2\ NaOH + CO_2 \longrightarrow Na_2CO_3 + H_2O$$

When the soluble salts are washed out from the A horizon and the exchange complex becomes impregnated with Na ions, the soil is known as *solonetz.*[2]

Because of the presence of Na_2CO_3, the solonetz is highly alkaline the pH may be as high as 10 and more, both in the A and B horizons.

As a result of the adsorbed Na, the clay and humus of the A horizon become highly dispersed. In this finely divided condition these colloidal materials are readily attacked by the free Na_2CO_3. The principal decomposition products are sodium aluminate, silica gel, and sodium silicate, a portion of which is eluviated from the A horizon.

As the products just described reach the B horizon, they meet the salts previously washed out from the A horizon (as shown in the equation under 1), giving rise to a number of possible reactions, as shown in the following equations:

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[1] For a discussion of the reactions of exchange of bases the reader is referred to the section on *Ion Exchange* (Ch. VIII).

[2] In nature, the reactions shown in the equation do not go as far as exchanging al the cations with Na. If 10 to 15 per cent of the bases are replaced by Na, the soi is said to be of solonetz nature. Solonetz is known to contain as much as 40 and 6 per cent Na.

1. $CaSO_4 + Na_2CO_3 \longrightarrow CaCO_3 + Na_2SO_4$
2. $2\ Na_2SiO_3 + MgCl_2 + CaCl_2 \longrightarrow MgSiO_3 + CaSiO_3 + 4\ NaCl$
3. $Na_2SiO_3 + 2\ H_2O \longrightarrow NaOH + H_2SiO_3$
4. $H_2SiO_3 \longrightarrow H_2O + SiO_2$

Since $MgSiO_3$ is less soluble than $CaSiO_3$, more Mg accumulates in the B horizon. The silica gel which splits off from the Na_2SiO_3 and from the decomposition of the clay may serve as a cementing agent in the B horizon, leading to concretions or to hardpan formations. These are, however, the exception to the rule. Generally, the B horizon of solonetz is merely very compact. When dry, this horizon can hardly be penetrated even with a crowbar.

A characteristic feature of the B horizon of most solonetz soils is the columnar structure, with rounded edges on the surface of the columns. A prismatic structure is also common.

The following is the profile description of a typical solonetz:

A_0: Very little vegetation, because of the high alkalinity, precludes the accumulation of organic matter; hence the A_0 is feebly developed.

A: The depth of this horizon depends on the stage of desalinization and deterioration of the clay fraction, and varies from 1 to 12 (or more) inches. If not deteriorated too far and blown away, the material is usually stratified, laminated structure, and very porous. The color is gray or yellowish gray.

The lower portion of the A horizon, which may be considered as the A_2, is lighter gray, more compact, resembling the ash-gray material of a podzol. If free Na_2CO_3 is present, black streaks (dissolved humus and other organic materials) appear in the gray mass; in columnar solonetz the A_1 is black.

The Ap layer of solonetz is often underlain by a plow sole. If not disturbed for several years (by changing the depth of plowing), this plow sole may attain the characteristics of hardpan.

B: In the prismatic solonetz, as the name implies, the material breaks into prisms, 4 to 6 inches high and 1 to 3 inches wide, with flat surfaces. These prisms are compact and are separated from the overlying A horizon and underlying C horizon. The latter contains appreciable quantities of $CaCO_3$ and infrequently some soluble salts.

The tops of the columns in columnar solonetz are rounded, and the bottoms are flat. The columns are from 3 to 5 inches high and 1.5 to 2 inches thick, brown to chestnut brown in color, often with shiny lacquer-like coated surfaces. When dry, cracks develop between the columns. These cracks become filled with material from the A_2 horizon. The transition between the A and B is very sharp, as shown in plate 8. Solonetz

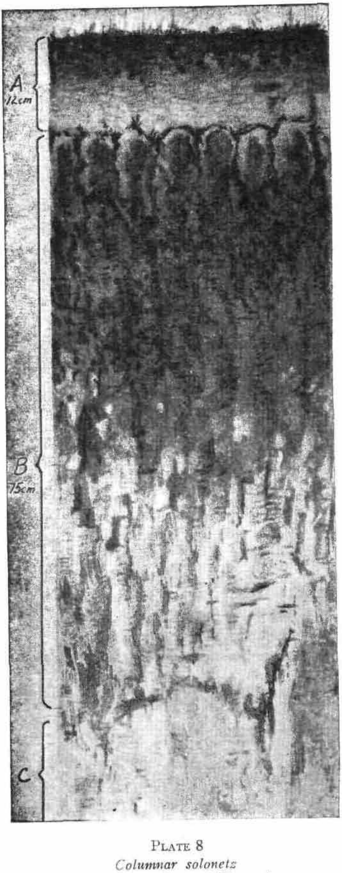

PLATE 8
Columnar solonetz
(After Kassatkin and Krasyuk)

soils high in Na have columns 4 to 6 inches deep, dark in color, permeated with streaks of $CaCO_3$. Most columnar solonetz contain soluble salts.

Solonetz Among Zonal Soils. — Since the formation of solonetz, under natural conditions, is associated with an increase in precipitation, the following relationships between the distribution of solonetz and the zonal soils prevail. More solonchak and less solonetz are found in the zone of the gray semidesert soils where precipitation is lowest. As we enter the zones of brown and chestnut brown soils, where precipitation increases progressively, the area of solonchak decreases and that of solonetz increases. The highest development of solonetz is to be found in the chestnut brown and adjoining stretches of chernozem soils. In the solonetzic state, these soils become highly dispersed and, therefore, most vulnerable to blowing. It is among these soils that the ravages of dust storms are most serious.

In the chernozem zone proper, because of increased precipitation, the area of solonchak is at a minimum; this, in turn, keeps down the area of solonetz. Here, the last stage of the saline process of soil formation, the solodi, is encountered.

RECLAMATION OF SOLONETZ

To reclaim solonetz, two things have to be accomplished: 1. Coagulate the dispersed colloids, thereby restoring the structure of the soil and allowing moisture and air to penetrate and circulate. 2. Reduce the alkalinity, i.e., lower the usually prevailing high pH (above 8.2).

Gypsum Treatment. — Gypsum is the most effective chemical agent for the reclamation of solonetz. When added to a soil containing both the free Na_2CO_3 and adsorbed Na, it reacts as follows:

$$CaSO_4 \cdot 2H_2O + Na_2CO_3 \longrightarrow CaCO_3 + Na_2SO_4 + 2H_2O.$$

$$2\text{Na-soil} + CaSO_4 \cdot 2H_2O \longrightarrow \text{Ca-soil} + Na_2SO_4 + 2H_2O.$$

Both the gypsum and the Na_2SO_4 coagulate the colloids. Some of the $CaCO_3$ is converted into calcium bicarbonate. The Ca-ions of the bicarbonate and of the gypsum replace the undesirable Na ions in the colloid fraction. As a result of the replacement of the Na, the colloids aggregate and improve the structure of the soil. As the Na_2CO_3 is taken out of circulation, the alkalinity of the soil decreases. As much as 5 tons of gypsum per acre have been used, depending on the state of solonetz development.

Sulfur Treatment. — If the solonetz contains $CaCO_3$ (which, as a rule, it does), S may be used in place of gypsum at a rate of 1000 to 2000 pounds per acre, depending on the alkalinity of the solonetz. In the soil, S is converted by microbiological action to H_2SO_4 which reacts with the carbonates according to the following equations:

$S_2 + 3O_2 + 2H_2O \longrightarrow 2H_2SO_4$
$H_2SO_4 + Na_2CO_3 \longrightarrow Na_2SO_4 + H_2CO_3 \longrightarrow H_2O + CO_2$
$H_2SO_4 + 2H_2O + CaCO_3 \longrightarrow CaSO_4 . 2H_2O + H_2CO_3 \longrightarrow H_2O$
$+ CO_2$

As in the case of the gypsum treatment, alkalinity is reduced, the structure is improved, and the soil is ready to produce normal crops.

Other Reclamation Measures. — Besides gypsum and S, limestone is added whenever the solonetz has no $CaCO_3$. Its effectiveness is due primarily to the supply of Ca ions for replacing the Na ions.

Incorporation of large quantities of manure is helpful in combating the dispersion effects of Na. The buffer action of the organic matter and *the replacing action of the H ions formed in the decomposition of the organic matter* are responsible for that. The effectiveness of manure or of other organic materials is of a transitory nature.

If available, Mg and Ca silicate slags (by-products of the smelter industries) may be used successfully. In sections of Haiti, distillers' slop containing acetic acid is used to combat the alkalinity of solonetz.

Solodi

Whenever the climate in regions of solonetz becomes more humid, this type of soil undergoes a series of changes. With the increase in precipitation, the remnants of the soluble salts of solonetz are washed out. The *columnar structure disappears; the A_2 horizon attains a distinct* bleached appearance. The soil is then known as *solodi*. Morphologically, it resembles the podzols. Chemically, however, these two soils differ. In the podzols, the SiO_2 coatings of the bleached layer are crystalline in nature, resulting from the breakdown of clay in an acid medium. In the solodi, the breakdown of clay takes place in the alkaline medium of solonetz. The result is an amorphous form of SiO_2. The difference in the two *forms of SiO_2 may be determined by extracting the material in question* with a 5 per cent KOH solution which dissolves amorphous but not crystalline SiO_2.

The B horizon of solodi is still on the alkaline side, the pH being 7.0 or slightly higher. This is caused by the Na lingering in the B horizon. The Ca and Mg which had been adsorbed during the solonetz period begin to disappear. Some H ions appear in the exchange complex. The poor *structure inherited by the solodi from the solonetz still persists.* However, the pH of the A horizon drops, thus favoring plant growth. Vegetation begins to invade the landscape, and the saline deterioration effects gradually vanish. This is nature's way of reclaiming a saline soil.

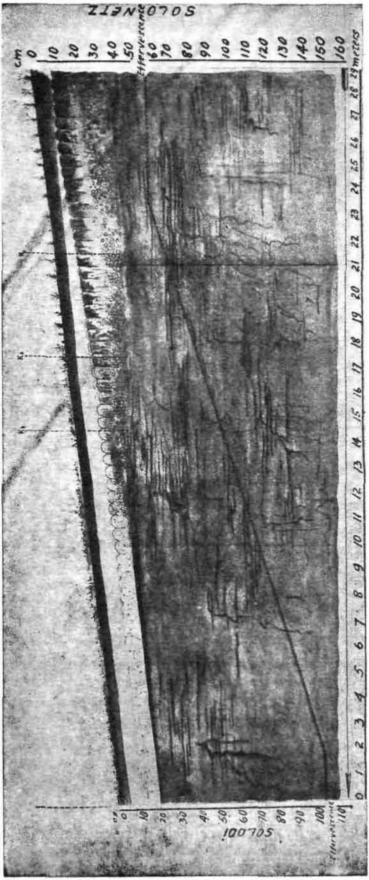

PLATE 9

A soil complex in western Siberia illustrating solonetz and solodi formations

(After Ivanova)

SALINE SOIL VEGETATION

The usual variety of cultivated plants cannot withstand the salt concentration of the average solonchak or solonetz. There is, however, a definite flora which is harbored by saline soils. Close to 200 species of plants native to California have been reported to be restricted to saline soils. Many of these plants serve as indicators of the degree of salinity in the soil. Hilgard, the American pioneer in the study of saline soils, lists the following desert indicator plants in California: Tussoc-grass (*Sporobolus airoides,* Torr); Bushy Samphire (*Allenrolfea occidentalis,* Wats, Ktze); Dwarf Samphire (*Salicornia subterminalis,* Parish); Stalwort (*Suaeda Torreyana,* Wats, and *suffrutescens,* Wats); Greasewood (*Sarcobatus vermiculatus,* Hook, Torr.); Alkali-heath (*Frankenia grandifolia campestris,* Gray); and Salt-grass (*Distichlis spicata*).

The plant species enumerated include those which thrive either in solonchak or solonetz soils. There are, however, species that are specific for solonchak, solonetz or solodi.

Factors in Salt Tolerance of Plants. — The tolerance of plants towards soluble salts depends on the following factors: 1, the type of compound or compounds; 2, the number of compounds which make up the salts; 3, the total concentration; 4, texture of soil; 5, organic matter content; 6, moisture content.

1. Compounds of Na vary in their injurious effects, in decreasing order, as follows: carbonates, chlorides, sulfates, nitrates.

Compounds of Ca and Mg vary in the following order: chlorides, sulfates, nitrates.

2. The more variable the composition of the salts, the less injurious they are. A 0.2 per cent (of total soil) concentration of a single salt is more injurious than the same concentration of a mixture of two salts. A mixture of a similar concentration of three and of more salts of different cationic and anionic composition is still less injurious.

3. The higher the concentration of the salts, the more injurious they are, subject to the limitations of 1 and 2.

4. It has been shown experimentally that in heavy soils plants may tolerate a higher concentration of salts than in light soils. In heavy soils, we have a high adsorptive capacity for salts, due primarily to the clay colloids. In adsorbed form, salts are not as harmful to plants as when in solution. Besides, heavy soils have a high moisture capacity which dilutes the concentration of the salts.

5. Organic matter has even a higher adsorptive capacity for salts and a far greater moisture capacity than the mineral colloids. In addition, carbonic acid is formed in the decomposition of organic matter. This acid

reacts with the injurious Na_2CO_3, which is common in solonetz and in some solonchak, converting it into relatively harmless sodium bicarbonate. The carbonic acid also reacts with the Ca and Mg carbonates which usually are present in these soils, forming the bicarbonates, as illustrated in the equation: $CaCO_3 + H_2CO_3 \longrightarrow Ca(HCO_3)_2$. These reactions tend to reduce the pH of these soils,[3] which by itself is desirable since a high pH is injurious to plant growth. Besides, the soluble bicarbonate of Ca is capable of replacing the Na; the soil is thereby improved.

6. An increase in moisture content of the soil dilutes the concentration of salts and reduces their injurious effects. That is why heavy irrigations are helpful in combating salinity of soils. On the other hand, a low moisture content increases the concentration of salts in the soil solution and it may easily become injurious to plants.

Salt Tolerance of Cultivated Plants

In their tolerance to soluble salts, cultivated plants are inferior to the native saline soil flora. Not much specific information is available on the salt tolerance of cultivated crops. Experiments have been conducted on the tolerance of these crops to salt concentrations in soil, sand, and water cultures and on a limited scale in the open field on different soil types. For practical purposes, only the field tests are to be relied upon.

Forage Crops. — Alfalfa is very sensitive to soluble salts in the *early stages* of its growth. A limit of 0.08 per cent of total soluble salts is mentioned for conditions in California. For Central Asia, the limit is reported to be as high as 0.2 to 0.3 per cent. *For well established* alfalfa, American workers report a limit of 0.7 per cent on loam soils and 0.2 per cent on sandy soils. For Central Asia, the limit is reported 1.0 to 1.5 per cent. The lower limits are for the lighter soils.

White and yellow sweet clovers are most resistant to soluble salts and, since they are not as exacting in their drainage requirements, they are preferable to alfalfa.

The hairy and common vetch (*Vicia sativa* and *V. villosa*) and field peas, sometimes known as Canada field peas, have a salt concentration tolerance limit of 0.4 to 0.6 per cent; ***Bromus inermis***—0.5 to 0.7 per cent; *Agropyrum repens* and Italian ryegrass (***Lolium italicum***)—0.6 to 0.8 per cent; salt grass (*Distichlis spicata*)—3.0 to 5.0 per cent. The last named grass is a typical representative of the solonchak flora and may be used in cropping off some of the soluble salts.

Grain Crops. — Among grains, barley is the most resistant to high

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[3] The pH of solonchak is seldom below 7.0 and may rise to 9.5 or higher, depending on the kind of salt present. The pH of solonetz may go up to 12.

salt concentrations and is, therefore, one of the principal grain crops for saline soils. The average salt toxicity limit is between 0.2 to 0.4 per cent. For hay, barley may be grown even at a salt concentration of 0.6 to 0.8 per cent. In areas where sea water occasionally covers the land, barley grows fairly well at a salt concentration of 1.6 to 2.0 per cent.

Oats are less tolerant to salts than barley. An upper tolerance limit for oats is 0.5 per cent of mixed salts in the first 6 inches of soil.

Wheat for grain is grown in Utah at a salt concentration of 0.1 to 0.4 per cent, and for hay at 0.4 to 0.6 per cent in the first foot of soil. Cases are on record for other parts of the United States where wheat was grown in soils containing as high as 2.0 per cent of a mixture of salts, probably with very little chlorides and carbonates.

Rye and buckwheat are next to wheat in their tolerance to salt concentrations, the upper limit being 0.6 per cent.

Root Crops and Tubers. — Sugar beets have a high salt tolerance, especially after they have rooted appreciably. In the young stage, the salt tolerance of sugar beets is low, the limit being 0.4 to 0.6 per cent. $NaCl$ and $NaNO_3$ exert a very marked negative effect on the sugar content of beets, but do not decrease the yield. Sugar beets tolerate a 0.4 per cent $NaCl$ content, but their sugar content may drop to that of fodder beets. Na_2CO_3 is injurious to sugar beets in concentrations as low as 0.025 per cent. On the other hand, Na_2SO_4 in concentrations of 0.06 per cent is stimulating.

Potatoes and onions suffer in quality in the presence of 0.1 per cent of $NaCl$ or $NaNO_3$. In the case of onions, it has been reported that $Ca(NO_3)_2$ in concentration of 0.45 to 0.57 per cent was stimulating whereas $NaNO_3$ was injurious.

Fiber Plants. — Cotton has been investigated more than any other of the fiber plants. Its tolerance to salt concentrations is relatively high, due probably to the high osmotic pressure, up to 16 atmospheres, of its cell sap. The short fiber cotton has a tolerance of 0.4 to 0.6 per cent salt concentration. The chlorides and nitrates of Na are more toxic than other salts. Flax is not very tolerant to high salt concentrations, the upper limit being 0.4 per cent.

Fruit Trees. — The date palms are the most salt-tolerating of cultivated fruit trees. A concentration of 0.3 to 4.0 per cent $NaCl$ in the upper horizons and 0.6 to 1.0 per cent in the lower horizons is not too much for these palms. Olive trees have a salt tolerance of 0.25 per cent; grapes—0.2 to 0.3 per cent; oranges, almonds, pears, figs, apples—0.1 to 0.2 per cent; lemons, apricots, and peaches—0.08 per cent.

General Statement. — The data on the salt tolerance by various plants are based on averages obtained in experiments under different conditions. In planning a reclamation program for the cultivation of a specific crop on saline soils, the data on salt tolerance may serve as a useful guide. Together with information on the other factors involved in the problem on salt tolerance of plants in relation to soil condition specifically with reference to the salt concentration of the different horizons in the profile, a workable program of reclamation may be hoped for. There are no saline soils that require no reclamation.

PEAT AND MUCK LAND

Peat and muck lands are arbitrarily classified on the basis of their organic matter content and the stage of decomposition of the plant residues. Land containing from 20 to 50 per cent of fairly well decomposed organic matter is called muck. Land with more than 50 per cent organic matter is called peat. In the latter, the plant residues are not as well advanced in decomposition as in muck.

Many terms, such as bog, marsh, swamp, fen, and heath, are used interchangeably for the organic deposits. Agriculturally, however, these are known as peat and muck. Moor is the general name for the organic deposits designated by the terms mentioned.

Two classes of moor are recognized: *lowmoor* which includes the marsh, swamp, and fen deposits; and *highmoor* which takes in the bog or heath deposits. Lowmoor deposits have a flat or slightly concave surface and are in many cases alkaline or neutral in reaction. Highmoor deposits rise from the edge towards the middle and thus show a convex upper surface; they are, as a rule, acid.

All types of organic deposits begin with aquatic plants. As they die, the basin gradually builds up a deposit of plant residues, encouraging a greater variety of species in the process. Eventually, the accumulated plant residues force water out of the area. In other words, the genesis of peat and muck land is a water basin which had become filled with vegetation and had gradually drained. In many areas, of course, depositions of silt and muck from the surrounding landscape help fill the depression.

Because of changes in drainage conditions and succession of botanical species, the layers of peat are stratified. We thus have layers of fibrous or woody peat.

Types of Peat and Muck

Peat and muck land are classified botanically (according to the conditions under which they are formed) into four groups: **aquatic, marsh, swamp, and bog.**

Aquatic. — As the name implies, this type of organic deposit is formed by plants living in water, such as the pond weed, water lily, water plantain, and hornwort. Such organic deposits originate in water, 2 to 15 and more feet deep, and are mixed with silt brought by inflowing waters. The material is finely divided; when drained and dried, it becomes hard, shrinks, and develops cracks. When cultivated, such deposits are subject to wind erosion. The color is olive green when wet, and almost black when dry. In general, these deposits, referred to as sedimentary peat, are difficult to handle agriculturally.

Marsh. — As the vegetation accumulates and builds up organic deposits, plants thriving on the periphery of the deep water areas invade the organic deposits. Reeds, cat-tails, rushes, and sedges occupy the landscape. In some ponds, the sedges form a felt-like mat and hide the water surface. This is known as a "floating" or "quaking bog." As this mat builds up, it sinks to the bottom; and in this manner a pure marsh type of material forms.

This type of organic deposit is usually made up of fibrous materials, with leaves and roots of the sedge, rushes, and reeds easily recognizable. The color varies from light to dark brown or brownish black. Such muck and peat deposits are sometimes referred to as fibrous peat.

Swamp. — The swamp group of peat and muck is formed primarily from forest litter. Among the species are tamarack, maple, elm, spruce, white cedar (arborvitae), ash, birch, alder, willow, and poplar. These represent the climax vegetation in swampy areas of temperate regions.

Forests do not occupy muck deposits until they have been well built up and the water table is below the surface for a considerable portion of the year. Tamarack, black spruce, and white cedar are among the first to enter the swamp, followed by ash, elm, and maple. If the conifers do not come in first, alder, dogwood, willow, or a mixture of these, serve as the advance guard for the forest. These species are followed by sphagnum moss growth. Organic deposits with trees as the climax vegetation are coarser in structure. The peat is brown or black. In reaction it is generally not very acid. The swamp type of peat, when drained, is very easy to cultivate.

Bog. — This group of organic deposits is similar to that of the swamp, except that the medium is distinctly acid. Because of that, the forest species thriving in the swamp deposits are not found in the bog. The most characteristic species of plants in bog formations are: swamp blueberry, often erroneously called huckleberry, leather leaf (Cassandra), Labrador tea, bog rosemary, and cranberry. These shrubs are sometimes invaded by tamarack. After a fire, the vegetation in a bog changes to forest species. Apparently, the ash formed during burning is sufficient to induce tree vegetation, such as poplar and birch.

Many of the bogs are associated with the drainage of small watersheds poor in calcium and magnesium. The lack of these elements imparts to bogs an acid reaction. In many bogs, however, the lower deposits are alkaline, whereas the upper deposits are acid. Such a condition is brought about by an earlier influx of drainage rich in lime, followed by drainage poor in lime.

The everglades in Florida, a marsh occupying about 5000 square miles, represent deposits of peat and muck underlain by calcareous marls. In places where the deposits are not deep, the peat is alkaline; in the deep beds, on the other hand, the peats are acid.

GEOLOGIC AND SOIL PEAT PROFILES

Geologic Peat Profile. — Some peat and muck deposits extend to great depths, 50 feet and more. These deposits are made up of different layers of organic matter, representing accumulations of flora successions associated with stages in the geologic cycle of the area (such as a change in the drainage system or an uplift) since the close of the last glacial epoch. A vertical section showing the various stages of organic matter accumulation is known as a geologic peat profile. It has no relation to a soil profile which is associated with humification, mineralization, eluviation, and finally differentiation into definite horizons.

In the progressive development of peat deposits, the nutrient medium within the swamp or bog area becomes poor, insufficient to support tree growth. In the final stages of moor development, a vegetation climax appears which is poor in nitrogen and ash constituents, such as sphagnum and cotton grass. The stages described earlier and summarized in the preceding paragraph may be found in the geologic profile of a typical peat deposit. The depth of the layers or horizons varies, depending on the progress made by the respective stages.

In recent years, a study of pollen grains and other plant remains preserved in the peat through ages has enabled botanists to reconstruct the flora at different periods. In this manner, the geologic age and time of formation of the various layers of peat deposits has been established.

Peat Soil Profile. — There are peat and muck deposits which are comparatively shallow. They are found at the edges of swamps or in the more elevated sections within the main body of a swamp. Whenever the mineral material underlying an organic deposit is affected by the reagents released in the decomposition of the surface organic matter, a peat soil profile having the following characteristics develops.

A_0: Organic matter debris in various stages of decomposition, ranging in depth from 3 to 12 or more inches; this accumulation of organic matter is referred to as the peat horizon.

A_1: Dark colored layer, sometimes even black, varying in depth; a mixture of humus and mineral constituents.

A_2: Lighter in color than A_1, frequently showing the bleached podzol features, smeary when wet and hard when dry.

B: Mottled, brown, rusty brown to bluish gray or greenish bluish gray; rusty spots and streaks; vestiges of root paths afford a chance for aeration at periods when the water table recedes.

G: Bluish gray glei.

Depending on the degree of swamping, source of seepage waters, drainage, and composition of mineral material, the morphology of the profile will vary. If the submergence period is long, the B horizon becomes a part of the glei.

Under the anaerobic conditions prevailing in the peat soil profile, reduction rather than oxidation takes place. This gives rise to gases and compounds not found in normal soils, such as carbon monoxide, methane, and hydrogen sulfide. In the *B* horizon, vivianite ($Fe_3(PO_4)_2.8H_2O$), pyrite (FeS_2), marcasite (FeS_2), and crystalline and amorphous siderite ($FeCO_3$) may be found.

The peat soil profile resembles very much the meadow podzol, differing from it by having a more distinct organic matter layer, the A_0 peat layer. In the muck soils, where the organic matter has undergone more decomposition and silt has been mixed with the organic deposits, the soil is known as silt hog, in distinction from the peat hog. The latter may either have a pure peat profile or a peat soil profile, as described earlier.

PROPERTIES OF ORGANIC SOILS

Peat and muck used agriculturally are generally referred to as organic soils. They are endowed with specific physical and chemical properties, a discussion of which might help to appreciate the problems encountered in farming them.

Physical Properties

Moisture. — Of the physical properties of organic soils, none is more perplexing than that of moisture. Organic soils may have a moisture holding capacity (the moisture content at saturation) two to three or more times their dry weight. It is evident that in evaluating moisture supply, the maintenance of optimum moisture (see chapter X) conditions is an important consideration.

In a wet season, it is difficult to maintain optimum moisture in organic soils because of the high water table usually prevailing in them.

When they are saturated, water drains slowly from these soils causing waterlogging, poor aeration, and subsequent injury to the crop. When the soil dries out, the 50 to 60 per cent optimum moisture relied upon to supply the crop is not sufficient (assuming that the moisture holding capacity is twice the weight of the soil). Not more than 60 to 75 per cent of this moisture can be utilized by the crop efficiently, since the wilting coefficient (the per cent of water in the soil at which plants wilt) is high for such soils. On the face of it, this 60 to 75 per cent figure looks like a formidable amount of moisture, but a simple calculation tells a different story.

An acre of peat soil weighs on the average 500,000 pounds. Taking the figure of 60 per cent optimum moisture (if the M.H.C. is twice the weight of the soil, it will amount to 120 per cent moisture), of which 60 to 75 per cent is available for plant use, the total moisture an acre furrow slice of peat can deliver is from 360,000 to 450,000 pounds. An acre furrow slice of a loam soil, weighing 2,000,000 pounds with an 80 per cent moisture holding capacity and a 50 to 60 per cent optimum moisture of which 75 per cent is available, can deliver from 600,000 to 720,000 pounds of water. A comparison of the figures clearly shows that the mineral soil is far more efficient in supplying moisture to the crop than the organic soil.

The resistance of peat and muck getting wet after they have dried out is a difficult problem frequently confronting the farmer. The cracking of dry peat prolongs the time required for wetting it.

Control of the water table is, of course, the proper remedy for peat soils in a dry season, providing there is enough water to back up in the canals or to pump from some reservoir. In many areas of peat and muck land, overhead irrigation takes care of the moisture problem.

In view of the aforesaid, it will be clear why students of practical problems of peat and muck and dirt farmers who till these refer to them as the group of soils which are most exacting in their moisture requirements.

Other Physical Properties. — The color of organic soils is usually black with an occasional dark brown shade. When wet, they are almost always black.

The weight of these soils varies (depending on the infiltration of mineral material into the swamp, marsh, or bog in the course of formation of the peat) from 15 to 30 pounds per cubic foot; this figure compares with 75 to 90 pounds per cubic foot of upland (mineral) soil. On an acre basis, a furrow slice (6⅔ inches deep) of dry peat or muck weighs between 300,000 and 600,000 pounds; whereas that of an average mineral soil weighs 2,000,000 pounds.

Depending on the origin of the material, organic soils may be fibrous or woody in structure; they are, therefore, open and porous, readily absorb water, and are well aerated. Cultivated for a number of years, the surface of mucks and peats tends to become pulverized. When dry, the loose organic matter drifts badly, sometimes causing extensive damage to crops bv bruising the tender tissues. Windbreaks of trees, or crop strips of tall grasses like the cereals, are used to prevent this injury. Dry pulverized peat is also subject to easy burning. It is the experience of the author that many muck soils have been damaged by excessive tillage with the rototiller. With the first rain, the pulverized material tends to aggregate causing crust formation. The result is poor aeration and the formation of hydrogen sulfide and marsh gas. Excessive use of nitrate of soda has also been found to cause dispersion of the organic matter thereby bringing about poor aeration.

Chemical Properties

Organic Matter. — Organic matter is the outstanding chemical characteristic of organic soils; it may run as high as 97 per cent and as low as 20-25 per cent.[3] The N content of such soils varies from 1.5 to 3.0 and even 4.2[4] per cent, with the limits between 2.0 and 2.5 predominating. Variations in N content may occur within the area of any one bog, depending primarily on the stage of decomposition of the organic matter. *As decomposition progresses, large quantities of C are lost, whereas the total quantity of N remains practically constant, as it is fixed in the bodies of the microbes.* For this reason, the C:N ratio of these soils is not constant. Whereas the C:N ratio of the Ap layer of well drained mineral soils fluctuates from 8:1 to 12:1, that of organic soils fluctuates from 15:1 to 30:1.

Alkaline Earth Bases. — Of the peat and muck soils exploited in the United States for agriculture, the larger portion is comparatively rich in Ca. Nevertheless, one may find among the organic soils of Minnesota variations in CaO content from 0.3 to 3.5 per cent; of New York—0.6 to 7.9 per cent; of Michigan—0.3 to 17.1 per cent. In general, the highmoor deposits are low in CaO, down to 0.4 per cent, and the lowmoor deposits are high in CaO, from 2.0 and higher.

As to MgO, it is of interest to note that it is far below the CaO content. Of 26 analyses of Michigan peats and mucks, the highest is 1.14 per cent and the lowest is 0.13 per cent, with an average of 0.5 per cent of MgO; in New York State, a group of 21 samples taken at random show a low MgO content of 0.15, a high 0.93, with an average of 0.47 per cent.

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[3] The lower limit of organic matter for muck soil is an arbitrary figure.

[4] This figure is reported for a peat in the middle of a swamp in Vermont.

The low Mg content is probably due to two factors. First, the organic soils are the result of plant residues, and these contain more Ca than Mg. Second, organic complexes form comparatively insoluble Ca humates; Mg humates, on the other hand, are soluble and readily lost by leaching.

Phosphorus. — An acre furrow slice of organic soils weighing 500,000 pounds contains as many as, and even more, pounds of P as that of a mineral soils weighing 2,000,000 pounds. Among 53 representative peat and muck soils of New York, the P_2O_5 content varies from 0.08 to 0.67, with an average of 0.254 per cent. The peat and muck soils of Michigan show a similar P_2O_5 content. It is of interest to note that the P content decreases with depth.

Potassium. — Of the three major fertilizer nutrients, this element is the lowest in quantity in peats, when compared with mineral soils. Among 40 samples of peat and muck soils of New York, the K_2O content varies from 0.1 to 0.35, with an average of 0.16 per cent. Like P, the K content decreases with depth.

Sulfur, Copper, and Manganese. — The S content varies from 0.2 up to 2.0 per cent, in terms of SO_3; Mn_3O_4 content varies from a mere trace to 0.075 per cent; CuO content varies from 0.0009 to 0.0186 per cent.

pH and Exchangeable Cations. — Generally, peat and muck soils are acid in reaction, i.e., the pH is below 7.0. Of the 57 samples of peat and muck soils reported in the state of New York, only one, the 12 to 24 inch layer overlying lime marl, had a pH above 7.0. The pH of the 0-12 inch layer of the same area had a pH 5.8, notwithstanding the presence of 4.3 per cent of CaO. About 15 samples had a pH above 6.0 and the rest varied from 6.0 to 3.6.

Samples of organic soils in Michigan vary in pH from 4.1 to 8.6, the latter being intermixed with lime marl. The organic soils of the Everglades in Florida are underlain with limestone or marl. Yet, where the peat or muck is deep (the deepest layers are near Lake Okeechobee and average about 12 feet), the pH is mostly below 7.0, ranging from 4.5 to 8.6.

pH values of mineral soils are an excellent index of acidity and of a low Ca content. In organic soils, pH values give just an inkling of the state of acidity, and no indication of the base status. There are peat and muck soils which have low pH value and high CaO contents. Among the organic soils of New York, one may find samples with a pH 4.0 and a CaO content of 1.5 per cent; pH 4.6, with 3.4 per cent; pH 4.8, with 4.9 per cent; pH 5.4, with 6.0 per cent. With such percentages of CaO there is no telling whether or not these soils would respond to lime in spite of the low pH. It is, therefore, generally agreed that a classification of organic soils based on lime content, especially exchangeable (adsorbed) Ca and Mg, is more accurate than one based on pH values. It should be added that this generalization applies to organic soils of pH above 4.6. Below these pH values, the organic soils, as a rule, respond to lime. High CaO contents and low pH values are possible in organic soils because of their high cation adsorption, 50 to 60 and more milliequivalents per 100 grams against 8 to 15 for an average loam in the humid temperate regions.

AGRICULTURAL AND OTHER USES OF ORGANIC DEPOSITS

In Europe, peat is used extensively as fuel. It is cut in brick-like forms, dried, and shipped to consumers. For this purpose, a light weight peat (as low as 6 pounds per cubic foot) containing very little mineral constituents is best suited. In excavating peat deposits, care is exercised to leave a layer of several inches, if the site is to be used agriculturally. At the same time, the drainage must be adjusted in accordance with the topographical lowering resulting from the removal of the peat. The mineral layer without any peat is not productive, and the expense involved in lowering and maintaining the drainage does not warrant the tillage of such an exposed mineral layer.

In a small way, peat is used as a source of organic matter for mineral soils. It is an excellent material, if composted for a season with a mixture of lime, acid phosphate, and some source of K. The procedure best followed is similar to that described for artificial manure. The value of such compost is about the same as of good manure.

Without composting, peat treated with lime may be and is used for the purpose of retaining nutrients and aiding sometimes in the moisture supply. Peat increases the porosity of heavy soils, i.e., it improves their structure. For this purpose the composted peat is superior to raw peat. Peat is used extensively by greenhouse men in mixtures for potting soils as well as for the benches.

Peat is used in barn gutters to absorb the liquid portion of the manure. As bedding in barns or stables or for litter on chicken roosts, ordinary peat is not suitable because it is too dusty; it stains the animals and is a general nuisance in the barn or poultry house. Good quality peat-moss, found chiefly in the northern countries, is used for this purpose.

Peat land is extensively used for agriculture. Any kind of crop, depending on climate, may be grown on peat land. In the United States, it is utilized primarily for vegetable production.

Managing Peat or Muck Land for Agriculture

Preparing the Land. — The first step in preparing peat or muck land for agriculture is to drain the excess moisture by digging main and auxiliary canals. The next step is to clear the land. If the bog is in forests, it has to be cut and stumped. Since trees in the bog are shallow rooted, clearing operations are not difficult. If grasses or brush occupy the landscape, a controlled burning program is most helpful. It should be done by experienced men in the late winter or early spring, when the peat is saturated with water.

Advantages of burning are threefold. First, the ash provides readily available alkaline substances. Second, after burning it is easier to break the land to the desired depth. Third, the grass and brush, if plowed under rather than burned, resist decomposition and thereby retard domestication of the land. A burning operation on brush land of a light muck in North Carolina under the guidance of the author brought about thorough domestication of the land in one season without resorting to any other measure, such as grazing. Peat and muck land should not be burned through the entire depth of the peat layer. Burning should be confined to the surface vegetation. Excessive burning may temporarily cause an undesirable high alkalinity.

In areas covered with forest, the land is cleared and turned into pasture for a couple of years. After that, the land is broken with a heavy breaking plow to a depth of 12 to 15 inches. After plowing and disking, it is rolled. In domesticated land, rolling helps the moisture rise from below and also serves to keep the muck in place. Heavy rollers, 700 to 800 pounds, are used. After the land has been domesticated, it is not plowed every year. Disking alone is sufficient. If, however, the fields become infected with weeds, the soil should be plowed again. Excessive disking is not advisable.

OROGENIC SOILS

In mountain regions, one may find within a distance of several miles a number of climatogenic soils. For example, several miles outside of Colorado Springs, Colorado, brown and chestnut brown soils prevail. On the way to Pikes Peak, about 15,000 feet above sea level, one passes through a chernozem formation; upon reaching the forest clad slopes, the brown podzolic and meadow podzols are seen; further up the mountain, meadows and tundra-like soils (beyond the alpine vegetation zone) come into view, until finally the skeleton mantle rock is reached, at the top of the mountain. In tropical humid regions, like Java, we pass from laterites at the foot of the mountain, through red and yellow loams, brown podzolic forest soils, podzols, mountain meadows, tundra, and finally reach the skeleton mantle rock.

The normal climatogenic soils stretch out for hundreds of miles in a horizontal plane, as they change from one zone into another. In moun-

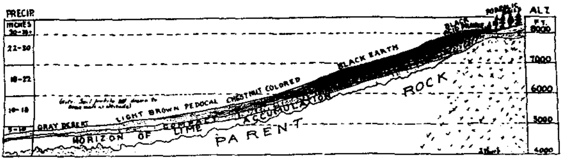

PLATE 10

Gradation of soil profile from desert to humid mountain top—west slope of Big Horn

(After Thorp)

tainous country, the climatogenic soils are distributed in a vertical plane within an area of a few miles. This, of course, is due to the change of climate with altitude. And yet, one must not forget that, whereas the fundamental features of the climates of horizontal and vertical zonation are the same, there are some points of difference. Thus, diurnal temperature differences are greater in mountain regions because of the more rarified conditions of the air. The length of day and night in the podzol and tundra zones of the mountains of Java or in the Rockies is different from that in the soils of the corresponding soils of horizontal zonation. These and other differences exert an influence on the vertically distributed soils. They are, therefore, in a way intrazonal, and since their specific features are due to the mountainous topography they are named *orogenic.*

LITHOGENIC SOILS

As the name implies, these soils are formed under the dominating influence of the native rock from which the parent material originated. These are soils in which the chemical properties of the parent material take, so to speak, the upper hand over climatic influences. These soils are sometimes referred to as *endodynamomorphic* in contrast to the *ectodynamomorphic* in which the climate and related influences determine the type of soil formation (see p. 37).

The outstanding example of lithogenic soils is the dark gray to black, chernozem-like soils formed on limestone (sometimes on gypsum and limestone) parent materials among the forest soils in the zone of podzolization. They are known under the names *humus-carbonate* soils or *rendzina.* The latter name originated in Poland where these soils were first studied by Russian pedologists. The exact etymology of the word *rendzina* is not known. It is claimed that the peasants of Poland use the name, pronouncing it *rhindzina,* for soils originating on limestone or gypsum.

There are many soils in the United States on limestone parent material.

such as the Hagerstown and Washington series, which have not the rendzina characteristics. It is claimed that hard crystalline limestones are not conducive to the formation of rendzina. Small areas of rendzina are found in Alabama and Mississippi. Some rendzina is found in northeastern Texas on the lime marls. These soils have been mapped under the Houston series.

The profile of rendzina is simple. There is, as a rule, no B horizon. Wherever the beginnings of a B horizon appear, the characteristics of the rendzina tend to disappear and podzolizing effects come in. Generally, the rendzina consists of an A horizon, black to dark gray in color, containing lumps of limestone mixed with the well granulated material, high in humus (up to 10 per cent and more) and usually shallow, 6 to 10 inches, but sometimes extending to a depth of 20 inches. The A horizon lies immediately in contact with the C horizon, easily recognized by the light colored to white limestone or gypsum parent material, as shown in plate 10. Any one who has traveled in the English Channel could not have failed to see the black rendzina soils on both sides, on the chalk-cliffs of Dover and of Normandy.

Another example of lithogenic soils showing the enduring influence of the parent material on the soil forming processes may be cited in the Penn series, which formed on Triassic shales and sandstones. The characteristic feature of these soils is the chocolate red color which predominates throughout the profile. These soils originate on parent material consisting of weathered sedimentary rocks, consolidated clay, silt, and sand. At some earlier geologic time this mixture represented some soil material. In other words, the parent material, as it appears now, has undergone several stages: an initial weathering, a process of soil formation, an erosion process, and another weathering process. The present process of soil formation followed the last weathering cycle. This type of parent material is not conducive to the processes of soil formation, since the bulk of the reagents essential in this process have been lost in previous cycles. The parent material consists primarily of the final products of weathering and cannot be changed much more.

Agriculturally, lithogenic soils may be rich or poor, depending on the composition of the parent material. Thus, the rendzina with its neutral or nearly neutral reaction and large quantity of organic matter is a very productive soil if it is deep enough. The Penn soil, on the other hand, with its low base content, high acidity and shale parent material, which is too open to keep water is limited in its productive capacity. A Penn soil, unless it has 8 to 10 feet of weathered material, cannot support fruit trees, because of the lack of moisture during the growing season.

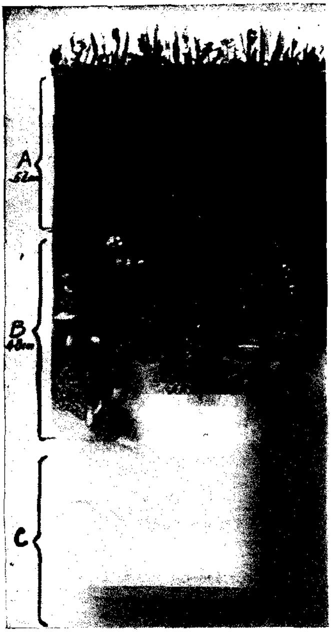

PLATE II

Rendsina on limestone
(After Kassatkin and Krasyuk)

FLUVIOGENIC OR ALLUVIAL SOILS

As the name implies, these soils are limited to areas affected by water deposition in recent geologic or even historical time. These soils are found along stream channels, in flood plains, deltas, and bottom lands in general. These soils vary considerably in their characteristics, depending primarily on the climatic zone in which they are located. The type of load carried by the stream also influences them. During floods, the loads are deposited on the old sediments, producing a stratified effect. These are young soils, with poor or no profile development. No generalized pedogenic attributes may be assigned to them.

Agriculturally, alluvial soils are among the most productive. They support, on acre basis, a larger proportion of the world's population than any other soil group. From time to time, these soils become submerged, causing misery and devastation to the inhabitants. Yet, in spite of the dangers, throughout the centuries, farmers have continued to stay on these lands. The great incentive spurring farmers to challenge the ravages of floods is the abundance of moisture which offers a virtual guarantee against crop failures.

PLANOSOLS

Poorly drained soils with a hardpan or claypan in the subsoil (it should read B horizon) have been designated by workers of the U. S. Department of Agriculture as *planosols*. They are grouped with the intrazonal soils. However, the primary profile characteristics of the soils associated with planosols are those of the zonal soils among which they are found. Thus, the soils of the Grundy series are the planosols of prairie soils: the Clermont series are the planosols of the gray-brown podzolic soils; the Crete series are planosols of the chernozem soils.

Instead of introducing a new group of soils, it might be simpler to consider these as poorly drained varieties of the respective zonal soils. There is nothing to be gained by singling out a characteristic common to a few soils and creating a new name. By this procedure we will soon be burdened with a nomenclature which will become an end instead of means to an end, a hindrance instead of a help.

Part II

The Soil As A Medium For Plant Growth

PART II

THE SOIL AS A MEDIUM FOR PLANT GROWTH

Introduction

The literature on the soil as a medium for plant growth deals primarily with the plowed layer. Tillage practices, liming, fertilization, moisture control, and other measures pertaining to soil management are carried out solely with reference to the plowed layer, the Ap. Very little attention is given to the subsoil (the soil below the plowed layer), except when drainage becomes a problem. Actually, plants are influenced very markedly by the physical and chemical properties of the soil profile below the plowed layer and also by the *true subsoil,* the C horizon.

Soil operations and treatments have to be related to the specific properties of all the horizons and not just to the plowed layer or any one horizon. A thorough survey of the soil profile is, therefore, the starting point in up-to-date soil management practices.

The different zonal soil types, because of the specific physical and chemical properties of their profile, have to be handled in accordance with their specific characteristics. Thus, $NaNO_3$ may be an excellent source of N for the laterites and lateritic soils; for chernozem $(NH_4)_2SO_4$ is a far superior source of N. Systems of working the land may vary considerably for the different zonal soils.

Every step planned to make the soil the ideal medium for plant growth must be guided by the following considerations: 1. The specific properties of the zonal and climatogenically subdued soil types; and 2. The way the different soil types respond to treatment. No absolute rules can be laid down that would apply to all soil zones. There are, however, some physical and chemical properties of all soil zones that are similar, and a knowledge of these is of fundamental importance in managing all soils.

All soils receive, retain, and lose moisture. Plowing, harrowing, cultivating, mulching, manuring, cover cropping, liming, fertilizing, timing harvests, systems of pasturing land, problems of erosion, drainage, and irrigation are intimately related to the moisture component of any soil.

Like animals, plants can get along without nutrients or water for a far longer time than without air. In the process of respiration, CO_2 may accumulate to a point more injurious to the roots than the lack of oxygen. Other gases, such as H_2S and marsh gas (under anaerobic conditions), have to be considered. The gas component of the soil varies considerably in the different zonal soils, but the fundamental principles of soil aeration apply to all soils.

In discussing properties of the soil, effects of temperature on the manifold relationships of plant growth to soil conditions must be looked into. The time table of farming operations and cropping systems depend in a large measure on temperature conditions. Very few expedients are available for the control of soil temperature; and yet, there are some measures of influencing the temperature of the soil.

Liming of soils in the zones of podzolization and laterization is an old established practice. Results of liming have been measured in terms of reduced acidity and increased crop yield. With the newer knowledge of pedology, a clearer understanding has been gained of the liming effects on soil conditions in relation to plant growth.

The problem of the loss of soil constituents by leaching and their removal by harvests and pasturing must he recognized and dealt witb. This brings us to the problem of mineral fertilization. As in the case of liming, fertilizer practices have to he considered in the light of their effects on the profile.

Methods of working the land, measures of soil erosion control, variations in the approach of meeting these problems in the different zonal soils and their subdivisions constitute the concern of the soils man; and finally, the knowledge acquired is to be mobilized in order to trace the soil troubles confronting the tiller of the soil from day to day.

CHAPTER X

MOISTURE AND AIR COMPONENTS OF THE SOIL

Pore Space

Conditions of moisture and aeration in the soil profile determine in a large measure the quality of the soil as a medium for plant growth. No problem of soil management may be adequately handled without a knowledge of the gaseous (air) and moisture components of the soil. Intimately related to these components is the pore space of the soil.

The individual units of the mechanical soil separates—clay, silt, and sand—vary markedly in size and are of irregular shape. Geometrically, they are a series of bodies in contact with one another at certain points of their surfaces. The particles do not pack into a solid mass; voids, or interstices, are always present between them. By the same token, there are voids between the unit particles of soil aggregates. Besides, paths of boring insects and worms and the openings left behind by decaying roots augment the volume of voids in the soil mass.

The sum of voids in the soil is known as *pore space*. In evaluating the importance of pore space, the volume as well as the size of the voids are to be considered. Clay soils, for example, have a high total volume of pore space, but the pores are small in size. On the other hand, coarse sandy soils, though possessing large pores, have a low total pore space.

Capillary and Non-Capillary Pore Space. — Capillary pore space is made up of minute pores which, when arranged in tubules and filled with water, do not empty under the force of gravity; the water is retained in the very fine tubules (known as capillaries) by virtue of forces designated as capillary.[1] Non-capillary pores have a diameter large enough to form tubes that can not remain filled with water against gravity; the pores are too large to exhibit capillary tension.[2]

Soils of the pedocals, especially the chernozem, are provided in a full measure with non-capillary pore space because of their favorable structure. Water penetrates easily into the lower horizons and the subsoil, thereby

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[1] Commonly observed examples of capillarity are the rise of kerosene in the lampwick and the action of a blotter.

[2] A porous clay cup is filled with water, connected to a mercury manometer and then placed in the soil. If the soil is dry, capillary forces will pull water out of the cup and cause the mercury to rise. The force responsible for the pull, expressed in terms of millimeters of mercury rise, is known as capillary tension. Such a porous cup device is known as a *tensiometer*.

reducing surface runoff to a minimum. It looks as if nature had purposely provided the chernozem with non-capillary pore space to compensate the crops in these regions for the scant precipitation.

In the soils of the pedalfers, non-capillary pore space is not ample because of the poor soil structure. This condition hinders the rapid removal of moisture through the soil body and enhances heavy runoff. Whereas this moisture relationship may cause loss of nutrients by erosion, it cuts down the leaching effects and saves nutrients. Other negative effects resulting from the paucity of non-capillary pore space are surface swamping and poor aeration.

A balance of the two types of pore space would be the ideal condition for the moisture and aeration of soils. While columns of water pass through the non-capillary pore spaces, the capillaries within the structural soil units may imbibe water. This ideal condition may be found in the chernozem soils.

Although there is no sharp line of demarcation between capillary and non-capillary pores, the two divisions are real and very useful for purposes of illustrating moisture movement in relation to pore space.

A number of factors control the volume and character of pore space in the soil. They are: 1, mechanical composition; 2, organic matter content; 3, structure; 4, biological activity; 5, moisture; 6, position in profile.

Mechanical Composition. — Generally, the finer the texture of the soil, the greater the total pore space. In coarse sand, the pore space may make up 40 per cent of the volume of the soil; in medium sand—42.3 per cent; in fine sand—45.0 per cent; in very fine sand—46.9 per cent; in a loam soil—47.4 per cent; in a clay chernozem—50.3 per cent; in clay—52.7 per cent; in peat—85.2 per cent. The figures given for the sands would be true, if the mass were to consist, more or less, of the same particle size separates. Soils, however, are a mixture of different particle size separates. Silt and clay particles may, for example, clog up the large pores and so decrease the total pore space. If soils were made up of uniform spherical particles with closest packing, the pore space would be 26 per cent of the total volume. In nature, this condition is never fulfilled. Pore space in Ap is generally over 40 and up to 60 per cent.

Organic Matter. — Additions of organic matter to heavy soils increase the total pore space: firstly, because of the large voids formed by materials which make up manure, stubble, or green manure; secondly, organic matter tends to aggregate the fine particles and to stabilize the structural units, thus increasing the volume of large pore space; thirdly, organic matter in itself has a large total volume of capillary pore space.

In sandy soils, organic matter tends to clog the large pore spaces between the coarse sand particles. The organic matter wedges itself in between the large particles; at the same time it contributes its own pore space.

Structure. — In the discussion on structure (p. 57), it was pointed out that with the aggregation of textural unit particles (clay, silt, and sand) the non-capillary pore space increases. A soil consisting of aggregates of clay and silt of a particle size equal to a mixture of coarse, medium, and fine sand would have its *non-capillary pore space* equivalent to that of the sands, namely about 42 per cent. Of the remaining 58 per cent volume of this soil, one-half consists of *capillary pore space,* or 29 per cent of the total volume of the soil, and the other half consists of the solid portion of the structural units of clay and silt. In other words, the total pore space could be $42 + 29 = 71$ per cent. These values are theoretical possibilities. Actually, the surface horizon of a well developed chernozem contains about 60 per cent pore space. A solonetz which, as a rule, is highly dispersed has less total pore space than a chernozem, and most of it is of the capillary type; and for this reason solonetz is impervious to water.

One of the most important physical attributes of chernozem and related soils, such as the prairie soils, is the favorable balance between capillary and non-capillary pore space, resulting from the ideal structure, as explained earlier. Because of this balance, moisture penetrates rather easily into the profile. A 20-25 inch rainfall in the chernozem zone is more efficient than a similar amount in the zone of podzolization, where the structure is poorly developed and a large portion of the rainfall runs off.

Biological Activity. — The biosphere is very important in influencing the non-capillary pore space of the soil. Of these influences, root activity is very prominent. In chernozem soils rooting is ideal, and because of it non-capillary pore space approaches its highest development in these soils. As a matter of fact, root development and non-capillary pore space go hand in hand; one helps the other. In soils with little non-capillary pore space, root development is poor. In turn, poor root development does little to develop the pore space. In humid regions, for instance, non-capillary pore space is generally not adequate for best rooting.

Applications of fertilizers and incorporation of the liming ingredients into larger volumes of soil, as discussed in chapters XI and XII, are beneficial expedients in forcing the roots deeper into the soil, thereby increasing the non-capillary pore space.

Acid conditions hinder root development even with adequate pore space. Liming the soil to a greater depth means the elimination of this condition. Rapid distribution of Ca in the profile can be accomplished adequately by supplementing lime with gypsum (see Ch. XI). The latter also furnishes sulfates that are conducive to rooting.

In the temperate region of the eastern seaboard of the United States, early spring seedings frequently fail because of the paucity of non-capillary pore space. At this time of the year the soil is dispersed, wet, and cold. The top inch or two of the soil is warm enough for the comfort of the roots of new seedlings. A warm spell for any length of time, 5 to 10 days, accompanied by high winds, may desiccate the few inches of surface soil and cause the death of shallow rooted seedlings. It is for this reason that lawns seeded in the spring are generally not successful in this region.

Deep plowing in the fall facilitates drainage and aeration which, in turn, help the soil to warm up early in the spring for cultivated plants to root deeper. Desiccating winds, under such conditions, have little adverse influence, especially if a soil mulch is kept up.

An increased earthworm population is an expedient to increase pore space. "Planting" of earthworms in the soil, as advocated by quack agriculturists, is a waste of time and money. If conditions are favorable, i.e., if the soil is well limed and supplied with nutrients, earthworms will soon invade the soil. Beside earthworms, grubs and many insects that produce channels in the soil increase the pore space.

It has been shown that under the acid environment of a pure stand of pine, where no earthworms, as a rule, are found, the pore space in the first 5 inches of soil was 40.6 against 54.9 per cent in a mixed stand of pine and beech which does harbor earthworms.

Moisture. — Moisture occupies the largest share of pore space in the soil, especially in the humid temperate region where about two-thirds of the pore space is generally taken up by the moisture. Even after a drought, moisture takes up about 30 per cent of the pore space. Thus, factors influencing the moisture capacity of the soil indirectly influence the pore space.

As water surrounds the soil particles, the total volume of the soil increases, since the films of moisture around the particles occupy space. This means an increase in pore space, in spite of the addition of water.

Upon freezing, water expands and the volume occupied by the soil increases. A soil poor in non-capillary pore space must, upon freezing, extend its volume primarily in the direction of the surface, causing heaving. As the soil is pushed upwards, the plant roots are torn away from the underlying stationary layer of soil. As thawing sets in, the soil sinks, exposing some underground portions of the plant.

To overcome the curse of heaving, the soil should not be saturated when frost sets in. The available pore space will thus make for the internal movement of ice crystals. It is, therefore, important to reduce the dispersion of the soil, thus increasing the non-capillary pore space. Mixtures of limestone and gypsum in the ratio of 2:1 at the rate of 600 to 1000 pounds per acre will go a long way in reducing the dispersion. Alfalfa stands that suffer from heaving will be relieved of the evil and will last longer if treated in the fall with one half of the following mixture, and in the late winter, when the frost is going out of the ground, with the other half: 600 pounds dolomitic limestone, 200 pounds gypsum, 500 pounds 20 per cent superphosphate, 100 pounds K_2SO_4, 50 pounds NaCl, 150 pounds Epsom salt, and 20 pounds borax. In place of the K_2SO_4 and Epsom salt, 200 pounds of sulfate of potash-magnesia may be substituted.

Position in Profile. — As a rule, the total and non-capillary pore space decreases with depth in the profile. The largest volume of non-capillary pore space may be found in the Ap. Deep plowing is effective in increasing the desirable form of pore space.

In the B horizon, the capillary pore space increases, while the non-capillary decreases. This is much more apparent in the zone of podzolization, where the ratio of capillary to non-capillary pore space may be as high as 10:1 or even 15:1 (peat podzols). On the other hand, in chernozem the ratio may be 2:1 and lower.

MOISTURE COMPONENT

In considering the moisture component, from the point of view of the soil as a medium for plant growth, two outstanding groups of phenomena present themselves: 1, the moisture requirements of plants; and 2, the moisture supply of the soil. In other words, the moisture problem in the soil may be reduced to the law of supply and demand. Indeed, environmental factors, such as temperature, wind, humidity, and evaporation, influence the moisture regime of plants and soils.

Moisture Requirements of Plants

Germination. — A seed placed in soil will remain dormant, unless it has a chance to imbibe water. The quantity of water required for seeds to germinate is rather small; from 30 to 150 per cent of their own air-dry weight is sufficient for most seeds of cultivated plants. For example, rye seed needs 60 to 85 per cent; barley—49 to 68 per cent; buckwheat—28 to 35 per cent; peas—95 to 108 per cent; horse beans—105 to 160 per cent.

On the face of it, the quantity of water required for germination is small. Peas, for example, take 160 to 240 pounds of water for 150 pounds of seed per acre. Yet, if we remember that seeds are placed just below the surface of the ground, where desiccating winds and sun are effective in drying the soil, moisture may well be a problem. For this reason, various expedients, such as rolling the seedbed, timing the seeding so that it precedes a rain, or soaking the seeds, become understandable.

The writer has observed peasants of the Baltic countries, Lithuania, Estonia, Latvia, and of the adjoining provinces of Russia and Poland soaking seeds of peas and horse beans. In the author's own experience, early peas when soaked for 12 to 24 hours came through earlier and better than unsoaked. Apparently, the cold soil in the early spring is not conducive to best germination. Once the seed is soaked, germination is started, and the heat of the reactions involved in the process of germination makes conditions more favorable for growth.

Transpiration. — From the moment it emerges from the ground to the end of its life, a plant uses tremendous quantities of water. A very large portion of it is given off through the stomata in a process known as transpiration. The amount of water transpired per unit of dry matter formed is designated as the *transpiration coefficient.* Its numerical value varies with the plant species, and within these the values vary with environment.

In table 17, the results obtained by Briggs and Shantz, workers of the United States Department of Agriculture, illustrate the variation in transpiration by various plants.

It has been shown, that in dry years the transpiration coefficient is high and in wet years it is low. It may fluctuate from 60 to 100 per cent. The transpiration coefficients for three years, two dry and one wet, for several plants are given in table 18.

As the moisture content of the soil increases or decreases (other conditions remaining constant), the transpiration coefficient increases or decreases, i.e., the transpiration coefficient varies with the soil moisture content, but not in direct proportion to it. Thus, in the Volga region (Russia), the transpiration coefficient of wheat at 30 per cent soil moisture was 328, while at 80 per cent it was 495. For barley, the coefficients were 352 and 510 at the respective moisture contents. Other crops showed similar tendencies.

As the osmotic pressure of the soil solution increases (due, generally, to an increase in soluble nutrients), the transpiration coefficient decreases. In the brown, chestnut, and chernozem soils where moisture is a limiting factor, additions of small quantities of fertilizer reduce the transpiration coefficient. In dry years, fertilized plots have yielded a fair crop while the non-fertilized plots failed. It is very probable, that even in the humid temperate region the effect of fertilizer in reducing the transpiration coefficient is something to consider.

TABLE 17

Weight of water transpired in the production of unit weight of dry matter; transpiration coefficient

Crop	Briggs and Shantz data for Colorado		Tulaikov data for Saratov, Russia
	Extreme values for different varieties	Mean value for genus	
Proso	268 to 341	293	266
Millet	261 to 444	310	
Sorghum	285 to 467	322	
Corn	315 to 413	368	
Wheat	473 to 559	513	406
Barley	502 to 556	534	382
Oats	559 to 622	597	430
Flax		905*	
Sugar beet		397	
Potato	554 to 717	636	
Cowpea		571	
Soybeans	672 to 815	744	
Clover	789 to 805	797	
Alfalfa	651 to 963	831	586
Sweet Clover		770**	
Grasses (Wheat and Brome)	705 to 1016	861	
Various weeds	277 to 1076		

*Flax, pumpkins, and lentils grown in the semiarid Volga region of Russia show coefficients from 800 to 1500.

**Other clovers show similar values.

TABLE 18

Transpiration coefficients in wet and dry years
(Bezenchuk Expt. Station, U.S.S.R.)

Crop and variety	1911*	1915	1917
Wheat, Beloturka	576.3	302.1	463.7
Wheat, Poltavka	628.4	316.4	467.1
Oats, Giant	655.1	293.6	478.4
Barley, Moravian	617.9	288.1	337.3
Buckwheat, Red	443.1	198.2	280.2
Corn, Chinkvantino	437.1	159.7	350.2

*The years 1911 nad 1917 were dry and 1915 wet.

Water Used by Crops, Supply, and Losses

Transpiration coefficients and factors controlling these determine the quantity of water a crop may need. Knowing these facts, one may estimate the possible crop yield. As an illustration, we shall take wheat, having a transpiration coefficient of 513 (see table 17).

A *20 to 25 bushel crop of wheat yields about 1350 pounds of grain,* 1600 pounds of straw, and 1800 to 2000 pounds of roots; in all, about 5000 pounds of dry matter. To produce it, 1282.5 tons of water (513 x 5000), or close to 12 inches of rainfall, must be available during the growing season.

In the arid and semiarid regions of the brown and chestnut brown soils, the precipitation is 10 to 15 inches in the northern section and 15 to 20 inches in the southern section. Obviously a crop of wheat requiring 12 inches of water is scarcely possible. To get around the difficulty, dry farming or irrigation is practiced in these regions.

In the semiarid-subhumid regions of the chernozems, with 16 to 20 and as high as 25 inches of precipitation, chances are better for a 20 to 25 bushel yield of wheat. In fact, double this yield is not uncommon. In these regions, crops utilize the moisture resources more efficiently, since 50 per cent of the rainfall comes during the summer months.

In considering the moisture available in the soil for crop production, some sources on the credit side are often overlooked. We do not know how much moisture the soil gets in the form of dew. Another source seldom mentioned is the condensed water vapor entering the soil by diffusion from the overlying blanket of air during the hot summer months. It has been estimated that condensation moisture during the growing season in arid regions where the nights are cool may amount to a couple of inches of rainfall. Coming as it does during the critical period of growing plants, this moisture may be the determining factor in crop failure or success in the grassland country.

In the utilization of natural precipitation or irrigation waters, the problem of losses is of paramount importance. Three types of moisture losses are prominent: 1, *evaporation;* 2, *surface runoff;* 3, *percolation.* Of these, percolation cannot be assigned fully to the debit side. Much of the water that enters the soil does not percolate to the ground waters. A large share of the percolating water returns to the rhizosphere by capillary action.

Evaporation. — A portion of the moisture reaching the soil evaporates from the surface. Temperature, humidity, wind, and vegetation cover are the most important factors influencing evaporation. The evaporation from a soil surface is not the same for all soils. It is influenced by the color, texture, moisture content, and structure of soil. The overall loss by evaporation may vary from 25 to more than 50 per cent of the total precipitation.

Evaporation of water intercepted by the forest canopy constitutes an important and significant loss of moisture. This water never reaches the ground. An average forest stand may intercept 30 to 40 per cent of the total rainfall. It has been reported that two thirds of a 1.5 inch rain and one half of a 2.5 inch rain were intercepted by the canopy of a 60 year old pine stand. The interception was never less than 20 per cent of the total rainfall. In an 88 year old beech stand, the loss of water by interception was much smaller than in the pine forest: only 20 per cent of a 2.5 inch rainfall.

As to the retention of snow, the following figures may be of interest. In a forest clearing, the snow cover was 5 inches; in an adjoining birch forest also 5 inches; in an oak forest 5.6 inches; in a mixed stand of pine and spruce about 3 inches; in a pure stand of pine a little over 2 inches.

Grass sod, a stand of wheat, corn, alfalfa, or any field crop intercept large quantities of water. Losses of this kind, varying from 13 to 43 per cent of the total precipitation, have been reported for these field crops.

Runoff. — The magnitude of runoff losses depends on a series of factors, such as slope, plant cover, intensity of precipitation, and rate of percolation.

With an increase in the degree of slope, more runoff is expected. By building embankments, better known as terraces, at intervals along contour lines of the slope, the downward flow of moving waters is broken and its velocity reduced. Under these conditions, more water percolates into the soil. Besides, the water is removed alongside the embankments at a reduced velocity, with less carrying power. Hence, the moving water does not cut into the land to form gullies or cause other types of soil erosion. Terracing of soil against erosion was known to the ancients. In his travels, the author saw terraces on the slopes of the hills of Judea, built by the Hebrews, and terraces on the slopes of the Caucasian mountains, built by the Georgians in the early centuries of the Christian era.

Under forest conditions, runoff losses are reduced to a minimum. The forest floor serves as a mulch which permits rapid percolation and adsorption of large quantities of water which enter the ground waters and slowly move to the rivers. Runoff is reduced; and in this manner the forests reduce flood hazards.

Sod retards percolation and thereby supplies water for runoff. However, turf reduces the velocity of moving waters, thereby allowing some water to penetrate into the soil. It is well to remember that grasses have a high transpiration coefficient and, therefore, deplete the moisture resources of the soil. Besides, sod intercepts large portions of water on the surface of the plants. This water never enters the soil.

On soils where wind erosion is no problem, the best method of reducing runoff is to plow the land and keep it in the rough until planting or seeding time. This expedient may be practical under conditions of dry farming.

In the humid temperate and subtropical regions, orderly (non-eroding) runoff is preferred to percolation, since the latter causes removal of nutrients. In this respect, a cover crop is helpful; it facilitates orderly runoff, retards percolation, and utilizes the residual nutrients. In poorly drained fields, where runoff is no problem, a cover crop is generally not advisable. The soil should rather be plowed and left in the rough, to permit and facilitate aeration and drainage.

Intensity of rainfall influences the runoff. Thus, slow or light rains penetrate without runoff, by virtue of the capillary and more so because of non-capillary pore space that is capable of taking in the rainwater at a rate approximating the rate of precipitation. During a downpour, however, the pore space is not capable of accommodating more than a fraction of the onrushing waters; runoff is correspondingly increased. When the surface soil is dry and compact, a sudden downpour may trap the soil air and prevent water from entering the soil. Under such conditions runoff is enhanced.

Quantitatively, the amount of water lost by runoff may be as low as 5 per cent, or as high as 60 per cent of the total rainfall, depending on the factors enumerated earlier, especially the degree of slope, soil texture, and type of cover (see section on *Erosion*).

Percolation. — The greater the non-capillary pore space, the greater the percolation; and the greater the capillary pore space, the lower the percolation. Of course, pore space is controlled by soil structure, as outlined earlier, and its improvement enhances percolation. In the humid temperate, tropical, and subtropical regions, percolation, because of the poor structure of these soils, becomes impeded more readily than in the chernozem region. As soon as the soil becomes saturated, the aggregates slake and clog the non-capillary pore space. Additions of 1000 - 1500 pounds of limestone-gypsum mixture, especially in the spring, on heavy soils will greatly enhance the removal of excessive water.

Percolation is also affected by the moisture content of the soil. A thoroughly dry soil does not absorb water as easily as a moist soil. A dry dust mulch hinders the entrance of water into the soil. Light rains, therefore, are a total loss under conditions of such a mulch. The lesson is not to pulverize a soil mulch.

Percolation is also affected by the type of rooting and abundance of earthworms and other boring animals. The deeper the rooting, the greater the number of insects, worms, and other animal burrows, and the greater the percolation.

Because of the variability of factors controlling percolation, reports on the quantity of water passing through the soil vary from 30 to 60 per cent of the total rainfall.

MULCH

One of the most efficient and practical measures of moisture control is the mulching of soils. *Mulch is a material used, or a condition brought about on the surface of the soil, primarily to reduce loss of water by evaporation, to prevent growth of weeds which compete with cultivated plants for soil moisture, and to prevent erosion.* The mulch material or condition may be any of the following: 1, a 1 to 2 inches layer of surface soil worked up in place or brought in; 2, a 3 to 5 inches thick layer of straw, leaves, needles, peat moss, salt marsh or other hay; 3, paper; and 4, aluminum foil.

By definition, the most important function of a soil mulch is to reduce loss of moisture by evaporation. It is assumed that by breaking up the surface soil layer, the capillaries lose contact with the outside air. The rise of capillary moisture is curtailed, since liquid water cannot move upward through the non-capillary pore space of the mulch. Besides, a soil mulch provides an air cushion that insulates the soil against the heat of the sun. Incidentally, soil mulch facilitates soil aeration.

Another important contribution of a soil mulch is the ease of penetration of rainwater into the soil. As much as 100 per cent more moisture from small rains enters into mulched soils than into compacted soils. Practically all the water that reaches the non-mulched soils in the form of small rains evaporates from the surface without benefiting the plants. Heavy rains on compacted soils run off from the surface. Moistening the surface may even cause the loss of soil moisture from the lower layers. Crops planted in the late summer and fall in sections of the country where moisture is a limiting factor at that time of the year derive substantial benefits from the mulch-like conditions of a well prepared seedbed. Benefits to crops from cultivation are in a large measure due to mulching action.

Organic mulches, in addition to the evaporation and cooling effects, keep the surface soil in better structural condition, permit greater ease of penetration of water into the soil, and reduce runoff, thereby retarding soil erosion. Organic mulches prevent packing and caking of soil caused by beating rains and so facilitate penetration of water into the soil profile.

In orchards, mulches, besides all other functions, also prevent bad bruising of drops. In the strawberry sections of the South Atlantic States, mulches of pine needles perform the extra service of keeping the fruit clean.

Different mulching materials vary in their capacity to prevent water losses by evaporation. Thus, under a 5 cm. layer of straw on 1000 sq. cm. of a loam soil the loss of moisture was 571 cc. for a period of one month; under a similar level of pine needles, the loss was 878 cc. and under fir needles, 621 cc.

Mulches also have their limitations: *First,* fresh straw mulches may reduce the N supply of the soil to crops, as pointed out earlier. *Second,* mulches stimulate surface rooting which may prove fatal to crops in humid regions plagued with periodic droughts. As the drought strikes, the shallow rooted plants are first to suffer. *Third,* mulches are fire hazards. *Fourth,* organic mulches serve as breeding places for injurious insects. *Fifth,* mulches on sandy soils retain the moisture of small rains which otherwise would enter the soil. In dry seasons, mulches on sandy soil may, therefore, become a hindrance rather than an asset.

Lawn clippings or any other grass rich in nutrients may be used around shrubs and flowers and in the home garden. Such mulching materials serve another purpose; they absorb the fertilizer generously applied by over-zealous home gardeners. The decaying mulch holds the nutrients by adsorption and releases them gradually to the soil.

SOIL MOISTURE AVAILABILITY CONCEPTS

Soil moisture terms designate the forms of moisture which exist in the soil and convey the concepts or indices which qualify the conditions of soil moisture in relation to plant growth. We thus have the terms *vapor, capillary, gravitational water, hygroscopic moisture, optimum moisture, moisture holding capacity, wilting coefficient, moisture equivalent,* and *field moisture.*

Vapor. — The humidity of soil air, as a rule, is high because of the presence of appreciable quantities of water vapor in it. In the exchange of air between the soil and plant tissue pores, water vapor condenses in the plant tissues whenever the temperature of the tissues is lower than that of the soil. The quantity of moisture thus made available to plants is, however, of very minor significance.

Water vapor may condense on the surface of soil particles as a result of differences in temperature at various points in the soil profile. This form of water may at times play an important part in crop production (see p. 204).

Hygroscopic Moisture. — Water vapor condenses in definite amounts on the surface of absolutely dry soil, i.e., dried at 105°C to constant weight, exposed to water vapor, generally at 75° F in an atmosphere saturated with water vapor. This form of water is known as *hygroscopic*. The number expressing the percentage of hygroscopic moisture is known as the *hygroscopic coefficient*. The forces exerted by the surface energy holding the hygroscopic water are stronger than the forces exerted by the imbibition forces of plant roots. This form of water is, therefore, not available to plants directly. However, forces of evaporation which are controlled by temperature-pressure relations may convert some of the hygroscopic moisture into vapor. Thus, some hygroscopic water may become available to plants indirectly when the vapor condenses.

The finer the texture of the soil, the greater the surface area and the greater will be the hygroscopic coefficient. A medium sand is reported to have a hygroscopic coefficient of 0.09; a fine sand—0.3; a chernozem sandy loam—4.1; and kaolin—16.7.

Wilting Coefficient. — The wilting coefficient of the soil is a ***number expressing the percentage of water at which plants wilt and do not recover when placed in an atmosphere saturated with water vapor.*** The plants do recover if water is added directly to the soil. It has been variously estimated that the wilting coefficient of any soil is generally from 1.5 to 3 times its hygroscopic coefficient.

Since soil classes vary in their hygroscopic and hence wilting coefficients, they vary in the amount of water they must have to support plant life. The actual figures, expressed in per cent of the total dry (at 105°C) soil mass, are of practical importance. In a sandy soil, plant life may be sustained with a mosture content of 2 to 3 per cent; in a loam—15 to 20 per cent; in a clay soil—25 to 35 per cent; in peats 40 to 50 per cent may be necessary. One can readily see that light showers may be of great significance to sandy soils and of no value to clay soils.

It has been reported that in podzolic soils the wilting coefficient of the Ap layer is 3 times its hygroscopic coefficient; of the A_2 horizon, 2.5 times; and of the B horizon only 2 times. This moisture property of soils may serve again as a reminder that in management practices, particularly in evaluating the capacity of a soil to produce, the entire profile—not just the Ap—must be considered.

Moisture Equivalent. — The amount of moisture expressed in per cent of dry weight, held by a soil subjected to a centrifugal force 1000 times gravity is known as the ***moisture equivalent.***)The determination is carried out in a porous cup which is centrifuged at a velocity sufficient to give the desired force. Fine texture and high organic matter content lead to high moisture equivalent values. The moisture equivalent is often identical with the wilting coefficient of the soil. Typical values for the moisture equivalent of several soil classes are: for sand—3.6; fine sand—4.3; sandy loam—10.3; silt loam—19.8; clay loam—23.1. From data on the moisture equivalent of soils one can approximate their texture.

Capillary Water. — Using a simplified interpretation, capillary water is water held by surface tension forces in the soil pores, after the free water—that which is subject to gravitational pull—has been allowed to drain away. Capillary water moves, irrespective of gravity, in all directions: upward, downward, and laterally. Thus, when a soil is flooded, either by irrigation or by natural rainfall, a good share of the downward distribution of water may be attributed to capillarity. Furrow irrigation waters are distributed through the soil by downward and lateral capillary movement.

As capillary moisture moves from points of saturation into masses of dry soil, or when moisture is removed from the soil by evaporation or transpiration, the columns of moisture in the capillaries thin out into hollow cylindrical films. This process of thinning out goes on until the films of moisture are under such tension that the moisture is no longer available to plants; i.e., the water is no longer considered as capillary, it is hygroscopic water.

Capillary moisture is the greatest source of available moisture, since plants can use it within its wide range: from full capacity, when the capillaries are filled, to the point when the films on the walls of the capillaries approach the wilting coefficient. An example may illustrate the wide range of capillary moisture available to plants. A loam soil with a 60 per cent capillary capacity—close to the moisture holding capacity—and wilting coefficient of 8 has a store of 52 per cent available moisture. A sandy soil with a 15 per cent capillary capacity and a wilting coefficient of 1.5 has 13.5 per cent available moisture.

Gravitational Water. — Gravitational water is a term used to denote that water which, under the influence of gravity, moves freely through the soil. Gravitational water is the mother source of all forms of moisture in the soil. Were it not for the gravitational pull, very little of the rain or artificially applied water would penetrate deep into the soil. In its downward movement, the so-called gravitational water feeds the capillaries and supplies the soil with available moisture.

Moisture Holding Capacity. — When a soil is saturated with water, i.e., after the free flowing water has drained away, it is said to be at its moisture holding capacity. This concept provides a useful index, especially in gauging applications of irrigation water and watering soils in greenhouse and pot culture experiments. The moisture holding capacity of any soil varies with the texture and organic matter. The finer the texture and the greater the organic matter content, the higher the moisture holding capacity. *Moisture holding capacity is the weight of water held by a given quantity of absolutely dry soil (dried at* 105°C) *when saturated.* This index is abbreviated by the letters M.H.C., and its value is expressed in per cent. *Example:* a soil at 105°C weighs 80 grams and upon saturation—100 grams; thus, it took on 20 grams of water; therefore, the M.H.C. is $x : 20 = 100 : 80$; and $x = 25$.

Optimum Moisture. — Optimum moisture is that quantity of soil moisture at which plants, as a rule, thrive best. Optimum moisture is not a single value, but depends rather on type of plants and other conditions of plant growth, such as supply of nutrients, temperature, and aeration. Generally, however, 50 to 60 per cent of the total moisture holding capacity of the soil is optimum for the majority of cultivated crops. In other words, optimum moisture value represents an attempt at an average. There are plants, for instance, which thrive better at higher than so-called average optimum. Barley has been reported to thrive best at a 60 per cent optimum, rye at 75 per cent and oats at as high as 90 per cent. There are, on the other hand, crops which do best with less moisture.

It is much easier to keep a sandy soil at optimum moisture than a clay or a muck. A light shower may suffice for sandy soils, but not for a loam. A sandy soil with a 12 per cent M.H.C. needs 6 to 7 per cent moisture for optimum conditions of plant growth; a clay soil with a 50 per cent M.H.C. needs 25 to 30 per cent moisture; and a peat or muck with a 300 per cent M.H.C. needs 150 to 180 per cent moisture. Sandy soils are, therefore, preferred in greenhouse culture. In heavy soils, the danger of overwatering, a common fault among greenhouse men, is real. The poor circulation of air in greenhouses makes soil aeration a problem. Since heavy soils are more readily influenced adversely by aeration, they are avoided by greenhouse men. The phenomenal successes reported on growing flowers and winter vegetables in gravel and similar media under greenhouse conditions are in a large measure due to the excellent aeration this method provides for the plant roots. Aeration in soils should be emphasized again and again in any discussion of soil conditions and plant growth.

Field Moisture. — The moisture condition of the soil, expressed in per cent of water in a field sample at any one time, is known as the *field moisture.* Quantitatively, it may vary from hygroscopic to moisture holding capacity. This term should not be confused with the field capacity, which is used by hydrologists in connection with irrigation and other moisture problems. ***Field capacity*** is defined as the amount of water held in the soil after the gravitational water has drained and the downward capillary movement has materially decreased. Field capacity is sometimes designated as normal capacity, capillary capacity, and normal field capacity. In terms of the forms of water just discussed, it is closest to capillary moisture.

DRAINAGE AND IRRIGATION

Drainage is the practice of removing water from lands suffering from excesses of it. Irrigation is the practice of supplementing natural precipitation. Under conditions of saline soils, both drainage and irrigation complement each other.

Drainage

Wet fields or wet spots in a field are a nuisance to the farmer. They warm up late in the spring, dry slowly, delay plowing, and hinder the general preparation of the land for sowing and planting. In the northern regions such delays may prevent the planting of the crops wanted because there might not be enough frost free days to mature them. In the winter, poorly drained fields cause heaving and drowning out of grains and hay. In short, poor drainage present special problems.

Occasionally local areas in otherwise well drained fields which have no high water table[3] develop a condition of retaining water on the surface of the soil. This condition appears generally in the spring, but it is not uncommon to see it any time during the summer or fall after heavy precipitation. From year to year these areas seem to extend and in many cases they turn into temporary or even all year around ponds. The cause of this condition, described as surface swamping or pond formation, is associated with the dispersion of the clay, as discussed in chapter VII. Treating the soil with lime-gypsum mixtures and installing dry wells whenever the subsoil is sandy or gravelly are efficient means of dealing with this problem. A full discussion of it may be found in the New Jersey Agricultural Experiment Station Extension Bulletin 215 (1940).

The chief problem of soil drainage deals with areas where the water table is high and systems of drainage, the open or the underground, have to be installed.

Open Drains. — This type of drains consists of ditches varying in depth from 3 to 5 feet and deeper. Generally, fields are ditched in units, leading the drainage water to a larger receiving ditch. Groups of units with their respective receiving ditches lead to the main outlet or canal. Such

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[3] Water table, ground water, and phreatic surface water mean the same, namely the position of water in the ground coming from below. The water may rise to the surface or to any point below the surface. In the ground, there may be several water tables. In soil work, reference is usually made to the uppermost water table.

canals may become large enough to serve as means of transportation and as fishing grounds.

In the so-called organic soils, such as the peat and muck lands of Florida (The Everglades), Michigan, Minnesota, New York, and other states, the open ditch type of drainage is the more common one in use. Only after the peat had settled (with cultivation, large quantities of organic matter decompose, causing shrinkages in volume), may the open ditch type of drainage be replaced by a system of tile drains.

There are a number of objections to open ditches. They have to be in constant repair; their banks harbor weeds; they must have sturdy bridges for the movement of animals and farm machinery; they occupy some land and the edges cannot be cultivated; they serve as breeding places for mosquitoes and other undesirable insects. In extensive drainage projects involving large areas, the layout of a ditching system requires the joint skill of an agricultural engineer and of a pedologist.

Underground Drains, or Underdrains. — Trenches filled with brush or stones and covered with soil serve, in wet areas, as excellent drainage channels. This type of underdrain is of ancient origin and is still used successfully in many parts of the world.

In the beginning of the 19th century, the burnt earthenware type of pipe, known as tile, was introduced in England. The first tile drain system in the United States was introduced in 1835 by John Johnston on his farm in Geneva, New York. It is reported that this system of tile drainage is still operating.

Water enters the tile at the joints. Not more than 5 per cent of the water carried by a system of tile drains enters the porous walls of the tile.

The depth at which tile is laid depends in a large measure on the texture of the soil. Fine textured soils, such as loams, silt and clay loams, require a shallower system than the coarse textured soils. Thus, in clay soils the depth would be 2 to 3 feet, whereas under similar environmental conditions the depth in sandy soils would be 3 to 4.5 feet.

Any system of underdrains must consider the condition of the B horizon, which is generally located below the 12 to 20 inch depth[4] and as deep as 30 to 40 inches below the surface. As a rule, the lag in the movement of water in the soil profile is due to the compactness of the B horizon and the dispersion of the soil resulting from a high water table. Barring other considerations, the tile should be placed in the upper portion of the B horizon. This arrangement will take care of the rising water table and of the water that passes through the A horizon and becomes trapped in

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[4] This is the average depth of the A horizon of a mature loam soil all through the humid temperature region down to the lateritic region of the southern states; the A horizon is somewhat deeper in the degraded chernozem.

the B horizon. By laying the tile, especially the laterals, along the B horizon, a rapid removal of water is assured.

In regions where the frost line extends 5 to 8 feet and deeper, tile systems are not effective. The tiles crack, heave, get out of line, and in a season or two the system is rendered useless. Open ditches are, therefore, practiced in northern regions.

Systems of Tile Drainage. — The spacing of mains and laterals depends on a series of factors, such as the quantity of water the system has to carry, texture of the soil, and height of the water table. Arrangement of mains and laterals, laying out lines of tile, making provisions for outlets, and carrying out other operations necessary for proper drainage, all of that is a specialized branch of engineering.

In the main, the principle of laying out a system of tile drainage is to lead the water along the lines of the natural slope towards a brook or stream. An important feature of any tile system is to protect the outlets against rodents. They are liable to clog up the drains by bringing in foreign material.

Tiles are placed end to end with joints fitting closely. Soil material from the Ap is packed around the joints. The trench is filled with material of the A horizon first, followed by material of the B horizon. To enhance the drainage, the surface of the trench is treated with a mixture of lime and gypsum, 2 to 1, at the rate of 1 to 2 tons per acre, the smaller amount for light soils and larger amount for heavy soils. The entire trench then constitutes a drain, with the tile serving as the means of the rapid removal of water.

Mole Drainage. — A knife edge from a plow beam cuts into the soil as much as 2 feet deep. A mole, ball, or bell is attached to the bottom of the knife. As the knife moves through the soil, the mole leaves behind a small channel which is supposed to take care of the excess water. Accounts on the efficiency of mole drains are conflicting. It is generally agreed, that at best they are temporary in nature. Occasionally, they fill with mud in one winter and cease to function. A serious objection to knifing operations is the formation of very smooth surfaces on the walls of the soil (due to the cutting action of the knife edge of the mole plow), whereby the movement of water is impeded.

Land Reclamation. — The broad meaning of land reclamation embraces the drainage of land under water, such as lakes, fens, marshes, and even ocean bays. Pumping operations on a gigantic scale and systems of dikes and canals are the chief engineering feats of such projects. The drainage of the Zuider Zee in Holland is the outstanding example of this type of land reclamation. One has to travel over the marvelous concrete roads on the top of the dams of this project to appreciate the magnitude of the undertaking. More than a half million acres of land have been reclaimed from the inland sea that was connected with the North Sea. The entire area is divided into 4 drainage units known as *polders*.

Land in delta regions and many lowland areas have to be pumped before they can be drained properly. In the United States, we have close to 57 million acres that can be classified as land reclaimed by the pumping method.

IRRIGATION

"And a river went out of Eden to water the garden" (Genesis 2:10), is the biblical record of the ancient practice of irrigation. Egyptian paintings and sculptures of 4000 years ago recount the bailing of water for irrigation. As the author traveled, in 1935, along the Nile Valley and marveled at the modern installations, he could not help but recall that these installations were nothing more than a modified form of the early basin system of irrigating with the flood waters of the Nile.

In the middle Rio Grande Valley in New Mexico, and in the San Pedro and Santa Cruz Valleys in Arizona, the Spanish settlers found in the Indian pueblos a well organized system of water rights and methods for irrigation. The modern system of irrigation in the United States was introduced in 1847 in Utah, when Brigham Young and his fellow Mormons started the diversion of water for irrigation from City Creek near the site on which now stands Salt Lake City.

Most of the irrigated lands in the United States are located in the 19 Western states west of the 100th meridian. According to the 1930 Census of Irrigation of Agricultural Lands, 17,465,000 acres out of a total of 49,489,000 acres of crop land were under irrigation in the following states: Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington, and Wyoming. Of the 503,047 farms in these states, 241,342 are listed as irrigated farms. The 1939 census records 21,003,739 acres under irrigation, and when the projects under way are completed, 31,305,949 acres will be under irrigation. The ultimate irrigable area in the Western states is 51,535,000 acres.

The soils under irrigation in the arid west belong to the following zones: gray, brown, chestnut brown, and sections of chernozem adjoining the chestnut brown. On soils in the zones of podzolization and laterization, irrigation is used primarily for specialized vegetable crops.

Irrigation in Arid Regions

From the most primitive method of bailing water by hand to the modern system of impounding water in huge lakes by gigantic dams, such as the Grand Coulee and Boulder dams,[5] lies a time period of thousands of years. Still, all stages in the development of irrigation methods find their application. While in Panama, in 1939, the author watched with mixed feeling of woe and admiration the infatigable Chinese bailing water and carrying every drop to their model vegetable gardens.

The old well sweep, the "shadoof" of Egypt, or the man-mounted "picotah" of India are still used in various parts of the world. A later development in hoisting water was the simple crane, the waterwheel, and the most modern method is the pump. Weirs (structures built across streams to raise the level of water on the upstream side with sluice gates to lower the level if necessary) were known to the ancients. From the raised level in the river, water could be diverted by gravity to higher points, as high as 15 to 20 feet. Water holes or basins filled with water during flood periods for irrigation are ancient methods still in use in Egypt; the basins are tilled and planted after the flood waters disappear or are drained off. Some basins cover an area of 50,000 acres.

Systems of Irrigation

Of the several systems of irrigation now in use, the following are the *more prominent:*

Flooding. — If large land areas of fairly smooth topography are to be irrigated and there is an ample snpply of water, flooding is the most common system of irrigation. Water is carried by trenches built with a grade and often in more or less curved lines. In many cases laterals are made to carry some of the water. In flooding, the land becomes submerged for a short period until the water penetrates to the depth desired. Grain crops, alfalfa, hay, and large orchards are adapted for this system of irrigation.

Furrow. — As the name implies, water is distributed by a system of furrows over the area. It is the common method of irrigation on hillsides where contour furrowing is possible. The distance apart and the length of furrows are determined by the texture of the soil and the grade. The finer the texture, the longer and closer the furrows have to be arranged. This system is well adapted to row crops that have to be cultivated and may be grown on ridges.

Pipes. — On land of broken topography and where water has to be pumped, one has to resort to a system of water pipes. This method of irrigation is expensive and is used only on crops which give a high return,

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[5] Boulder dam impounds 30,500,000 acre feet of water which is expected to provide 2,100,000 acres of irrigable land. Grand Coulee will impound 208,000,000 acre feet of water which should take care of 14 million acres of irrigable land.

such as the valuable orange or avocado groves of California. Pipes, of course, are used in permanent or portable sprinkling systems.

Installing an Irrigation System

In planning an irrigation system, the following two factors are to be considered: 1, the quality and quantity of the water supply; 2, the soil conditions.

Water Supply. — Irrigation water is precious in the arid regions and expensive even in the humid regions. Farmers have learned to appreciate the *duty of water,* a term meaning the quantity of irrigation water the land must receive to produce a crop. This includes the water required to produce the dry matter and that lost directly from the soil by evaporation. Rains during the growing season, scant as they may be, and moisture condition of the soil profile at the beginning of the growing season have to be considered in figuring the duty of water.

Other elements to be considered in calculating the duty of water are the anticipated yields, which depend on soil management and cultural practices. The quantity of water necessary to produce the dry matter may be calculated from the transpiration coefficient. Knowing the quantity of water necessary to produce one pound of dry matter, it is simple to calculate how much water it will take to produce a crop of 3 to 5 tons.

In evaluating the quantity factor in irrigation, depth of watering has to be considered. The ideal course to follow, is to irrigate the soil to its field capacity to depths of root penetration, which means 3 to 5 feet. Excess of irrigation water is not only a waste, but sometimes may cause a rise of the water table whereby injurious salts may appear in the root zone (see Ch. IX).

From experience in Utah, it has been learned that wheat on fertile heavy soil required from 7 to 8 inches of water in 2 waterings. Wheat on poor gravelly soil needed 15 to 18 inches in 4 or 5 waterings. A vigorous alfalfa crop on a heavy soil may use as much as 24 inches in 3 waterings.

In planning an irrigation system, quality of water is the first consideration. Quality refers to ***concentration*** of salts, usually reported in parts per million (ppm), and kind of salts, i.e., how much Ca, Mg, K, and Na compounds make up these. In general, if the water contains less than 1000 ppm of soluble salts, and the quantity of sodium compounds among these is low, it is suitable for irrigation. For purposes of comparison, the soluble salt content of several river waters is given: The Blue Nile—120 ppm; the White Nile—150 ppm; Arkansas River at Rocky Ford, Colorado—2000 ppm; Jordan River, Utah—890 ppm. (see Chapters

IX and XIII for quantitative conductivity measurements of irrigation waters).

Irrigation water of a high salt concentration may convert a normal soil into a solonchak within a few years. If the salts are made up of sodium compounds, the inevitable solonetz with all its noxious features may ensue. Many reclamation projects have failed because of a lack of information on the quality of the irrigation waters.

Losses of water in transmission are an important factor in the calculation of the water supply for irrigation. Ditches, canals, flumes, and furrows lose water by leakage, percolation, faulty grade, and speed of delivery. These losses may amount to 30 per cent or more of the water delivered at the source. Some of these losses may in part be eliminated by silting the bottoms, dispersing the clay with sodium chloride, or lining the canals with concrete.

In concluding the discussion on water supply for irrigation, it may be added that the problems of the duty of water are to be examined jointly by a hydrologist-engineer with experience in the area and a pedologist.

Soil Conditions. — In determining the suitability of land for irrigation, the following factors pertaining to the soil have to be explored: 1, water soluble salt content of the profile and of the subsoil; 2, the texture and chemical composition of the soil; 3, drainage conditions of the area.

1. If the *water soluble salt* content of the soil is high, irrigation may bring about a solonetz condition within a few years. Under such circumstances, one has to anticipate ameliorative measures, as described (Ch. IX).

Before inaugurating any irrigation project, the soil profile should be thoroughly investigated. One should be on the lookout for a hidden solonchak (see Ch. IX) through a depth of 5 to 6 feet below the surface. Many reclamation projects have gone on the rocks because the irrigation water caused a rise of the salts of the hidden solonchak towards the root zone or even to the surface. To overcome such difficulties, a sufficient supply of water to flush the soil and proper drainage facilities are essential.

2. The texture of the profile and of the subsoil is an important factor in determining the suitability of the soil for irrigation. Heavy plastic clays or clay loams, particularly those of the adobe type,[6] are difficult to handle, especially if some sodium is present in an adsorbed state. After a season or two of irrigation, the clay becomes highly dispersed and the soil as a whole impervious to water. It can be treated as a solonetz, as

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[6] Adobe is a heavy clay and silt material of alluvial and aeolian origin. It is found in the arid West where it is popular for its stickiness when wet and brick like in nature when dry; in the latter state it is used for building purposes. If adobe has no adsorbed Na and enough Ca, it may be irrigated.

discussed in chapter IX, but this is an expensive procedure. Except for special circumstances, clay soils should not be put to irrigation.

In bottom lands, materials are often laid down on an unevenly eroded landscape, giving rise to deep but wet spots in water holes and to dry and shallow spots on the outcrops. These features may cause local spots of salt accumulations and of uneven drainage. Such soils should never be put to irrigation.

In general, the coarse textured soils, such as gravelly sandy loams, sandy loams, and loamy sands, are preferred for irrigation, because they take the water much better than heavy soils. The paucity of nutrients in coarse textured soils does not disqualify them for intensive cropping with irrigation. Nutrient deficiencies may easily be made up with mineral fertilizers. With judicious watering, very little of the fertilizer salts are washed out. As a matter of fact, the better method of applying fertilizer is to introduce fertilizer solutions with the irrigation waters (see Ch. XII).

3. In examining land for irrigation projects, drainage facilities have to be scrutinized. Lack of these facilities preclude the irrigation of solonchak. Even light soils must have an outlet for flush water, otherwise salts will accumulate. In some areas, the natural topography takes care of the drainage. Generally, however, drains have to be provided for.

Most irrigated lands are located in valleys where drainage is usually a problem. About 25 per cent of the land under irrigation is in need of drainage. Tile is laid 4 to 8 feet deep, 200 to 300 feet apart.

AIR COMPONENT

The importance of air circulation in the soil has been discussed in chapter VI. It may be recalled that roots need oxygen for respiration, but they can survive a much longer time with a low oxygen content than animals can. Some species of willows may live for weeks without a sufficient oxygen supply. Swamp plants thrive in a medium almost free of oxygen. On the other hand, most mesophilous[7] plants (mesophytes) begin to suffer as soon as the oxygen content is reduced by an increase of CO_2 concentration equal to one per cent.

Composition of Soil Air. — Soil air, like that of the atmosphere, consists primarily of nitrogen and oxygen. The 78.03 per cent nitrogen (by volume) is inert, whereas the 20.9 per cent oxygen is most reactive.

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[7] The ecologic classification of plants, with reference to the moisture factor, is made up of three groups: xerophytes—desert plants, hydrophytes—water habitats, and mesophytes—the greatest number of land plants which stand between the other two extremes.

The important difference between soil air and that of the atmosphere is in the CO_2 content. The atmosphere contains, by volume, 0.03 per cent CO_2, whereas soil air may contain 0.2 to 1.0 and more per cent.

Another constituent of air that varies is water vapor. In the atmosphere, it averages between 1 and 3 per cent by volume, but may locally and temporarily rise to 7 to 8 per cent. Soil air contains relatively more water vapor than the atmosphere.

Factors Influencing Soil Air. — The composition of soil air, unlike that of the atmosphere, fluctuates within wide limits. As plant roots respire, they give off CO_2. Unless an exchange of air takes place, the concentration of CO_2 in soil air may reach the dangerous threshold, i.e., about 1 per cent, a concentration toxic to most cultivated plants. On the other hand, plants derive the greater part of CO_2 for photosynthetic activities from soil air.

Most of the gas exchange between soil air and the atmosphere takes place by diffusion. Soils of the pedocals, which are endowed with a large volume of non-capillary pore space, have a high capacity for exchange of gases. They diffuse with difficulty through heavy soils of the pedalfers because of the excess capillary pore space. These soils may, therefore, suffer from an excess of CO_2 in the soil air.

A complete change of soil air takes place after saturating rains. Fluctuations in temperature and movement of air currents contribute to the exchange of gases. Sudden changes in barometric pressure also cause a movement and exchange of gases.

The CO_2 content of the soil air increases with depth. This is especially true for soils in the podzol zone where the B horizon is, as a rule, of fine texture and compact. Because of the high CO_2 content, roots do not penetrate deep into the soil. It is therefore important to plow deep, keep the moisture moving through the soil, and to expedite all measures which increase the non-capillary pore space. It has been reported, that at a depth of 2 feet the soil air may contain as much as 4.5 per cent CO_2 and only 11.0 per cent O_2; at 6 feet the soil air may have 15.5 per cent CO_2 and only 0.2 per cent O_2. Such high CO_2 content in soil air is rather rare. Besides these two gases, the soil air may contain H_2S, CH_4, NH_3, and some rare gases. Most of these gases appear under anaerobic conditions and are injurious to plants. During the growing season, the air of the surface foot of soil contains more CO_2 than during the dormant season.

Variability in Plants in Relation to Aeration. — In concluding the subject on the factors of aeration in soils as related to plants, it may be well to remember that plants vary physiologically. It has been pointed out that certain plants, such as the willows, can thrive without any or on very little oxygen. Unfortunately, the physiology of most cultivated plants in relation to aeration is not well known. Some general information has been collected. Most of the grains are more resistant to anaerobic conditions than legumes, oil bearing plants, tubers, and roots.

SOIL TEMPERATURE

Soil temperature is in many respects associated with the moisture regime of the soil. It is, therefore, appropriate to consider at this point some of the salient features of soil temperature.

Temperature Effects at Various Stages of Plant Growth.— Definite information is available on the relation of temperature to seed germination, formation of early roots, and crop prospects.

Table 19 shows the influence of temperature on speed of germination and appearance of true roots, and table 20 shows how germination temperatures vary with the plant species. Some inferences of practical value,

TABLE 19

Influence of temperature on speed of germination and apperance of first true roots.
(After Haberlandt)

Crop	At 40°F	At 50.5°F	At 60°F	At 66°F
	Number of days it took for germination and root formation			
Rye	4	2.25	1.0	1.0
Oats	7	3.75	2.75	2.0
Peas	5	3.0	1.75	1.75

TABLE 20

Temperature effects on germination of seeds
(After Haberlandt)

Crop	Temperature (°F)		
	Minimum	Optimum	Maximum
Rye	34 - 36	77	86
Hemp	34 - 36	95	113
Barley	37.5 - 40	68	82 - 86
Wheat	37.5 - 40	77	86 - 90
Oats	39 - 41	77	86
Sorghum	46 - 50	89 - 95	122
Corn	46 - 50	89 - 95	104 - 111
Tobacco	55 - 57	82	95
Cucumbers	54 - 59	91 - 95	104

based on the data of these tables, may be cited. Planting dates are generally scheduled on the basis of air temperatures which do not necessarily imply favorable soil temperatures. Good tomato growers in the temperate zone do not set out plants in a cool soil; knowing full well that no new roots will form and that if the low temperature should prevail for a week or ten days the crop may be doomed. Delayed germination of corn or sorghum, because of low soil temperatures, may ruin a seeding.

Not much is known about the effects of either too low or too high a temperature on the performance of plants at advanced stages of growth. In general, low temperatures are more troublesome than high temperatures. Still, there can be a soil temperature too high for the best comfort of plants. We do know of cool temperature plants, such as the cruciferae, lettuce, and onions, and warm temperature plants, such as corn, cucumbers, and melons.

Texture and Organic Matter Effects. — Moisture is a dominating factor in regulating soil temperature. This may be best illustrated by the following physical law: it takes 5 times as many heat units to raise 1 unit weight of water through 1°C, than 1 unit weight of dry soil, i.e., the heat capacity of water is 5 times as high as that of dry soil. It is, therefore, self-evident that the heavier the soil, or the higher the organic matter content of a soil, the more water it will hold and the greater its heat capacity. This heat capacity factor is responsible for heavy soils and those rich in organic matter keeping cooler for a longer time in the spring and warmer in the fall.

A cold rain in the spring is more damaging to a crop in a heavy soil than in a light soil. In the latter, water drains away, and the soil warms up fast. A warm rain, on the other hand, is a boon to a crop in the spring, inasmuch as the warm rainwater speeds up the rise of the soil temperature.

Other Factors. — Fields of a rolling topography with a southern exposure have a higher soil temperature than those of northern exposures. The variations in soil temperature on slopes of different exposures have their effect on the type of vegetation and soil. On a trip to Pikes Peak in the Rocky Mountains, it was noted that on slopes with a northern exposure conifers prevailed, whereas on southern exposures deciduous or mixed forests prevailed. Correspondingly, the process of podzolization was much farther advanced in the soils of the northern exposure. Long ago geobotanists recognized flora variations due to differences in exposure. They have not, however, evaluated the effect of soil temperatures on the flora variations.

Under controlled conditions, there is an optimum soil temperature range for best growth of plants. Under natural conditions, one may expect such an optimum in equatorial regions, where temperatures tend to approach constancy. It is very likely that the prevalence of optimum soil temperatures in the tropics is a primary factor in the production of the rank vegetation. Conversely, the constantly fluctuating surface soil temperatures in the other climatic regions is a negative factor in plant growth.

Soil temperatures become constant (or close to that) at a certain depth below the surface. Soils conducive to deep rooting, such as the pedocals, offer optimum temperatures below the surface 6 to 8 inches or so. It is reasonable to assume, that this property of pedocals is beneficial to plant growth. Better aeration in the soils of the zone of podzolization is conducive to deep rooting and should be encouraged.

An excellent expedient towards more uniform soil temperatures is mulching. Readings taken to a depth of 4 to 6 inches on mulched plots at the New Jersey Experiment Station Vegetable Farm have shown a difference of 8 to 10°F on hot days. In general, the mulched plots suffered least from soil temperature fluctuations at a depth of 6 to 8 inches.

CHAPTER XI

THE NEWER KNOWLEDGE OF LIMING SOILS

Calcium and Magnesium in the Zonal Soils. — In the gray semidesert soils, Ca accumulates in the profile as $CaCO_3$ and gypsum. The formation of the latter salt is very fortuitous, for it is the ideal material to combat Na in ameliorating saline soils (see Ch. IX).

In the brown and chestnut brown soil zones there is sufficient rainfall to remove the gypsum from the profile. However, Ca and sometimes Mg-carbonates accumulate in the B and sometimes also in the lower layer of the A horizon. The abundance of Ca in circulation keeps these soils in favorable structural condition, unless solonchak and solonetz invade these soils.

In the chernozem soils, large quantities of Ca are released and sent into circulation as a result of the huge turnover in the formation and decomposition of organic matter. Although Ca and some Mg accumulate in the B horizon as the insoluble carbonates, enough $Ca(HCO_3)_2$ is formed to supply active Ca ions. They stabilize the structure of the soil and enhance the accumulation of organic matter, as discussed in chapter VIII. In short, it is Ca that is responsible in large measure for the granular structure of chernozem, for its high organic matter content, and its proverbial fertility.

In the vast zones of podzolization and laterization, Ca and, in a large measure, Mg are subject to severe leaching and loss from the soil profile. The result is soil acidity (see Ch. VII).

The implications of an abundant supply or loss of Ca and Mg in the plant-soil relationships may be broadly stated as follows:

Retention of Ca in the profile is, in a large measure, the saving grace in the utilization and management of the *pedocals*—the gray semidesert, brown, chestnut brown, and chernozem soils. Loss of Ca and Mg from the *pedalfers* (the soils in the zones of podzolization and laterization) is, on the other hand, the most challenging problem in managing them. For successful farming on land of the pedalfers, the return of the lost Ca and Mg to the soil is imperative. A thorough appreciation of the functions of lime, an understanding of the reactions between the soil and the liming materials, and skill in carrying out the liming program are fundamental in the solution of many puzzling problems in the zones of podzolization and laterization.

EFFECTS OF ACIDITY IN THE PLANT-SOIL SYSTEM

1. As the soil becomes acid, because of the leaching of the Ca and Mg, Al, Fe, Mn, and some acid soluble organic substances originate in the A horizon and moves into the B horizon. As the pH of the soil decreases, these elements appear in the B horizon in quantities toxic to plants. Plant roots stay away from this horizon and restrict their activities to the Ap, where the organic matter serves as a buffer against toxic substances.

In dry years, with a reduced moisture supply for percolation, toxic materials may rise to the Ap and damage the crop, despite the buffer capacity of the organic matter. Potatoes, which are forced to grow in acid soils because of the scab plague (the validity of this generally accepted idea is now being questioned), are seriously handicapped in dry years. Their limited root system (only 7.5 per cent of the weight of tops) is cramped into the Ap layer; the plants are apt to suffer from toxic materials and chance to utilize the moisture resources of the B and C horizons.

Applications of 1500 to 2000 pounds of a 5-10-10 fertilizer (5, 10, and 10 per cent of N, P_2O_5, K_2O respectively) per acre are practiced in potato culture. Of the 150 or 200 pounds P_2O_5 supplied by the fertilizer, a 300 bushel crop of potatoes (tubers only) removes 30 to 35 pounds. What happens to the remainder 115 to 165 pounds P_2O_5 supplied by the fertilizer? The surplus of soluble phosphates combines with the soluble Al, Fe, and Mn present in acid soils rendering these elements insoluble and tying up (immobilizing) the phosphates. Unless the farmer applies an excess of P_2O_5 every year, the crop may suffer.[1]

2. Acid soils absorb very little of the basic ions, such as NH_4, K, Ca, and Mg. These ions can not compete successfully with the H ions for positions in the exchange comples and are more easily leached.

3. Fertilizers added to an acid soil tend to stimulate the crop, with the result that plants put a heavy demand on the soil for available Ca and Mg. Failure to supply these elements reduces the efficiency of the fertilizer.

4. The clay and humus fractions tend to disperse in acid soils, causing waterlogging and impeded aeration. They also seem to induce compaction.

5. The activity of bacteria and actinomyces is depressed in acid soils. Even fungi become autolized, i.e., they perish in the toxins of their own making. The result is a quiescence in the processes of humification and

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[1] The quantity of P in potato fertilizers may be reduced and higher yields obtained by supplementing the fertilizer with 500-600 pounds of a mixture of dolomitic limestone, gypsum, and Epsom salt (or sulfate of potash-magnesia) in the ratio of 2:2:1. This mixture tends to eliminate the soluble Al in the soil and to release more P. In general, too much P is used in potato fertilizers.

mineralization. Without these processes, a large supply of plant nutrients, especially N and minor elements, is cut off.

Activities of symbiotic and non-symbiotic N fixing organisms are reduced to a minimum in acid soils. These sources of N have not been as yet thoroughly appreciated.

6. Lastly, H ions are in themselves not conducive to plant growth. However, it is the activity of the H ions (and the resulting acidity) that is most troublesome in the plant-soil system.

LIMING OF SOILS

Since the ill effects of soil acidity are caused by the depletion of Ca and Mg, the restoration of these is the only rational, effective, and economical remedy. Properly administered, applications of lime eliminate acidity and its injurious effects on crops and soils.

History of Liming. — The use of liming materials in agriculture antedates the Christian era. Besides being applied to the soil, they have been used to combat insects and diseases of plants. Whitewashing fruit and ornamental trees is an ancient practice still in vogue. In 1938, the author visited many orchards in the Baltic countries, in Poland, and in Czechoslovakia, that had been whitewashed to insure protection against disease and insect pests.

In England, lime was used very early, much earlier than on the continent. Some claim that in Britannia and in Gallia (France) liming was known and practiced in the days of the Romans. Roman writers tell of the marling and liming of land by the Gauls as early as 500 B.C. There could have been no interest in liming among the prehistoric settlers, the inhabitants of the valleys of the rivers Euphrates and Tigrus, known as Messopotamia (Iraq), and all through the Middle East. These arid countries had no need for liming. Only after the extension of agricultural settlements to the humid regions did the liming problem come to the fore.

In the first quarter of the 19th century, marling or liming of soils was very popular in England. The practice fell into disfavor a few decades later, because it failed to maintain the high crop yields of the first few years and in many cases even depressed yields. They did not realize then that the early flare-up in yield was due to the neutralized acidity, improved physical condition of the soil, and to the sudden increase in the supply of nutrients at the expense of organic matter decomposition. Farmers, as well as soil specialists of that day, did not realize that by removing increased crop yields and returning only a portion of the nutrients in terms of manure, there must come a time when the soil will run short of certain nutrients. This depletion of the natural supply of nutrients was especially noticeable in the non-legume rotations where N became a limiting factor.

Not knowing the cause of the crops' decline, liming was blamed for the failures.[2] Later, however, the researches of the Rothamsted Experiment Station, one of the oldest of its kind in the world, and of others on the continent, reestablished the reputation of liming and placed its practice on a more scientific basis.

In Germany, liming was not as popular as in England. There are, nevertheless, records on the use of marls in the lower Rhine provinces in the 12th century. In the 18th century, burned lime was used in Silesia, Holstein, Saxony, and other minor areas. Lime was recognized as a remedy against sour soils, poor drainage, and as an agent for the improvement of heavy soils.

The history of liming practices in England repeated itself in Germany. In the early period, there was great enthusiasm, followed by disillusionment, and ending with a scientific appreciation of the effects of liming soils.

In the United States, liming did not become a widespread practice until the last years of the 19th century. The Land Grant Colleges, established during Lincoln's administration, and the network of Experiment Stations that soon followed had to catch up with the rapid expansion of agriculture during the reconstruction period. There was no scarcity of land and very little effort was made to face the problems that had arisen in the older sections of the country. Gradually, however, well organized state and national institutions took in hand the complex problems of agriculture. In the region of intensive agriculture, the eastern part of the country, soil acidity has been recognized. Extensive campaigns on the benefits of lime have been conducted by most of the Experiment Stations and by the United States Department of Agriculture.

DETERMINING LIME REQUIREMENTS

How much lime is required to counteract the acidity of the soil? With information available on the range of pH values at which the various crops grow best, the question is reduced to this: how much lime is required to raise the pH of the soil to the one desired for any given crop? Theoretically, the answer to this question is simple. We have to replace the H ions of the exchange complex[3] with a cation, *titrate the acid that has gone into solution with a standard alkali to the desired pH, and from the titration figures calculate the quantity of* $CaCO_3$ *needed.* A practical example will illustrate this.

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[2] Before the real value of lime was clearly understood it came to be an adage: "Liming makes the father rich and the sons poor."

[3] The portion of soil material which has the property of exchanging cations; hence also, exchangeable hydrogen. For a more detailed explanation the reader should consult chapter VII.

A weighed sample of air-dry soil (10 grams for a heavy sandy loam, or heavier, and 25 grams for a loamy sand or sandy soil) is placed into a 250 cc. Erlenmyer flask and 200 cc. of a 0.5 or 1.0 *N* Ba-acetate, adjusted to pH 7.0, is poured over it. The mixture is allowed to stand for several hours or longer, shaken a few times in the interim, and then filtered. The soil is transferred onto the filter paper in the funnel and leached with successive 50 cc. aliquots of the acetate solution to a volume of 500 to 750 cc. in the case of light textured soils, or 750 to 1200 cc. in the case of heavy soils. The filtrate, which should contain all the replaceable hydrogen ions (total acidity), is then titrated with a 0.05 *N* KOH solution to pH 7.0. The following reactions take place:

1. HX-soil + Ba-acetate $\longrightarrow$ Ba-soil + H-acetate (CH_3COOH) + X-acetate

   H = hydrogen; X = other cations of the exchange complex

2. $CH_3COOH + KOH \longrightarrow CH_3COOK + H_2O$

If it took 2.5 cc. of 0.05 *N* KOH to neutralize the acid replaced by the acetate in leaching a 10 gm. sample of soil to pH 7.0, then its equivalent, in terms of $CaCO_3$, is 6.25 mg (the theoretical value for a 0.05 *N* $CaCO_3$). To neutralize the acidity of 2,000,000 pounds of soil (a furrow slice $6\frac{2}{3}$ inches deep over an acre) 1250.00 pounds of $CaCO_3$ will be necessary.

Theory and Practice. — Tests have shown that an application of lime equal to the quantity calculated does not bring about the desired pH in the soil. In the case of heavy soils and those rich in organic matter (these soils have a high exchange capacity), additions of lime double, treble, and even quadruple the theoretical value have not raised the pH to the desired level. The discrepancy between the theory and practice may be clarified by following through a concrete example.

In determining the acidity present in a soil, the procedure is to leach the soil, as described above, with about 750 to 1000 cc. of a 0.5 or 1.0 *N* Ba acetate solution. If we examine the titration data (see above), we find that all in all 2.5 cc. of a 0.05 *N* KOH solution were necessary to neu:ralize the acid replaced. This means that not more than an equivalent uantity of Ba ions actually entered the complex, i.e., 2.5 cc. of a 0.05 *N* a acetate solution. In terms of the 0.5 *N* Ba actetate it is just 0.25 cc. he other 749.75 cc. of the Ba acetate solution (assuming that 750 cc. of .5 *N* Ba acetate was employed in replacing the H ions) have acted as a eserve army without which the tiny 0.25 cc. could not have accomplished he job of occupying the position formerly held by the H ions. Now, if e were to add the theoretical quantity of lime, namely 6.25 mg. of $CaCO_3$, ould it be reasonable to expect replacement reactions similar in magnitude to those accomplished by the vast armada of Ba from the 750 cc. of Ba acetate? The answer is, of course, no! First of all, the quantity is very small; secondly, one cannot hope to contact the entire vast surface of the soil with such a small quantity of lime; and thirdly, the lime is insoluble, and relatively few calcium ions are therefore available for replacement reactions.

Besides, there are side reactions that have to be considered in evaluating the potential replacement activity of Ca and Mg when added to an acid soil. When Ca and Mg carbonates are acted upon in an acid medium, some of the acid is neutralized. This might not change the overall pH, but locally, at points of contact with the soil particles, the pH does rise. As a result, the hydrated oxides of Fe, Al, Mn, and sometimes SiO_2 in solution or as sols (pseudo-solution) form gels at these points. Some particles of lime may become coated with these gels, thus preventing the ionization of the Ca and Mg and their reactivity with the acids. How much of the lime is blocked in this manner is difficult to estimate.[4]

All in all, additions of the theoretical "lime requirement" (calculated by the method of replacing the H ions with a cation, as outlined above) can not and do not raise the pH of the soil to the desired value. Practices the world over have demonstrated that the theoretical lime requirement is not sufficient to overcome the injurious effects of acidity. For light soils, where leaching takes a heavy toll, 50 to 75 per cent above the theoretical lime requirement, and more frequent applications of lime are recommended. In heavy soils, leaching is not as important a factor, and 50 to 100 per cent above the theoretical is recommended, with less frequent applications. It is well to remember that in calculating lime requirement, the acidity of the soil to a depth of 15 to 20 inches has to be corrected.

Determining Lime Requirement from pH Readings. — A low pH reading of a soil extract is a danger signal, a warning of serious trouble. It gives, however, no clue as to the quantity of acid the soil contains. The reason for that was discussed in chapter VII.

It must be thoroughly understood that pH is a *function of* (H^+) *ion concentration and not of acid concentration per se.* 0.1 *N* HCl, for example, has a much lower pH than 0.1 *N* CH_3COOH, because the former is more strongly ionized and so gives rise to a greater concentration of H^+ ions than does CH_3COOH; pH is an intensity factor and not a quantity factor. Only when an acid is almost 100 per cent ionized, such as HCl

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[4] As much as 25 to 30 per cent of limestone added (and for that matter also of hydroxides which turn into carbonates in the soil) have been recovered in heavy soils even after several months, especially during the spring months. Sometimes the paucity of CO_2 formation without which the soluble bicarbonates cannot form is responsible in part for the inactivity of the lime.

in very dilute solution, will the intensity factor and the quantity factor have one and the same numerical value.

If the acids causing a pH reading 5.0 in the soil were all ionized, it would be simple to raise the pH to 6.0, since pH 5.0 represents an acid 0.00001 *N* and pH 6.0 represent one 0.000001 *N*. A simple titration would tell the story. However, if one attempts to neutralize soil acidity on this basis he soon finds out that additions of alkali do not correspond to the calculated value. The pH does not rise correspondingly. This behavior is due to the fact that acids in the soil are not of the type that are completely ionized. Carbonic acid, the most prevalent acid in soils, ionizes ($H^+HCO_3^-$) only 17 per cent, as against 92 per cent ionization for 0.1 *N* HNO_3. This means that lime additions cannot be based on normalities, as calculated from pH measurements.

The added lime will neutralize the H ions in equilibrium with the acid. As soon as this neutralization has been accomplished, another increment of the acid ionizes and reestablishes the equilibrium resulting in no change in pH reading. In short, soil acids are buffers (see Ch. VII). Because of the buffer effects, the theoretical *lime requirement of a soil cannot be determined from pH readings.* However, from long years of experience in liming soils and from empirical greenhouse and field tests with lime, soils men have evolved a scheme whereby the lime requirement of almost any soil class *may be recommended from a pH reading.*

Table 21 gives the lime requirement of a furrow slice 6⅔ inches deep in the most important soil classes. It will be noted, that the clay soils have been placed with the various loams, despite the variations in the lime requirement of these classes. Thus, a clay or a clay loam might need the full 10,000 pounds or even a little more limestone, whereas the loam would get along with 8000 pounds.

With the data on the lime requirement, the approximate organic matter content of the different soil classes is also given. Since organic matter has a high capacity for cation adsorption, it is natural that a decrease of this constituent means a lowering of H ion adsorption, or a decrease in acidity. Hence, this condition means a somewhat lower lime requirement. In practice, however, the decreases is not significant enough and may be disregarded. The pH table, therefore, may be used for all soils in the zone of podzolization and for the red and yellow soils of the southern and Gulf states. After all, a wrong guess of 1000 or 2000 pounds of limestone above the so-called lime requirement (see next paragraph) will have very little effect on the soil and crop. No matter what method of lime requirement has been followed in making the lime applications, it is a wise policy to determine the pH of the soil in advance of planting and, if it is not up to the desired point, more lime should be added.

TABLE 21

*pH values as a guide in determining the approximate lime requirement of different classes of normal, well drained soils.**

(Acre basis)

Soil class	Organic matter; percentage range†	Pounds of limestone to raise the pH of the various soil classes to 6.5-7.0 from:			
		4.0-4.5	4.5-5.0	5.0-5.5	5.5-6.0
Clay, clay loam, shale loam, silt loam, and heavy loams	3.0-2.5 2.5-2.1	10000-8000	8000-6000	6000-4500	4500-2000
Sandy loam	2.2-1.7 1.8-1.3	7500-5500	5500-4000	4000-3000	3000-2000
Loamy sand	1.7-1.1 1.3-0.8	4500-3500	3500-2800	2800-2000	2000-1500
Sandy	1.0-0.5 0.8-0.4	3500-3000	3000-2500	2500-1800	1800-1500

*Artificially drained soils which are naturally endowed with a high organic matter content need more lime than indicatel above. For every per cent organic matter above normal, 250 to 500 pounds more $CaCO_3$, or its equivalent, is to be added to raise the pH of a soil from 4.0 - 4.5 to 6.5 - 7.0. The reason for the extra lime is the high potential acidity of the organic matter. When the soil has an organic matter content above 5 to 6 per cent, the pH value cannot be used as a guide in recommending quantity of lime to be used.

†The higher ranges of organic matter are for the soils in the North-Atlantic States and the lower in the South-Atlantic States. For the soils in the zone of podzolization west of the two regions mentioned, the organic matter content is of the higher range, decreasing from north to south.

Overliming. — If lime is available at a low price, an excess of it, even 3 or 4 times the theoretical lime requirement, may be added without running into the so-called "overliming" injuries. Indeed, we know that the gray semidesert, brown, and chestnut brown soils may contain 5 to 20 (and more) per cent Ca and Mg carbonate, with no damage to crops from overliming. *In the chernozem soils which are proverbial for their productivity, the pH varies from 7.0 to 8.2 and carbonates of Ca and Mg are present in the B and sometimes also in the A horizons.* The author has applied as much as 75 tons of dolomitic limestone per acre on podzolic soil with no ill effects whatsoever and with marked improvement of practically every crop tried. Of course, *the anticipated temporary disturbances have been taken care of,* as explained presently.

Generally, the injuries attributed to overliming are only indirectly due to the liming and may be traced to the following causes. First, the exclusive use of the Ca forms of lime (against the dolomitic forms) introduces large quantities of Ca ions which disturb the balance of bases and other nutrients, such as K, NH_4, Mg, Mn, B, Zn, Cu, and probably other elements. One should appreciate the fact that the average fertilizer carries large quantities of Ca in the form of Ca-phosphate and gypsum. Second, injury may be the result of wrong timing in applying lime, such as heavy applications in the spring, too close to planting time, or when plants are about to enter the active growing period. Lime applied in the fall, even at extraordinarily high rates, cause very little trouble. During the fall and winter the reactions in the soil come to an equilibrium and the balance of bases become adjusted.

Liming Materials

In soil literature and among farmers in regions where acidity is a problem, the term *lime* covers practically all materials used in counteracting soil acidity. In chemical terminology, *lime* is the term given to what soils people call burned lime, CaO. *In this treatise, however, the farmer's concept of lime is to be used.* The most popular liming materials are carbonates, hydroxides, and oxides of Ca or mixtures of Ca and Mg.

Limestone. — This is the most common liming material. It is generally made up of calcite and is sometimes called calcitic limestone. Chemically it is calcium carbonate—$CaCO_3$. When free of impurities, limestone contains 56 per cent CaO. Commercial grades of limestone vary from 45 to 55 per cent CaO.

High grade limestone deposits abound in the United States. All through the Appalachian Mountain and Valley region there is a belt of limestone, from Lake Champlain almost to the Gulf of Mexico. A more extensive belt of limestone spans the Ohio Valley, from Alabama to Lake Erie. An irregular belt of limestone is also found in the central part of the Mississippi Valley. Scattered local deposits of limestone are to be found in almost every state along the Atlantic and Gulf coasts.

There are other liming materials, made up primarily of $CaCO_3$, which are frequently classified as limestones. Thus, oyster shell is a high grade limestone, with a CaO content varying between 45 and 50 per cent. The rest is made up of impurities, with traces of P and N.

We also have calcareous marls,[5] shell limestone, like the Coquina and

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[5] These generally contain much clay and graduate into calcareous clays. The economic utilization of marls depends on the CaO content.

coral limestone of Florida, and chalk, like that of the cliffs of Dover in England, of Normandy in France, and of some areas in Texas. All of these materials consist chiefly of $CaCO_3$, with an admixture of silicates of Ca and Mg and even some $MgCO_3$.

Dolomitic Limestone. — The normal mineral dolomite is a mixture of Ca and Mg carbonates, 54.35 and 45.65 per cent respectively (30.4 per cent CaO and 21.7 per cent MgO), or a 1:1 molar ratio. The general run of dolomitic limestone, often referred to as magnesia limestone, contains varying amounts of dolomite. The MgO content of this limestone may vary from 3.5 to the possible maximum 21.8 per cent.

Burned Lime. — Burned lime is also called *lump lime, quicklime, builders' lime,* and *caustic lime.* This lime (CaO) is produced by the thermal decomposition of limestone. Magnesia (MgO) is produced from magnesite, $MgCO_3$, in similar fashion.

$$CaCO_3 + \text{heat} \longrightarrow CaO + CO_2$$
$$MgCO_3 + \text{heat} \longrightarrow MgO + CO_2$$

The caustic properties of burned lime make it difficult to handle. Since no special advantage is gained by the use of burned lime, it is not favored.

Hydrated Lime. — This material is also known as hydrate, milk of lime, water slaked lime, or $Ca(OH)_2$. In the trade, the mixture of Ca and Mg hydroxides is also sold under the name hydrated lime. It is also called dolomitic lime. Hydrated lime is formed by the addition of water to CaO or MgO, and the process is known as slaking.

$$CaO + H_2O \longrightarrow Ca(OH)_2$$
$$MgO + H_2O \longrightarrow Mg(OH)_2$$

The CaO content of pure hydrated lime is about 75 per cent. The CaO equivalent of a mixture of Ca and Mg hydroxides may be high as 80 per cent or more, since one mole of MgO is by weight equivalent to 1.39 moles of CaO, as indicated:

$$\frac{CaO}{MgO} = \frac{56}{40} = 1.39$$

Hydrated lime, when exposed to the air, takes up CO_2 and reverts to the carbonate.

$$Ca(OH)_2 + CO_2 \longrightarrow CaCO_3 + H_2O$$

Minor Sources of Lime. — *Blast-furnace slag,* a waste product of the manufacture of pig iron, contains some $CaCO_3$ and $CaSiO_3$. *Hardwood ashes* may have a Ca equivalent of limestone containing 60 to 70 per cent $CaCO_3$. In addition, hardwood ashes contain about 4.0 per cent K_2O and 1.5 to 2.0 per cent P_2O_5. *Waste lime* is a by-product of various industries. Paper mills, tanneries, beet-sugar mills, acetylene plants, and some food industries have waste lime consisting primarily of carbonates of Ca and sometimes Mg. The value of these sources of lime for neutralizing soil acidity may be determined on the basis of their CaO equivalent. However, *caution should be exercised with the industrial by-products, since some of them may contain alkali, such as $NaOH$ and KOH. In one case, the author found $LiOH$.*

CHOICE OF LIMING MATERIALS

Except for the specific limitations of the different sources of liming materials, which are discussed presently, cost is generally the deciding factor in making the choice between limestone, hydrated lime, or any other liming material. In calculating cost, CaO is taken as a standard. Thus, 100 pounds of $CaCO_3$ is equal in neutralizing power to 56 pounds of CaO; 100 pounds of $Ca(OH)_2$ is equal to 74 pounds of CaO; 100 pounds of $Mg(OH)_2$ is equal to 96 pounds of CaO; 100 pounds of $MgCO_3$ is equal to 66.4 pounds of CaO; and 100 pounds of MgO is equal to 140 pounds of CaO.

Magnesium Lime. — The advantage of this form of lime is that, in addition to Ca, it also carries Mg. For best conditions of plant growth, a balance of bases and other nutrients is important. Nature, fortunately, has provided a wide range of ratios for this balance. For example, Ca:Mg ratios as wide as 10:1 and as narrow as 3, and even 2:1, have been found to be favorable for crops. By using magnesia lime (such as dolomitic limestone or hydrated lime derived from this type of limestone), the danger of widening the Ca:Mg ratio is avoided.

Preponderance of a single base, even Ca, is unhealthy for the soil-plant system, just as a one-sided diet is unhealthy for the human. Magnesia lime usually carries some Zn which seems to facilitate the intake of other elements, such as K, Cu, Mn, and others. In speaking of Ca:Mg ratios, we refer to the relative proportions of these elements in the exchange complex. A desirable Ca:Mg ratio is generally found in pedocals, especially the chernozem, but not in acid soils. Mg carrying lime for these soils will correct the Ca:Mg ratio. Of course, the soluble Ca and Mg salts added to the soil should be considered in evaluating Ca:Mg ratios.

Where only Ca limestone is available, some source of Mg, either magnesium sulfate, sulfate of potash-magnesia, or calcined magnesium, MgO[6] (preferably the first two) should be supplemented to keep the Ca:Mg ratio within the range of not more than 10:1. Whenever available, dolo-

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[6] Wherever available, ground serpentine (43 per cent MgO) may be used as a source of Mg. On podzolized soils, this material has proved to be as effective (and on some crops even more so) as any other source of Mg.

mitic lime is to be preferred to calcitic limestone. In the author's experience, supplements of soluble sources of Mg have proved highly beneficial even with dolomitic lime because the usual excess of calcite in dolomite dissolves first, giving a high Ca:Mg ratio to start with.

Limestone Versus Hydrated Lime. — Initial neutralization of very acid soils can be made effectively with the hydrated forms of lime. They work faster than limestone because of greater solubility and higher pH, about 12.5 and 8.2-8.4 respectively. The increased rate of neutralization of acidity enhances the intake of Ca, Mg, and other bases by the exchange complex. The result is an improvement in the physical condition of the soil, and a higher retention of nutrient cations, such as NH_4, K, etc. Of course, some hydroxide is converted into carbonates as the CO_2 of the soil atmosphere combines with it, as shown in the equation:

$$Ca(OH)_2 + CO_2 \longrightarrow CaCO_3 + H_2O$$
$$Mg(OH)_2 + CO_2 \longrightarrow MgCO_3 + H_2O$$

Until all residual hydroxide has been converted into carbonate, the high pH and the increased concentration of Ca and Mg will continue to replace the H ions more efficiently than limestone.

For limestone to react in acid soils, one has to depend on the formation of the bicarbonates. Only then can the Ca and Mg ions go into action to attack and replace the H ions. With the low pH of the carbonates (as compared with the hydroxides) and the low concentration of Ca and Mg ions, replacement reactions proceed at a slower pace. Limestone is, therefore, not as efficient as the hydroxide in the initial stages of neutralizing acidity when the pH of the soil is low.

Whenever the soil has reached a higher pH, through previous liming, and an additional increase, or maintenance of prevailing pH is desired, limestone should be used. At the higher pH even the relatively few Ca and Mg ions available from the carbonates are quite efficient in replacing H ions. For surface applications of lime on pasture, lawns, meadows, and golf courses, finely ground limestone only should be used. Hydrated lime cakes and injures the sod.

Whenever hydrated lime is to be used, *it should be applied as much in advance of planting as possible;* its high pH is not conducive to plant growth; in contact with seed it may even impede germination. It can not be too strongly stressed in this connection that locally where the soil is in direct contact with the hydrated lime the pH is 12.0 to 14.0.

LIMING IN SPECIAL CASES

Sandy Soils. — For sandy soils, continuous use of high magnesia dolomitic lime may sometimes be troublesome. As dolomitic limestone is dissolved, an excess of Ca appears in solution. This is conditioned by the usual excess of calcite ($CaCO_3$) present in dolomitic limestone. Gradually, however, the ratio of Ca and Mg going into solution narrows down. In fine textured soils (heavy), some of the Mg becomes immobilized either as the $MgSiO_3$ (there is usually some ionized SiO_8 in the soils of the zones of podzolization and laterization), or in the exchange complex. In light soils, these reactions are limited. It is, therefore, possible (though not very probable) to have an excess of Mg in circulation. To avoid this possibility, a low grade dolomitic lime, i.e., one of a low MgO content, should be used. Alternating straight calcium limestone (sandy soils should never be treated with hydrated lime) with dolomitic forms of lime is another way of getting around the difficulty.

Soils in Zone of Laterization. — One of the troublesome features of acidity in these soils is the circulation of Fe and Al. Besides being toxic, these elements combine with the phosphates and render them insoluble. Raising the pH, by the addition of any form of lime, is a good way of decreasing the solubility of the Fe and Al.

Blast furnace slags, ground rock phosphate, and combinations of these with dolomitic lime, are very efficient in immobilizing acidity. These substances leave behind a residue of SiO_3 or PO_4 which combine with the ionized Fe and Al, giving rise to clay-like silicate and phosphate compounds. Slags are, therefore, very effective in neutralizing acidity of lateritic and laterite soils. The newly formed compounds, silicates of Fe and Al, increase the base adsorption capacity of these soils. Slags and phosphates have been tested on a limited scale and have justified their use in the red soils of the subtropics.

Soils in Zone of Podzolization.—Ground rock phosphates have proved their value on podzolized soils in the United States and in Europe, especially in Russia. These phosphates neutralize the acids and also serve as a source of P in plant nutrition. However, for most effective results, dolomitic limestone, as discussed in this chapter, is the best choice for neutralizing the acidity of soils in the zone of podzolization. When rock phosphate is used, a source of soluble Mg is to be added.

Liming Mucks and Peats. — Peats and mucks, known as organic soils, have a high adsorption capacity for cations and, therefore, require large quantities of lime. As much as 8 tons of dolomitic limestone have been applied profitably and with excellent results. In using lime for these soils, it is important to keep down deflocculation that raises havoc in all soils. Hydrated lime should, therefore, never be used on organic soils.

Since organic soils are low in Mg, the application of dolomitic limestone high in Mg is a must. With this, one should mix 300 to 500 pounds gypsum and 100 to 200 pounds Epsom salt (or sulfate of potash-magnesia) per ton of limestone. The gypsum and the soluble Mg salt supply available Ca, Mg, and S; these salts also serve as coagulating agents. The result is an improvement in structure, drainage, and aeration of the soil.

TIME OF APPLYING LIME

On theoretical considerations, experience, and observations, fall application of lime has a number of positive effects, whereas spring application of lime has negative effects on the soil-plant system.

Fall Liming. — 1. High temperatures and, more so, periodic dry spells during the summer are efficient agents in promoting soil structure. The structure attained during dry spells is retained through the fall and early part of winter. During this period of plant dormancy, electrolytes accumulate in the soil and they also favor soil structure. Because of the improved structure, lime applied during the fall or early winter, before the ground is frozen, readily penetrates into the profile. In spite of the usually reduced autumn rainfall in the eastern United States, the open structure of the soil permits movement of salts down through the B horizon. The increased pH and the accumulated electrolytes precipitate the toxic substances throughout the profile. When the next growing season rolls around, roots have access to a greater volume of soil for nutrients and water.

The secret of a long term stand of alfalfa lies in inducing penetration and distribution of liming materials throughout the profile. To attain this, two thirds of the lime required should be incorporated into the soil with the crop preceding the alfalfa, and the other third should be plowed under in preparing the soil for the alfalfa. A light dressing of lime, 1000 to 1200 pounds, a few weeks before seeding should complete the liming program. With this dressing of lime, the fertilizer materials, such as superphosphate, potash, Epsom salt (or sulfate of potash-magnesia), and a little nitrogen, may be introduced. *An indispensable amendment in liming for a new seeding of alfalfa is B at rates given below.* This amendment may be applied either with the last third of the lime, or with the lime dressing and fertilizers.

2. During the fall, the pH of the soil invariably increases as a result of two factors: (a), the mobilization of minerals in the process of humification and mineralization of crop residues; (b), the absence of a crop on the land to utilize the minerals released. The pH increase in the fall is very effective in replacing the H ions. (See discussion on hydrated lime).

3. A sudden influx of lime during the active growth of plants causes disturbances, such as B deficiency and a general unbalanced supply of nutrients. Besides, microbes stimulated by lime compete with plants. Liming cover crops, pastures, meadows, and sod in general, in fall or early

winter, prevents these disturbances. At that time of the year, plants are on the way to dormancy and are not affected by the disturbances mentioned.

4. In the fall, moisture and temperature conditions are comparatively favorable for microbial action. Plant residues are readily decomposed, releasing an abundance of CO_2 enhancing the conversion of the difficultly soluble carbonates of Ca and Mg to the soluble bicarbonates. The increased pH and concentration of Ca and Mg ions favor the replacement of H ions.

Spring Liming. — 1. In the spring, the soil structure is the least stable. Excessive moisture and lack of electrolytes in the soil during this season are conducive to the slaking of the structural units. The result is a dispersion of some organic constituents, clay, and fine silt, whereby the movement of water through the profile is impeded. Limestone and more so hydrated lime, at the time of application and for an indefinite period after that, increase dispersion and inhibit the downward penetration of constituents.

To overcome the dispersion effects, a mixture of dolomitic limestone and gypsum should be incorporated into the soil. Two thirds of the mixture should be broadcasted and plowed under and the remaining third harrowed in. The ratio of limestone to gypsum should be 4:1 for light and well drained soils and 3:1 for heavy soils that usually are more subject to sluggish drainage.

2. Additions of lime in the spring may cause immobilization of minor elements, such as B, Mn, Zn, and Cu. Of these elements, B is the most critical in most soils. To prevent B deficiency, it is well to mix borax, $Na_2B_4O_7$, into the lime at the rate of 15 to 25 pounds per acre; the lower quantity on light soils, the higher on heavy soils. If borax is to be applied alone, a cyclone seeder will distribute it uniformly.

With the precautions given, if lime has not been added in advance of planting (the better way), it may be applied together with the fertilizer, even at planting time. If the band method of fertilizer application is used, the lime and B mixture must be broadcast separately. *Under no circumstances should the quantity of B recommended be used in any kind of a row or band method of applying fertilizer.* The concentration of B would become too high, and serious injury to the crop may result. In general, B applications should be carried out with caution.

Spring Liming and Boron Deficiency. — Experience has shown that spring liming[7] brings about B deficiency in crops. Three reasonable ex-

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[7] It has been reported that magnesia lime causes much less B deficiency. This favorable effect may be due to the competitive action of Mg for the borate anion. Incidentally, this fact may serve as another argument favoring the use of magnesia lime.

planations may be advanced for the phenomenon observed. First, some unknown groups of soil microorganisms, stimulated by the lime, immobilize the small quantity generally available and leave none for the growing crop. Second, the borates of Ca are insoluble and the excess of Ca ions introduced by liming is bound to decrease their solubility in accordance with the law of mass action. Third, the accelerated growth of plants, stimulated by the lime, calls for a higher rate of supply of B that the soil can not supply.

The fact that fall liming does not, as a rule, bring about B deficiency symptoms in crops corroborates the aforementioned explanations. The excess of Ca in the soil does not seem to interfere with the slow growth of the crop during the fall and its dormancy during the winter.

By spring, the microbiological and chemical reactions come to equilibrium in the soil. Adsorption of Ca by the exchange complex, formation of stable Ca compounds, such as silicates and phosphates, intake of some Ca by microbes, and loss of some Ca by leaching bring about the equilibrium conditions. By spring, the flare-up in microbial activity is over and the microbes are humified and mineralized. As the microbial cells decompose, the B and other mineral constituents go into solution. At that time there are no large excess of Ca ions to repress the solubility of the Ca borates, and the plants may freely utilize the B.

Fall limed soils, carrying a cover crop or green manure crop to he followed by a cash crop, should receive in the spring an application of 200 to 500 pounds per acre of a mixture of dolomitic limestone and gypsum, in the ratio of 4:1, 25 to 50 pounds of manganese sulfate, and 5 to 10 pounds[8] of borax. These ingredients may be applied together with the fertilizer, if broadcasted.

Fineness of Limestone for Best Results

The fineness of limestone is an important factor in neutralizing soil acidity. Fineness beyond 100 mesh (100 meshes to the inch as provided by the U. S. Bureau of Standards) is not desirable, because very fine materials behave like fluids. Coming out from the tubes of the limespreader, such materials run together into the crevices, low spots, and other depressions of the soil. This means poor distribution of the limestone. Besides, grinding costs beyond 100 mesh fineness become prohibitive. Tests the country over show that limestone most satisfactory for the average soil should consist of 90 per cent passing through a 20 mesh screen and 50 per cent through a 100 mesh screen.

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[8] The higher figures are for heavy soils and the lower for light soils.

For light soils, such as loamy sands and sandy soils, coarser limestone is advisable because fine particles may be carried down through the profile mechanically into the subsoil before the carbonates have a chance to neutralize the acidity of the soil. Ground limestone, 25 per cent of which would pass through a 50 mesh and 90 per cent through a 20 mesh screen, is suitable for sandy soils.

Incorporating Lime

Initial Application. — As a general recommendation, two thirds of the lime to be applied should be plowed under the remainder disked or harrowed in. In case fertilizer is to be broadcasted, it may be mixed and applied simultaneously with the lime. There is a common notion that lime mixed with fertilizer releases ammonia causing reversion of phosphates. Actually, even hydrated lime will not bring about these reactions in any appreciable degree, if the mixture is applied immediately after mixing.

Deep Placement of Lime. — An effective and speedy method of deep liming is to have in the rear of the plow some sort of a distributor depositing lime into the bottom of the furrow, and an attachment following the plow, capable of digging into the furrow 6 to 9 inches deep. In this way it is possible to lime the soil profile to a depth of 12 to 18 inches in one operation. Of course, surface liming has to precede or follow the subsurface liming. Such a procedure is recommended whenever crops like alfalfa, some other legume, or any sod are to be established.

Annual or Periodic Incorporation of Lime. — The question is often raised: is it best to lime annualy, every other year, once in five years, etc? The answer lies in the status of the alkaline earth bases, especially Ca, in the soil.

Grasses and especially legumes have a high ash content, of which Ca may come to 30 per cent. Alfalfa hay contains from 1.6 to 3 per cent CaO, which means that a 2 ton alfalfa hay crop removes from the soil 65 to 120 pounds of CaO annually. On the other hand, these crops mobilize appreciable quantities of lime through their roots. It is clear that the removal of bases by harvested crops, even by such heavy feeders as the grasses or legumes, is not of major significance. More serious are the annual losses by leaching, and because of it losses should be compensated annually instead of arbitrary fixed periods. By following this system of liming, one may avoid wide fluctuations of pH and of balance of nutrients in the soil; these fluctuations are indeed not relished by plants. For perennial crops, such as asparagus, pastures, meadows, alfalfa, and sod in general, the soil should be limed to full capacity through a depth of 15 to 18 inches. The Ap, the layer below it, and the upper part of the B iould be tested in the spring for pH every year, and lime added accord-igly in the fall. If the pH should drop to 5.6-6.0, one should use dolo-itic limestone, 50 pounds magnesium sulfate, 25 pounds manganese sul-ite, and 10 to 20 pounds borax, without waiting for the fall season.

Farmers have frequently observed that in some unlimed pastures olunteer clovers have appeared after a number of years. The explana-on for this phenomenon is that cows do not remove (in the form of milk) ery much Ca from the grass; at the same time they return some Ca rough the manure. There is, however, another very important com-ensating factor. The organic matter of the sod mobilizes lime from the ntire profile through the roots. The dying tops and roots also give up ases to the A horizon. This mobilization of lime is by far greater in oils on limestone parent material.

For cultivated crops, a single full capacity addition of lime to raise e pH to 6.5-7.0 through a depth of 15 to 18 inches is not imperative, s is the case with perennial or sod crops. During the first season, one ay add (in the late summer or fall) just enough lime to take care of e acidity of the Ap layer. By the next season, some of the lime will ave penetrated into the lower part of the A horizon and in the upper art of the B horizon. This condition will result in better utilization of e lime added the next season, since by that time the pH will be slightly gher even in the A_2 and B horizons. If all the lime required is added once to fallowed or cultivated land, an appreciable loss of lime due to aching takes place.

A fundamental guide to follow in liming is to avoid heavy applica-ons in the spring, or at any time prior to a period of plant activity. Small uantities of lime may be added at any time without disturbing the nu-ient balance in the soil and bring about the ill effects discussed earlier. *here is no danger of overliming, providing the application has been made e right time, and the B, Mg, and Mn salts have been added with the ning materials.*

GYPSUM IN THE LIMING PROGRAM

When lime is added to the soil, the immediate effect is an increase in e hydroxyl ions, due to hydrolysis:

$$CaCO_3 + 2H_2O \longrightarrow Ca(OH)_2 + H_2CO_3$$

he alkaline system causes temporary dispersion of the soil, an undesirable ndition, especially in the spring. To avoid the dispersion, it is important repress the concentration of the OH ions. Additions of gypsum, 300 to 500 pounds for every 1500 to 2000 pounds of lime, accomplish this tas successfully, as represented by the following equations:

$$2\text{H-soil} + CaSO_4 \leftrightarrows \text{Ca-soil} + H_2SO_4$$
$$Ca(OH)_2 + H_2SO_4 \longrightarrow CaSO_4.2H_2O$$

It should be clear that the pH will be temporarily lowered by addition of gypsum (exchange of H by Ca) to the soils of the humid regions—zon of podzolization, laterization, and degraded chernozem. Gypsum also increases the available (adsorbed) Ca, providing free lime is present t react with the H_2SO_4 formed in the exchange reactions.

In general, it has been found that soils with a tendency to waterlogging are generally benefited by a mixture of lime and gypsum (see Ch. X). Besides, the sulfate ion helps to balance other anions, supplies necessary S and is conducive to root development.

In liming cultivated perennial crops, pastures, meadows, or any lan in sod (such as alfalfa), a mixture of limestone and gypsum in the proportions mentioned above has been found to be highly beneficial. Thi practice facilitates deeper penetration of Ca and more efficient replacemen of H ions.

In the opinion of the author, liming materials for acid soils shoul carry dolomitic limestone and gypsum.

Summary On Liming Acid Soils

1. Ca and Mg are the most suitable bases to replace the H in the exchange complex. They are, therefore, the best for neutralizing the acidity of the soil. The alkali bases, K and Na, are not suitable for this purpose, because they tend to disperse the colloids, dissolve organic matter, and ar injurious to plants due to their caustic properties. The author has use successfully some K_2CO_3 in mixtures of limestone and gypspm to rapidly neutralize highly acid soils. For the present, this approach is still in th experimental stage.

2. When Ca and Mg are restored to the exchange of the soil, most of the deleterious effects of acidity are eliminated.

3. An outstanding function of lime is to improve soil structure. However, soon after applying lime, hydrolysis may bring about dispersion. The dispersed condition may last several weeks or longer. This behavior of lime is one more reason why it should not be added in the spring close to planting time. When lime is added in the late summer or fall, the dispersion effects spend themselves over the period of plant inactivity. By spring, the hydroxyl ions have become inactivated. For an immediate immobilization of the hydroxyl ions, the additions of gypsum is recommended.

4. Heavy applications of lime should be supplemented with salts of B and Mn which are temporarily immobilized when large quantities of Ca enter into circulation.

5. As the Ca enters the exchange complex and the pH of the soil increases, Mg, K, NH_4, Mn, and other so-called minor or trace elements, such as Cu and Zn, are more easily absorbed and retained.

6. When the fine roots are out to "collect" nutrients, they get in close contact with the soil particles on which the cations are adsorbed; the roots exude CO_2, thus forming H_2CO_3 in the film of moisture surrounding the particles. Upon ionization, H_2CO_3 furnishes H ions that replace the bases, send them into the film of moisture, where the rootlets imbibe them. Without sufficient adsorbed Ca in the exchange complex, the other cations are not easily retained.

When a soil is properly limed, the quantity of bases *and* H *in the* exchange complex fluctuates as follows: 40 to 60 per cent Ca, 10 to 20 per cent Mg, 5 to 8 per cent K, and the rest is H.

CHAPTER XII

THEORY AND PRACTICE OF FERTILIZER USAGE

Historical. — In the early days of human efforts to produce food, little thought was given to the need for replenishing the soil with the minerals removed in the form of harvested crops. This neglect led to what is known as soil exhaustion. But the world was "larger" then and the horizons broader, so when the soil ceased to yield sufficiently and the people faced starvation they migrated to new lands. Even today, natives of many countries in the humid tropics migrate from exhausted land to new productive areas in a way of their own. They burn the forest and brush, of either virgin soils or cultivated soils that have been abandoned and have reverted to forest and brush. This system of acquiring new land is known as *assartage.* The author observed many such fires while surveying tracts of land in the Republic of Panama. The loss of organic matter incurred by firing land is more than offset by the economy and ease of this method of land preparation.

As the populations increased, it became increasingly difficult to solve the problem of population pressure by migration. New lands were scarce. To expand meant to trespass upon neighbor states, causing disastrous conflicts. Peoples and states have been forced to make adjustments within their immediate surroundings. The natural inclination was to make the available land produce more.

The practice of manuring dates back to early days of agriculture when the tillers of the soil had noted that vegetation was vigorous and healthy on land where domesticated animals deposited manure or where night soil was disposed of. To this day, barnyard manure is highly valued by farmers the world over.

Manure was not the only material used in the prefertilizer era. Gypsum, wood ashes, common salt, marl, and wool waste found their way into the soil. George Washington experimented with these materials and with green manures. The North American Indians added fish, and the South American Indians guano to grow better and bigger crops of corn. Lupines and clovers as standard crops in raising yields were known to the Romans. But of all the materials tried, manure was the one that has maintained its reputation as a means of increasing soil productivity. With the introduction of mineral fertilizers, the indispensability of animal manures has been questioned.

The French and American revolutions put an end to feudalism and gave rise to the development of the industrial system. These factors as well as others, such as the democratization of learning, led to a shift in population from the farms to the cities. Agriculture was called upon to feed an ever increasing non-agricultural population. New and excessive demands have been made on the soil. The spirit of learning and discovery, characteristic of that period, came to the rescue.

De Saussure, a Frenchman, discovered in 1804 the process of photosynthesis. This discovery and his investigations on the composition of plants unraveled many secrets about the relation of plant growth to soil conditions. The discovery of the process of photosynthesis sounded the death knell of the humus theory, a fact not appreciated at the time. According to this theory, plants obtained their carbon directly from soil humus.

Boussingault, another French scientist, was the first to champion the vital importance of N. He reasoned that since the N of grains and other crops are not returned to the soil, there should be eventually an exhaustion of this element. Logical as this conclusion was, experience did not fully bear it out. In some cases, as a matter of fact, the N content of the soil had increased. To establish the source of this increase, Boussingault carried out a three year (1836-1838) rotation experiment with and without legumes. By carefully analyzing the manures added and the crops harvested, he demonstrated clearly that the longer the legumes were retained in the rotation the greater was the increase of N in the soil; he, therefore, postulated that this increase came from the air. Later, after Pasteur threw light on the functions of microbes, it was possible for Hellriegel and Wilfarth to demonstrate the fixation of N by the symbiotic action of legume bacteria with their hosts, thus proving Boussingault's postulate.

In the 40's of the last century, Liebig, a German chemist, advanced what is known as the mineral theory. He maintained that knowing the mineral composition of plants, we should be able to add these to the soil and thus keep the supply constant. Later investigations proved, however, that the problem of plant nutrition in relation to soils was not as simple as that. Nevertheless, the theory served notice that farmers could not continue to remove minerals from the soil by cropping without returning any.

Lawes, the founder of the world famous Rothamsted Experiment Station, Harpenden, England (established in 1843), coordinated the findings of Boussingault and Liebig. He showed that returning the ash of burned manure to the soil, i.e., adding minerals without N, as advocated by the mineral theory of Liebig, did not increase crop yields. It was necessary to supplement the ash with some source of N, as advocated by Boussingault. Thus was laid the foundation of the modern fertilizer industry.

Of the various nutrients taken up by plants (see Ch. V), NPK are most generally deficient in the soil or unavailable to the crop. For this reason, the manufacture and use of fertilizers have been limited chiefly to the salts of these elements.

Within the last 50 years or so, great strides have been made in increasing crop yields, doubling these in some cases. Estimates show that fertilizer may be credited with 50 per cent of the increases in yield; improvement of varieties of crops are credited with 30 per cent; and improved methods of tillage operations, with 20 per cent.

The world consumption of mineral fertilizers prior to World War II amounted to about 50 million tons: 25 million tons P and 12.5 million tons each, N and K. In 1948, the United States consumed about 15.956 million tons fertilizer. Of these, more than 8 million tons were used in the South Atlantic and South Central states on cotton, tobacco, and vegetables. The bulk of the remainder was used on truck crops and fruits: in regions of intensive cultivation, such as on citrus and vegetable crops in California; and in sections of the country where specialized crops (such as vegetables, sugar beets, and fruits) are grown extensively, usually with irrigation. It should be noted that the greatest volume of fertilizer is consumed in the zones of podzolization and laterization.

The introduction of mineral fertilizers revolutionized the concepts and methods of land utilization. The old three field system, with one in clean fallow as a measure of restoring fertility to the soil, was eliminated. Fields have since been planted and good crops harvested year after year with the aid of mineral fertilizer. The capacity of a given land area to produce has thus increased by a third. In addition, with the introduction of fertilizers, the yield per acre has increased by about 50 per cent.

Fertilizer Practices

Fertilizers are added to the soil for three reasons: 1, to replenish nutrients removed by harvested crops; 2, to replace losses due to leaching and erosion; 3, to provide a reserve of nutrients in excess of the natural supply. The first two reasons are self-evident and need no elaboration; the last one deserves further elaboration.

Native Versus Cultivated Plants. — Nature is often unkind to its fauna and flora. Countless generations of animals and plants die before a few become established. For example, many forest species go through several seasons before some of their seeds find favorable conditions to germinate and to prosper. Huge quantities of seed of *native* plants perish without even germinating because of unfavorable conditions. Those that survive never produce the high yields cultivated plants do. Nature, apparently, wants no bumper crops.

The average soil contains vast resources of nutrients, enough to produce hundreds of crops. For example, a sandy loam soil, with a .05 per cent N contains in the first 2 feet about 3000 pounds of this element, enough to produce 50 crops of a 300 bushel yield of potatoes per acre; the same soil, with .05 per cent P_2O_5 has enough P to produce 100 crops; and the same soil may contain as much as 30,000 pounds or more K_2O, enough for 350 crops. However, the rate of release of these nutrients during any one season is not adequate to satisfy the needs of high yielding cultivated crops, such as 300 to 1000 and more bushels of potatoes per acre, 10 to 25 tons of tomatoes, 150 to 300 bushels of corn, 400 to 1200 bushels of onions, or 400 to 1000 crates of celery. To meet the demands of such yields, the farmer has to provide nutrients to supplement the natural supply.

An Ideal Setting for Cultivated Crops. — Seeds or plants of cultivated crops are carefully selected stock, bred with well defined objectives: capacity to yield, quality of product, resistance to ravages of disease and insect pests, and such other properties that might enhance the utilitarian and commercial value of the crop. For best results, such seeds or plants require: good drainage of profile; optimum pH; proper system of cover cropping and manuring; appropriate time and depth of plowing, the type of plow, disk, harrow, and other implements adapted for the soil in question for the preparation of seedbeds; adding starter solutions; cultivating the soil to destroy weeds and to conserve moisture; dusting and spraying whenever the necessity arises.

The proper setting having been provided, the farmer has yet to furnish one thing more, namely a reservoir of nutrients available to the plants at all times during the growing season. Though the operations leading to the so-called ideal setting result in an increase of the natural supply of nutrients, this increase, however, is not sufficient to meet the demands of the crop. In other words, the rate of the natural supply is rarely adequate. More nutrients must be supplied in the form of fertilizer, often referred to as *artificial fertilizer,* since most fertilizer salts supplying NPK are produced artificially from various materials. Artificial fertilizers are also called *mineral fertilizers* because most of the materials, except some sources of N, originate from minerals.

Fertilizer for Zonal Soils

The differences in the nature and properties of zonal soils make it obvious that their fertilizer requirements should also differ. Thus, some soils need little or no fertilizer and others need more. Some soils may respond more to one or another element, or to some combination of elements. Even within the individual zonal soils, the different textural classes, drainage conditions, cropping systems, farm practices, and seasonal variations may require special approaches in fertilization. For these reasons, only principles of zonal fertilization may be expounded here. The details and departures have to be worked out in accordance with these principles.

Zone of Podzolization. — In these soils, N is, as a rule, in the first minimum. This simply means that N is the most limiting factor in crop production and when used singly usually gives the highest returns. In the soils of this zone, the content of organic matter and hence of N is low. The N released during the growing season is readily consumed by the vegetation. In late summer and early fall, some N in the form of nitrates may accumulate in the soil and much of it leaches out in late fall and early winter, unless a cover crop is planted. In addition, the process of nitrification is frequently impeded in these soils because of the low level of aeration. In general, N is one of the critical elements for maximum yields in the soils of the zone of podzolization, and high N fertilizer grades are used.

Very little P is lost from these soils because the mobile Fe, Al, and Mn in the B horizon readily form insoluble phosphates. This condition makes P the second in minimum. It is evident that K is in the third minimum. Whereas this is generally true, there are many exceptions. Besides, the crop requirement must be kept in mind. Tobacco, beets, and potatoes are specific in their K requirements.

A point to remember in connection with the factors of minimae is that after supplying the element in any minimum, the need for other elements increases and they have to be supplied.

Chernozem and Related Soils. — In general, chernozem soils do not respond to either N or K. In this zone, the rainfall during the growing season is not excessive to wash out the nitrates produced in the natural course of humification, mineralization, N fixation, and nitrification. This factor, coupled with their high organic matter content, causes chernozem soils to have a high N content. The chernozems also seem to have plenty of K within easy reach of plants, despite their power to fix (immobilize) this element. The large amount of free Ca present in these soils does, however, immobilize phosphates.[1] Chernozems, therefore, respond to P fertilization, and acid phosphate is practically the only fertilizer used for grain crops. On the light texture soils, N and K have proved their worth even in the chernozem soils. $(NH_4)_2SO_4$ is the better source of N in this

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[1] The apparent discrepancy on the role of Ca in releasing P in podzols and immobilizing it in chernozem may be explained by the *law of mass action.*

soil zone. The following mixture is an excellent substitute for $(NH_4)_2SO_4$: NH_4NO_3, gypsum (equivalent to the sulfate content of $(NH_4)_2SO_4$), and 15-25 pounds of MgO as Epsom salt or sulfate of potash-magnesia, whichever is cheaper.

In the chernozems bordering the prairie country and in the prairie soils proper, the natural supply of nutrients is on the decrease and leaching on the increase. N or K, or a combination of these, are just as effective as P fertilization. In practice, the system of fertilizing these soils approaches the one in the zone of podzolization.

In the zone of brown and gray soils, grazing and dry farming are the principal forms of agriculture, and very little fertilizer is used. Here and there phosphates and small quantities of manure are applied. Under irrigation, these soils, if properly fertilized, may produce huge crops.

Zone of Laterization. — Soils of this zone are lowest in organic matter. As in the zone of podzolization, the N released during the growing season is utilized by higher plants and microbes. Leaching is even more pronounced than in the zone of podzolization because of the higher rainfall and lack of freezing. N is, therefore, in the first minimum, and heavy applications are made to maintain high yields.

Phosphorus may also be in the first minimum in these soils because of the prevalence of mobile Fe, Al, and Mn. These cations, as pointed out repeatedly, form insoluble and, therefore, unavailable forms of P. This will explain why the southern states use such huge quantities of fertilizers, the base of which are the phosphates. By raising the pH of the soil to 6.6-7.2, one can reduce the activity of the Al and Fe and thereby reduce the necessity for large quantities of phosphates and even make available some of the immobilized phosphates.

Posassium Status. — There are practically no soils in which K is in the first minimum. The quantities present may vary much more within subdivisions of any one zone than between the zones. Potassium fertilization is guided not so much by the supply of this element in the soil, as by the crop requirement. Certain crops respond more effectively to K than others. Thus, tobacco, potatoes, and sugar beets have a high K requirement.

Losses of Fertilizer Elements

For intensively fertilized crops much more nutrients than required are added to the soil. For example, Maine or New Jersey potato growers may apply per acre as much as 2000 pounds of fertilizer containing 80 to 100 pounds N, 160 to 200 pounds P_2O_5, and 140 to 200 pounds K_2O. A 300 bushel potato crop removes about 60 pounds N, 30 pounds P_6O_5, and

90 pounds K_2O. Practically the entire excess of N in the fertilizer and most of the excess K are lost by leaching. Some K and most of the excess P is tied up by the soil.

PK Losses. — Very little P is leached from any of the soils, even from real sandy ones in any of the soil zones. After its addition, most of the P is rapidly immobilized in some part of the profile. The specific horizon in which this occurs depends on the soil zone. In the pedalfers P is tied up in the B horizon of the podzolized soils and in the A horizon of the laterites as insoluble compounds of Fe, Al, and Mn, and in limestone rich soil also as phosphates of Ca and Mg. In the pedocals, P is primarily tied up as calcium phosphate. Insoluble organic forms of phosphate in chernozem must also be considered as partially immobilized. In short, while most of the excess P applied as fertilizer is retained in the soil, it soon becomes unavailable to crops. Thus, no matter how great the total quantity of P stored in the soil is, its availability to a fast growing crop is insignificant. Phosphorus deficiency becomes more acute when the other nutrients are abundantly supplied. In the podzol soils, proper liming may release some of the P tied up with the sesquioxides.

As for K, some is leached out; some becomes adsorbed, but is available to plants; some, however, is fixed in the soil and becomes available only gradually.

Nitrogen Losses. — After the growing season, any mineral N in the soil is lost, if the land is in clean fallow. Also, the lighter the soil, the greater the rate of loss. With a cover crop on the land, the losses may be reduced considerably, almost to zero. To attain maximum results, the cover crop must be well established before the late fall rains.

Nitrogen losses vary with the season. As pointed out, the residual N leaches from the soil during the fall and winter, mostly in the form of nitrates. Even in the zone of podzolization and laterization, *losses by leaching are meager, during the spring and summer.* During exceptionally wet summers, however, the critically needed N salts may be either permanently or temporarily washed down into the soil profile beyond the reach of the roots. In exceptionally dry summers, nitrate N may come to the surface and concentrate in the first two or three inches of the soil. Since moisture is usually a limiting factor in the surface few inches of the soil, roots will not move upward to obtain these nutrients.

There are no authentic figures on N losses by leaching. Under natural forest conditions the losses are negligible. They are more serious in cultivated podzol and laterite soils. The presence of soluble mineral N in drainage water and rivers is sufficient evidence that some escapes from the soil. It is estimated that N losses in the humid regions vary from 15 to as high as 100 pounds per acre, depending on whether the soil is fallowed or cropped.

The soils in the zone of podzolization, because of poor structure, suffer from a low O supply in the horizons below the Ap, especially during periods of waterlogging. Reduction reactions (such as denitrification) are apt to set in, leading to a considerable loss of N, estimated to vary from 10 to 60 pounds per acre. Part of this N undoubtedly originates from the decomposition of the humus resources and of the roots and underground stems remaining behind after the growing season.

On the credit side of the N ledger, two principal items are to be considered. First, about 5 to 7 pounds of N per acre, as NH_3 and NO_3 in the ratio of 3:1, are added annually to the soil by precipitation. Second, there is some N fixation, especially in cultivated soils. In all, the debit and credit in the N balance, under natural conditions, apparently cancel each other.

In summarizing the losses of N by leaching, it may be said that these are, generally speaking, not serious. They occur when the crop is not on the land, or is in dormant state. As a rule, problems of N fertilization confront the farmer during the active growing season. The crop is either having too great a supply at one time or too little at some other time. Thus, if all the N necessary to make the crop is supplied at the initial fertilizer application, either one of the following may happen. (a) Some of the N may be removed by leaching during the early stages of plant growth, thereby leading to a shortage later when the plants need it most. (b) If not leached out, the excess of N may cause soft and succulent vegetative growth; and in case of a prolonged drought may cause root injury, known as burning.

Fertilizing the Soil and the Crop

On the basis of their behavior in the plant-soil system, fertilizer elements are to be differentiated into two categories. (1) P and K that enter into chemical reactions with the soil mass and form new compounds and adsorption complexes, or become fixed in the soil; (2) mineral N which, by and large, persists in the soil solution, moves through the profile, and is utilized by plants primarily as nitrates. The surplus is leached out, because nitrates do not form insoluble compounds in the soil. In other words, P and K fertilize the soil and have to be released from the soil by some reaction before they can be used by the plant. Nitrates, on the other hand, stay in solution and fertilize the crop, not the soil.

If water soluble compounds of P and K were available at a reasonable price, it would be possible to work out a system of adding the 3 fertilizer nutrients to the soil as the plants need them. Under such a scheme, the soil would be a carrier of nutrients, as are the sand or solution cultures of the plant physiologist. Indeed, on light soils it is very simple to similate the plant physiological system. In heavy soils, the adsorption of P and K makes it difficult to maintain a balanced concentration of these elements. It is, however, fairly simple to control the concentration of N even in heavy soils, if nitrates are used.

From the behavior of P and K in the soil one can see no injurious effects to plants by adding two to three times as much phosphate as the plants need and *almost* equally large amounts of K salts. On the other hand, one may get into serious troubles by adding just a trifle too much N at one time or another. A lesson to be learned from the aforesaid is that, except for the waste of money, the farmer may be reckless with applications of PK salts, but he must watch his step in applying salts of N. Of course, on sandy soils excesses of any salt may cause trouble, and good farmers know it.

Sources of Fertilizer Elements

The time is not far off when a soluble compound carrying the 3 fertilizer elements will be available, and it will be applied in solution. In all probability, PK will make up the bulk of such a compound, with only a small quantity of N in it, just enough to give the plants a start.

By far most fertilizers available now are a mixture of N, P, and K compounds. As a rule, only one of the three elements is carried by a compound. There are, however, some compounds which carry two elements, such as potassium nitrate and ammonium phosphate.

Nitrogen Carriers

Three principal forms of N are available for fertilizer: 1, nitrates; 2, ammonia, and 3, organics. Other sources, like cyanamide and urea, when added to the soil are readily converted into ammonia compounds and are, therefore, to be considered with group 2. The organics are seldom used as the exclusive source of N. When added, they, as a rule, make up from 10 to 20% of the total N.

In 1944, the fertilizer industry used 625,000 tons of N. Of that, 160,000 tons came from $NaNO_3$. The bulk of the rest was supplied by nitrate and sulfate of ammonia. Of the total N, 271,000 tons was available for top-and sidedressing and 354,000 tons for use in mixed fertilizer.

NITRATE NITROGEN

Sodium Nitrate (*$NaNO_3$—16 per cent N*[2]. — Better known among farmers and in the trade as *nitrate of soda*, this material was until World War I (1914-1918) the leading and almost exclusive source of N in fertilizer mixtures or for sidedressing cultivated crops or topdressing sod, meadows, and pastures. At present, nitrate of soda supplies about 40 per cent of the total N used in fertilizer.

Under the name *Chile saltpeter* (genuine saltpeter is KNO_3), $NaNO_3$ from the natural deposits in Chile has been known for more than a century. These deposits, claimed to contain 270 million tons of $NaNO_3$, are located 15 to 50 miles from the Pacific Coast on the eastern slope of the coast range mountains which form the western rise of the great desert plateau Tarapaca, in northern Chile. It is 450 miles long, north and south, 15 to 90 miles wide, and has an elevation of 3 to 9 thousand feet. On the east of the plateau the Andes rise.

Refining Nitrate of Soda. — The crude $NaNO_3$ is covered with an overburden of sand, gypsum, and other rock deposits. When exposed, it is blasted, crushed, and dumped into hot water. The 12 to 25 per cent $NaNO_3$, the 8 to 25 per cent NaCl, and 2 to 12 per cent Na_2SO_4 go into solution. The nitrates are separated by recrystallization and piled in the open to dry. In this form, Chile saltpeter appears on the market as dirty pink to grayish-white crystalline salt. In another process, the salt is crystallized out at the freezing point, centrifuged to expel the excess brine, melted to drive off the water, and then sprayed into a large chamber to form pellets which are almost moisture free.

Synthetic Versus Natural Nitrate of Soda. — With the perfection of the processes for fixing atmospheric N, synthetic $NaNO_3$ and other nitrogenous salts have been produced and used in the fertilizer industry. Claims have been made that because of the B, I, and Br as impurities ($Na_2B_2O_7$, $NaIO_3$, $NaBrO_3$) in Chilean nitrate, this material is superior to synthetic nitrate. Whereas there may be some merit in the claim, conclusive experimental evidence is lacking.

The Na Component of $NaNO_3$. — Nitrate of soda is one of the physiologically alkaline fertilizer salts. Thus, 100 pounds of $NaNO_3$ has a neutralizing value equivalent to 60 pounds of ground limestone. As plants take up the nitrate ions, the residual Na ions replace the H ions or the exchangeable bases. If used in large quantities, as in cotton and tobacco culture and in sidedressing vegetable crops, $NaNO_3$ may impart to the

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[2] The percentages of N given for $NaNO_3$ as well as for other compounds to be mentioned are those usually found in commercial products. Chemically pure compounds have a somewhat higher assay.

soil solonetzic-like properties, causing its dispersion and thereby destroying the structure of the soil. These effects are partly offset by the heavy applications of the 18 to 20 per cent acid phosphate used in mixed fertilizers. The gypsum associated with the acid phosphate combats the injurious influence of the Na. However, if high analyses phosphates are used, such as triple superphosphate, ammonium phosphate, or metaphosphates, gypsum must be added to the soil, about 60 pounds (⅔ the neutralizing value) for every 100 pounds of $NaNO_3$.

Nitrates Versus Ammonia.— $NaNO_3$ has the edge over the ammonia forms of N because of the neutralizing power of the Na and the ease of movement of nitrate ions which are not adsorbed by the soil colloids, except perhaps locally where the soil becomes less negatively charged, as in the *zone of laterization and in the* B *horizon in the zone of podzolization* because of the high R_2O_3 content. Another advantage of nitrates is that plants absorb them more readily than ammonia. In addition, plants can tolerate much higher concentrations of nitrate than ammonia. These advantages of the nitrate may explain its great popularity. However, the free movement of nitrates sometime carries them beyond the root zone (rhizosphere), either temporarily or, when they are washed down into the ground waters, permanently. By fractional applications of nitrates, losses by leaching may be reduced to a minimum.

Calcium Nitrate (*$Ca(NO_3)_2$ - 15 per cent N*).—This salt is a synthetic product, made by the reaction of limestone and nitric acid:

$$CaCO_3 + 2HNO_3 = Ca(NO_3)_2 + H_2O + CO_2$$

Calcium nitrate, sometimes called Norwegian saltpeter, was one of the first commercial synthetic N products. Before the war, this material has been manufactured largely in Norway and Germany and none in the United States. The hygroscopicity of $Ca(NO_3)_2$ and its relatively low N content place it in an unfavorable competitive position as compared to other sources of N.

It would appear that since $Ca(NO_3)_2$ is a carrier of Ca, it should be preferred to $NaNO_3$. In practice, however, $Ca(NO_3)_2$ has found only limited use in mixed fertilizers. As a sidedressing material it has not proved its worth. It is probable that the increased concentration of Ca ions may be locally a hindrance instead of an advantage. They are apt to upset the balanced ratios of Ca:K and Ca:Mg; an abundance of Ca may force luxury consumption of this element and, perhaps, immobilize some phosphate.

Potassium Nitrate (KNO_3 - 13 per cent N and 44 per cent K_2O).—Known as ***niter, saltpeter,*** or ***nitrate of potash,*** this salt carries two fertilizer elements, N and K. Natural deposits, not of commercial value, occur in various parts of the world. It is mined to a limited extent in India. It is obtained in small quantities as a by-product in the production of $NaNO_3$ from the Chile caliche which contains in mine-run material 2 to 3 per cent KNO_3.

Sodium Potassium Nitrate. — Known on the market as *Nitropo,* this product is a mixture of Na and K nitrate, containing about 15 per cent N and 15 per cent K_2O. It comes as a natural product from the Chile caliche.

Ammonium Nitrate (NH_4NO_3 - 33 to 35 per cent N). — This synthetic compound contains half of its N as nitrate and the other half as ammonia. If not used in excess, NH_4NO_3 may be used to good advantage, provided a source of Na is provided in the form of rock salt. The Na also prevents the rapid intake of NH_4 which may be injurious. The author has used ground rock salt with NH_4NO_3 with excellent results.

NH_4NO_3 is almost a physiologically neutral salt, except that some of the ammonia becomes nitrified giving HNO_3. One may expect some of the NH_4 ions to be used by plants and some to be adsorbed by the exchange complex of the soil within a few inches of the point of placement. The NO_3 ions, however, move up and down.

One of the chief drawbacks of NH_4NO_3 is that it takes up water quickly when exposed to the air. The crystals then form one solid mass which has to be crushed with caution because NH_4NO_3 is explosive. When piles of paper bags that had been used as containers of NH_4NO_3 catch fire, there is always the danger of an explosion. Such paper bags should, therefore, not be accumulated; rather they should be burned as they are emptied.

To overcome the property of caking, the crystals of NH_4NO_3 are coated with ground limestone. With 40 to 60 per cent of limestone, a product containing from 15 to 21 per cent N is obtained, known on the market under the name of Cal-Nitro. In France, the NH_4NO_3 is mixed with gypsum, and the latest development is a coating of paraffin or a similar substance that protects the crystals from taking up water. In this form the salt can be used in fertilizer mixtures, or alone for sidedressing.

AMMONIA NITROGEN

Fixation of Atmospheric Nitrogen. — Over every acre of the earth's surface there are about 34,000 tons of free atmospheric N. Except for the amount brought into the soil by the N fixing organisms, the vast supply of atmospheric N is useless to plants. The process of fixing N by chemical means has, however, made this tremendous reserve available for fertilizer and explosives.

Arc Process. — One of the earliest processes, but the least used now, is the union of N and O, by passing air between two energized electrodes which develop a temperature of 3590°C (an electric arc). This is known as the arc process. The reactions involved are as follows:

$$N_2 + O_2 \longrightarrow 2NO$$
$$2NO + O_2 \longrightarrow 2NO_2$$
$$3NO_2 + H_2O \longrightarrow 2HNO_3 + NO$$

This, by the way, is the process by which lightning causes N fixation.

Cyanamide Process. — The second process of importance in fixing N is the cyanamide process. In the trade, the product is known as *cyanamid* or *Nitrolim.* It is made by treating finely powdered calcium carbide with pure N at 1000°C. The following reactions are involved:

$$CaO + 3C \longrightarrow CaC_2 + CO$$
$$CaC_2 + N_2 \longrightarrow CaCN_2 + C$$

Ammonia Fixation. — The Haber process for NH_3 synthesis revolutionized the N industry. It has supplanted both the arc and cyanamide process of fixing atmospheric N. In this process, air and live steam are blown through glowing coke to produce H and CO; the N of the air passes through unchanged. These gases are purified (only N_2 and H_2 remain) and subjected to a temperature of 450 to 600°C at pressures of about 900 atmospheres, in the presence of a catalyst, usually Fe and Mo salts. Ammonia is formed and from it various compounds are made for various purposes, and of course, for fertilizer. In all, about ⅔ of the N which the world uses is made by fixation from air, mostly through the NH_3 process. Much of the NH_3 is converted to nitrate by catalytic oxidation, as represented by the equation:

$$4NH_3 + 5O_2 \longrightarrow 4NO + 6\,H_2O$$

Toxicity of Ammonia. — In the late nineties of the last century, Kostychev, a Russian plant physiologist, proved that plants may use ammonia as such. This was more convincingly brought out in the first decade of this century by Pryanishnikov, another Russian plant physiologist. It was shown, however, that the concentration of NH_4 ions in the medium must be low. In quantities equal to a concentration of NO_3 which plants can comfortably tolerate, NH_4 ions become extremely toxic. The actual tolerance concentrations of either of these two sources of N depend on the presence of other ions, the kind of ions, and total concentration of salts. This phase of study is known as differential absorption of ions by plants, and it belongs to the realm of plant physiology.

Adsorption of Ammonium Ions. — It was pointed out in chapter VI, that NH_4 ions are adsorbed in part by the exchange complex. The quantity adsorbed depends primarily on two factors: the exchange capacity of the soil and its pH. The higher the exchange capacity, the greater the chances for the NH_4 ions to be adsorbed. With reference to the pH factor, it should be recalled that the lower the pH, the greater the quantity of H ions in the exchange complex; the H ions are tightly held and exchanged only with difficulty. It is apparent, then, that NH_4 ions can not successfully compete with H ions for exchange positions. Thus, in acid soils not much of the ammonia is adsorbed. However, since there are very few crops that thrive in acid soils (pH range of 4.8 to 5.6), the progressive farmer endeavors to maintain a pH of about 6.0 to 7.6 by proper liming. Under these conditions appreciable quantities of NH_4 ions are adsorbed.

Placement of Ammonium Salts. — The phenomenon of NH_4 adsorption puts a definite limitation on the placement of fertilizer containing NH_4 salts and on the use of such fertilizers for sidedressing and topdressing. Because of the adsorption phenomenon, NH_4 ions are not likely to move more than two to three inches in any direction from the point of placement in the soil. If fertilizer containing NH_4 salts is distributed on the surface of soils heavier than sands or loamy sands, it is quite likely that this nutrient will not find its way to the rhizosphere. There is a further hazard. A dry spell following the fertilizer application may cause an appreciable portion of the NH_4 ions to become fixed and, hence, unavailable for plant use during that season.

A logical inference from the above is that NH_4 salts, or fertilizer carrying these, should be placed in the soil 5 to 7 inches below the surface or at the hottom of the furrow. Only then will this source of N be efficiently utilized by the root system. Here, the NH_4 can be replaced by H ions (from the carbonic acid of the roots), or nitrified hy appropriate microorganisms. From the point of view of resistance to leaching, ammonia N is far superior to nitrate. The latter is not adsorbed and moves up and down with the movement of moisture in the soil; NH_4 ions stay put close to where they are placed.

Because of the limitations discussed, NH_4 salts cannot be used successfully for topdressing sod or for sidedressing cultivated crops. Accordingly, the use of $NaNO_3$ is widespread for these purposes. For rice culture or for other plants grown in water cultures, ammonia as a source of N, especially $(NH_4)_2SO_4$, has been found to give excellent results.

Ammonium Sulfate ($(NH_4)_2SO_4$—20.5 to 21 per cent N).—This salt, known in the fertilizer trade as *sulfate of ammonia*, was in use ever since it was produced from the distillation of coal in the manufacture of coke and illuminating gas by passing the NH_3 into dilute H_2SO_4. It has been estimated that 30 pounds of $(NH_4)_2SO_4$ and 10,000 cubic feet of gas are obtained from a ton of coal.

Synthetic NH_3 production has led to the development of other processes for the production of $(NH_4)_2SO_4$. In one process, ammonia water is brought in contact with a suspension of gypsum through which CO_2 is bubbled under pressure. The $(NH_4)_2CO_3$ thus formed reacts with the gypsum, giving rise to $(NH_4)_2SO_4$ in solution which is filtered off, and the $(NH_4)_2SO_4$ salt is recovered by evaporation.

Sulfate of ammonia is a physiologically acid salt, i.e., it leaves behind an acid residue. First of all, when NH_3 is nitrified HNO_3 is formed. Secondly, the sulfate anion combines with replaceable H to give H_2SO_4. For that reason, the use of $(NH_4)_2SO_4$ year after year tends to produce an acid reaction in the soil. This acidity may be overcome by adding to the fertilizer mixture an equivalent quantity of dolomitic limestone, one pound for every pound of $(NH_4)_2SO_4$. In some cases, such as in potato culture on soils infested with scab, $(NH_4)_2SO_4$ is preferred for its acid producing property which is effective against scab.

On rice paddies $(NH_4)_2SO_4$ proved to be a better source of N than $NaNO_3$ which, under submerged conditions, is reduced to toxic nitrites.

Effect of Sulfate Ions. — The sulfate ion of $(NH_4)_2SO_4$ is important in the soil-plant system. First of all, it supplies S which is an essential element in plant nutrition. Secondly, the sulfate ion facilitates coagulation and thus improves the soil structure. Thirdly, the sulfate aids in the precipitation of Fe and Al as colloidal hydrated oxides at low pH values.

Other Ammonium Salts. — Besides $(NH_4)_2SO_4$ and NH_4NO_3, which make up the bulk of ammonium fertilizer salts, others have been manufactured and used: 1. Monoammonium phosphate, $NH_4H_2PO_4$, carrying 12.17 per cent N and 61.7 per cent P_2O_5. The commercial grade, sold under the trade name *ammo-phos* contains 11 per cent N and 49 to 51 per cent P_2O_5. Another grade of ammo-phos contains about 16.5 per cent N and 20 per cent P_2O_5. 2. Diammonium phosphate, $(NH_4)_2HPO_4$, carrying 21.2 per cent N and 53.35 per cent P_2O_5. 3. *Leunaphos* is a trad name of mixtures of $(NH_4)_2HPO_4$ and $(NH_4)_2SO_4$ and/or NH_4NO_3 Some of the mixtures contain 10.7 per cent N, others—16.5 per cent N with 48 and 20 per cent P_2O_5 respectively. 4. *Leunasalpeter* is a doubl salt, combining in equal molecular proportions 80 pounds NH_4NO_3 wit 132 pounds $(NH_4)_2SO_4$. This mixture contains about 26 per cent N one-fourth of which is in the nitrate form. 5. Ammonium chloride, NH_4C is a salt that is not used extensively; its drawback is the Cl ion.

Ammoniated Superphosphate. — In recent years, the production cheap synthetic NH_3 has made it profitable and practical to produce amm niated superphosphate. This is done by allowing freshly prepared supe phosphate to adsorb anhydrous NH_3 or aqueous ammonia which may co tain some dissolved urea, $NaNO_3$ or NH_4NO_3. Ammonia is readily taken up by superphosphate forming $NH_4H_2PO_4$, $(NH_4)_2SO_4$, dicalcium and some tricalcium phosphates. The reactions taking place in ammoniated superphosphate improve the mechanical condition of the mixture. The amount of NH_3 taken up by superphosphate may be as high as 6 per cent. This gives the mixture as much as 20 per cent $(NH_4)_2SO_4$ and 6 per cent $NH_4H_2PO_4$.

Sodium Supplementing Ammonia Salts. — Based on limited personal experience and on sound theoretical grounds, the use of some Na salts is recommended as a supplement to NH_4 salts. With NH_4NO_3 as the source of N, the addition of 100 to 150 pounds of Na_2SO_4 per acre is advisable. With $(NH_4)_2SO_4$, 100 to 150 pounds $NaNO_3$ make a more desirable source of N. With ammonium phosphate, some $NaNO_3$ and some Na_2SO_4 (50 to 75 pounds each) make a better mixture. If no Na_2SO_4 is available, a similar quantity of NaCl may be substituted.

CYANAMIDE AND UREA

The N of cyanamide and urea is converted into NH_3 by the soil microbes and chemical oxidation. These compounds have the same limitations and advantages as NH_4 salts.

Calcium Cyanamide. ($CaCN_2$ - 21 per cent N). — This synthetic source of N carries 15 per cent free lime (CaO) in addition to the Ca of the 70 per cent of $CaCN_2$. In all, 100 pounds of cyanamide carry 63 pounds of bases. In other words, it is physiologically basic. Some of the benefits derived from this source of N may be ascribed to the lime it carries. When cyanamide is mixed with superphosphate, heat is evolved. An addition of 40 to 60 pounds of cyanamide to a ton of mixed fertilizer gives off enough heat to dry the mixture. When exposed to the air for a long time, cyanamide deteriorates giving rise to dicyandiamide, a very stable compound which is of little value as a fertilizer.

When added to the soil, cyanamide is converted into urea and then to ammonia. It takes 2 to 7 days for the conversion to take place, and during this period the undecomposed cyanamide may be injurious to the crop. For this reason, it is not used much as a single salt. When dusty cyanamide is applied to a standing crop, it may cause serious injury to the foliage. In contact with the exposed skin, this material causes inflammation. In pellet form, covered with an oil, the cyanamide is harmless.

Urea ($CO(NH_2)_2$ - 46 per cent N). — Urea occurs naturally in guano and stable manure. It is manufactured synthetically by combining pure ammonia and pure CO_2 under pressure.

$$CO_2 + 2NH_3 = CO(NH_2)_2 + H_2O$$

tion of the products that make up the tankage determines its quality; it may contain 5 to 9 per cent N and 9 to 14 per cent P_2O_5. The quantity of N depends on the amount of meat, and P_2O_5 on the amount of bone in the tankage. It is sold under the name *meat meal* or *bone tankage*. At present, 95 per cent of the tankage is consumed as animal feed, fortifying the dairy and poultry rations.

There is also on the market a *process tankage*. It is manufactured from such materials as wool waste, hair, hoofs, horns, scrap leather, and similar animal products. It has to be digested with acid to make the N available.

Fish and Fish Meal. — Fish is used as a fertilizer in regions where it can be easily procured. In 1910, the author used dry flounders to fertilize hills of corn in South Jersey. This practice, it is claimed, was copied by the white men from the American Indian. Raw fish unfit for market and scrap from fisheries are utilized even now by farmers located near the source.

Fish prepared like tankage is known as fish meal, and farmers know it for the strong odor. The better grades of this material go into hog and poultry feed. On the average, fish meal contains 8 per cent N and 8 per cent P_2O_5; it blends well in the fertilizer bag. The presence of waste bones decreases the N and increases the P_2O_5 content. Along the Atlantic coast, king crab is used as a fertilizer both in the green state or dried and ground. The latter form contains 9 to 12 per cent N and some P_2O_5.

Garbage Tankage.— It is manufactured from household waste in the same way slaughterhouse materials are in the manufacture of regular animal tankage. Garbage tankage contains 2 to 3 per cent N, 1 to 3 per cent P_2O_5, and 0.5 to 1.5 per cent K_2O. Because of its low nutrient value, garbage tankage cannot be used as a source of N or as a fertilizer by itself. If available locally, it can be put to good use.

Sewage Sludge. — Suspended matter separated from sewage is known as sludge. The moisture content of sludge varies, depending on the process of sewage disposal. In the wet form, sewage sludge is as valuable as barnyard manure, if it contains no injurious materials that usually enter the sewerage systems with industrial wastes.

In some cities, the sludge is dried and ground, and may contain about 5.5 per cent N and 3 per cent P_2O_5. It is marketed under the name *milorganite*.

In many cities in Europe and in a few cities in the United States, raw sewage is used in irrigating crops. In the United States, most of the crops grown in this manner are prohibited for human consumption. In Europe, there seems to be no objection to the use of any crop grown with raw sewage. *In China, night soil is the principal fertilizer source in crop production*, and the people do not seem to object either.

Base Goods. — Garbage tankage, wool waste, hair, hoofs, horns, scrap leather, shoddy, felt, tobacco stems and other materials of organic origin are mixed with rock phosphate and treated with H_2SO_4, giving superphosphate carrying some N. This type of superphosphate is known as *base goods* or *basemix,* because it is the basis for making up fertilizer mixtures.

Mineral Nitrogen in Organics. — Most prominent in this category are combinations of mineral N, primarily NH_3, with organic materials, such as peats, sawdust, brown coal, lignin residues in the manufacture of paper pulp, wool waste, and leather scrap. Any one of these materials, especially the peats, may be treated with NH_3 at ordinary temperatures and pressures, or at elevated temperatures and pressures. With pressures up to 50 atmospheres and at 250 to 270°C, peat and brown coal give a product containing 17 to 30 per cent N; sawdust gives a product containing 8 to 20 per cent N. Without pressure, some peats may absorb 6 per cent N. The fresh product retaining some free NH_3, when treated with H_3PO_4, may give a product containing as much as 9 per cent N, with as much as 20 per cent P_2O_5.

The N in the products of high pressure and temperature is not in available form. Apparently, the NH_4 combines with the organic constituents, forming heterocyclic organic compounds which do not decompose very readily in the soil. The products of ordinary temperature and pressure, however, have proved to be a good source of N for various crops.

The above and many other N and organic matter combinations have been made and tried out on crops in various parts of the world. Thus far, these products have found only limited application. One drawback in using these products is their bulkiness which presents a transportation and freight cost problem.

Phosphorus Carriers

Rock Phosphate. — Rock phosphate, or phosphorite, is a rock rich in calcium phosphate. Besides the definite *mineral phosphates,* there are extensive deposits of *amorphous phosphates,* consisting largely of *bone phosphate,* which have no definite chemical composition. These deposits occupy the original position in which the bones of vertebrates, shells of invertebrates, and the excrements (usually of birds) had accumulated. Other deposits are the result of solutions of phosphatic materials and Ca compounds which precipitate in ocean waters. Upon emergence from the sea, the bulk of the lime is dissolved leaving behind the phosphate.

The deposits of rock phosphate in the United States are located in Arkansas, Florida, Idaho, Kentucky, Montana, South Carolina, Tennessee, Utah, and Wyoming. The principal sources of the present supply are the Florida and Tennessee deposits. Outside of the United States, important deposits are in Morocco, Algeria, Tunisia, Egypt, Nauru and Ocean Islands, and Russia. There are plentiful supplies in many other parts of the world.

Rock phosphate, or phosphorite, is composed largely of fluor-apatite. Limestone, oxides of Fe and Al, and SiO_2 are important impurities associated with the rock phosphate. The mineral apatite is found in igneous rocks.

The quality of rock is determined by its H_3PO_4 equivalent (P_2O_5 in terms of the fertilizer trade). A high Fe and Al content (more than 2 per cent) makes the rock undesirable for the production of superphosphate, because these impurities impart a poor mechanical condition to the product.

The Florida deposits, discovered in 1888, appear in the following forms: hard rock, soft rock, land pebble, and river pebble. *Hard rock* varies in thickness from a few inches to 100 feet and is embedded in clay, sand, or soft rock phosphate. It contains as much as 75 to 80 per cent $Ca_3(PO_4)_2$ or 35.5 per cent P_2O_5 and very little R_2O_3. *Soft rock* (really a powdery mass) carries only 40 to 60 per cent $Ca_3(PO_4)_2$ and contains appreciable quantities of limestone and clay. *Land pebble* phosphate occurs as light gray to black pebbles mixed with clay and sand. It carries 68 to 75 per cent $Ca_3(PO_4)_2$ or as much as 34 per cent P_2O_5, and 5 to 6 per cent Fe and Al oxides. Land pebble accounts for more than 90 per cent of Florida's phosphate production. *River pebble* is of minor importance at present, since the best sources of this material have been exhausted.

The Tennessee deposits, discovered in 1894, are found in veins and pockets as very hard and compact rock, varying in $Ca_3(PO_4)_2$ content from 68 to 90 per cent. The color of the rock is brown, blue or white. The beds of rock range in thickness from 1 to 4 feet and are mined from open surface pits and also underground.

Raw Ground Phosphate. — Raw rock phosphate brought from the mine is washed, dried, crushed and ground. The finely ground mass is known as floats. Because of its insolubility, rock phosphate as such is not used much as a source of P in fertilizer. It has been found that on podzol soils or on acid peats and mucks finely ground phosphates rock does give good results. In Illinois, rock phosphate has been used successfully for the last 50 years. There is a general feeling that legumes utilize raw phosphates better than many other crops. This is probably due to the relatively large quantities of nitric and other acids formed locally in the rhizosphere. In the author's experience, buckwheat is one of the few non-legumes that uses raw phosphates effectively. Of course, large applications of raw phosphate may supply enough P in solution to meet the demand of any fast growing plant. If a cheap source of raw ground phosphate is available, it may be used for a great many crops on almost any soil in the zones of laterization and podzolization. It should be remembered that rock phosphate is alkaline and, therefore, neutralizes acidity. *In preparing soils for alfalfa to last a number of years, an incorporation of several tons of rock phosphate floats through a depth of 12 to 18 inches will go a long way toward maintaining the supply of available P and reducing acidity.* Such an application of raw phosphate on alfalfa does not obviate the necessity of liming, as outlined in chapter XI, and for annual dressings with a mixture of 20 per cent acid phosphate and muriate of potash, about 300 and 50 pounds of each respectively.

Superphosphate. — In 1842, John B. Lawes, founder of the world famous Rothamsted Experiment Station (1843), having failed in previous attempts to increase the yield of turnips with ground bone, treated the bone with H_2SO_4 to make the phosphate soluble. This worked. He then applied the same acid treatment to ground rock phosphate and laid the foundation for the process of superphosphate, sometimes known as acid phosphate, manufacture. Except for modern equipment and techniques, the process developed by Lawes is used to this day.

The reactions involved in the manufacture of superphosphate are simple:

$$Ca_3(PO_4)_2 + 2H_2SO_4 + 4H_2O \longrightarrow CaH_4(PO_4)_2 + 2CaSO_4.2H_2O$$

This equation shows that a 100 per cent $Ca_3(PO_4)_2$ gives a product (a mixture of monocalcium phosphate and gypsum) containing about 25 per cent P_2O_5. Since rock phosphate, as a rule, carries not more than 80 per cent $Ca_3(PO_4)_2$, the resulting superphosphate cannot contain more than 20 per cent P_2O_5, unless extra H_3PO_4 is added to the mixture or some of the gypsum is removed. The usual run of superphosphate contains not less than 16 and not more than 20 per cent P_2O_5 and about 50 per cent gypsum. With a mixture of H_2SO_4 and H_3PO_4, a superphosphate containing 32 per cent P_2O_5 is produced; it is known as *double superphosphate.* Rock phosphate treated with H_3PO_4 only gives *triple superphosphate* containing as much as 48 per cent P_2O_5. Triple superphosphate is used in making concentrated fertilizer mixtures. The 18-20 per cent superphosphate is the most widely used source of P and constitutes the major part of nearly all mixed fertilizers.

Reversion of Superphosphate. — The principal compound of superphosphate is $CaH_4(PO_4)_2$. It can exist as such only at a pH about 2.5-2.8. Since most acid soils in cultivation never reach this pH, the $CaH_4(PO_4)_2$ when mixed with the soil is gradually converted into the insoluble dicalcium and tricalcium phosphates, $Ca_2H_2(PO_4)_2$ and $Ca_3(PO_4)_2$. This conversion process is known as *reversion*. It has been shown that superphosphate thoroughly mixed with the soil reverts within a few days. When placed in bands, the reversion slows down, with the outer coating of di- and tricalcium phosphates protecting the inner portion of the superphosphate from rapid reversion. It should be pointed out, however, that the reversion of the soluble phosphate to the insoluble form is not as serious as it might appear at first thought.

It has been shown that precipitated $Ca_3(PO_4)_2$ is just as good as superphosphate, even though it is relatively insoluble. The huge surface of the amorphous state of the precipitated $Ca_3(PO_4)_2$ gives the plant roots a chance to come in contact with a large number of nests of this phosphate, and it is this type of phosphate that forms in the process of reversion. In the course of time, especially during periods of drought, the amorphous phosphate changes to the crystalline form, and it takes on the properties of apatite. This is one reason (the other is the fixation of phosphates as Fe, Al, and Mn compounds) why soluble phosphates have to be added year in and year out, disregarding the fact that phosphates accumulate in the soil.

Phosphates that have been fixed may be released in appreciable quantities by adding lime and gypsum to the soil. The increased circulation of Ca ions causes the formation of precipitated $Ca_3(PO_4)_2$ (by virtue of the law of mass action) as soon as any phosphate ion is released from Fe, Al, or Mn compounds. By this method, the phosphates accumulated in soils of potato or tobacco culture may be utilized.

Because of the reversion, superphosphates should be incorporated deep into the plowed layer, in the zone of the rhizosphere. Superphosphate incorporated into the plowed furrow may intercept toxic ions like Fe and Al moving upward.

Gypsum of Superphosphate. — The value of the gypsum in superphosphate has not been appreciated fully. Some of the merits of gypsum have been noted (p. 241), but they will bear repetition. First, gypsum supplies a large quantity of available Ca to the plant and to the soil. Secondly, gypsum supplies S which is used for building plant proteins. Thirdly, the sulfate ion helps to eliminate toxic Al, Fe, and sometimes Mn present in acid soils. The presence of gypsum lowers considerably the pH at which these elements precipitate as the hydroxides or phosphates. It is probably because of the specific property of gypsum to precipitate these that the 16 to 20 per cent superphosphate is so effective in acid soils.

Calcium Metaphosphate. — Calcium metaphosphate, $Ca(PO_3)_2$, as a fertilizer, was developed by the Tennessee Valley Authority (T.V.A.).

It is prepared by passing burning P into towers containing rock phosphate at a temperature of 1200°C; a slag is formed consisting of Ca-metaphosphate which contains 62 to 65 per cent P_2O_5. Extensive tests conducted by the T.V.A., in cooperation with Experiment Stations, have proved the metaphosphate to be an excellent material of high P availability. In using this material, one should add gypsum in quantities that a superphosphate source of P would supply.

Basic Slag. — This is a by-product in the manufacture of steel from ores or pig iron containing P. The P unites with the lime in the Bessemer converter. The molten slag rises to the surface and is poured off. When solidified, the slag is crushed and ground. It contains about 17 to 18 per cent P_2O_5 and compares favorably in availability with superphosphate. The excess of lime in this material makes it especially valuable for acid soils.

Very little of this product is manufactured in the United States. In Europe, however, large quantities are used, and it ranks next to superphosphate as a P carrier. The product is often referred to as *Thomas slag,* after S. Gilchrist Thomas who in 1879 improved the Bessemer process of steel manufacture of which the basic slag is a by-product.

Bone Phosphates.—Ground bone as a valuable soil amendment has been known for ages and was especially popular in England. Bone meal, either of raw or steamed bones, may be obtained on the local market. It contains from 22 to 30 per cent P_2O_5 and about 2 per cent N, and is considered almost as good as superphosphate.

Bones, bone black (from sugar refineries), and fish scrap are treated with H_2SO_4 to give superphosphate that is highly esteemed by some farmers. Its P_2O_5 value is about the same as that of the regular superphosphate, and it contains a little N besides.

Other phosphate carriers, such as the mono- and diammonium phosphate, ammo-phos, base goods and fish are used as sources of P_2O_5. This was pointed out in discussing these products as sources of N.

In recent years, a Mg-superphosphate, made by acidulating serpentine with H_3PO_4 and H_2SO_4, has come into use. The merits of this product is the higher solubility of the Mg-phosphates.

Potash Carriers

The word potash, K_2O, originates from *pot ashes,* wood ashes, that used to be leached and then evaporated to dryness to give lye. Actually, the salt thus secured is K_2CO_3 with some impurities.

For centuries, unleached wood ashes were used by farmers who appreciated their value for crops. The farmers also knew of the caustic properties of wood ashes and were careful not to place these in close proximity to seeds or plants. Depending on their origin, wood ashes may contain 5 to 25 percent K_2O. Young twigs contain a higher percentage of K_2O than old wood.

Until the first World War (1914-1918), German and French potash interests controlled the world market. The United States has since developed its own resources, and so has Russia, Spain, Poland, and Israel. Up to the beginning of the second World War, foreign imports still made up about 50 per cent of the K_2O used in America. When this supply was cut off because of the war, the United States had no difficulty in making up the difference from its domestic sources.

United States Potash. — The principal source of K_2O in the United States (in 1944 domestic plants produced 700,000 tons of K_2O for fertilizer) is the brine of Searles Lake at Trona, California. This lake covers an area of 12 square miles and averages 70 feet in depth. Other important sources of K_2O are the brines of lakes in Western Nebraska and in the desert west and southwest of the Great Salt Lake, Utah. The brine, which is pumped from wells, is evaporated in vacuum pans to form a crystalline mass. The 35 per cent salt brine contains only a little over 4.0 per cent KCl (2.5 per cent K_2O), about 17 per cent NaCl, about 7.5 per cent Na_2SO_4, about 1.5 per cent anhydrous borax, and other impurities.

Other salt deposits, of a nature similar to those in Germany, are found in New Mexico and Texas. The crude salts as mined contain 20 to 30 per cent K_2O. At present, New Mexico supplies the bulk of native K_2O.

German and French Deposits. — The German Stassfurt deposits are located in an area bound roughly by Thuringia on the south, Hanover on the west, and Mecklenburg on the north. The French deposits are located in Alsace. German deposits have been mined extensively since the sixties of the 19th century. French deposits were not exploited until 1908. They were worked more extensively after the First World War when Alsace was returned to France.

The deposits of K salts are found at about 650 to over 5000 feet below the surface. The beds of salt vary in thickness from a few inches to more than 150 feet. The salts consist of a number of minerals, carrying varying quantities of K_2O and impurities.

Carnallite. — This is the principal K mineral of the German deposits. It is a mixture of K and Mg chlorides, $KCl.MgCl_2.6H_2O$, with impurities of NaCl and $MgSO_4$. This mineral may carry from 9 to 12 per cent K_2O, depending on the impurities. It is, therefore, not being used directly as a source of K_2O, except locally.

Kainite. — In the pure form, this mineral has the composition $KCl.MgSO_4.2H_2O$ with Mg and Na chlorides as impurities. It carries from 14 to 20 per cent K_2O. At one time, large quantities of kainite was imported by the cotton growers of the South. There is no reason why it should not be used more extensively; the accessory salts are important ingredients that add to the value of the product.

Sylvinite. — This is the principal mineral of the French deposits; it consists primarily of KCl, with NaCl as the impurity, and carries 20 to 42 per cent K_2O. The run of the mine salt can be used effectively, except for the prohibitive cost of transporting extraneous salts.

Muriate of Potash. — KCl, known in the trade as muriate of potash, is the most important carrier produced from the impure potash salts. About 90 per cent of the K_2O in the fertilizer trade comes from muriate. The average per cent of K_2O in muriate is about 50 per cent. A grade with as high as 60 per cent K_2O is available on the market.

Sulfate of Potash. — This is prepared by the metathetical reaction of natural KCl with a sulfate. A product containing 90 to 95 per cent K_2SO_4 is separated by fractional crystallization. Because of the expense involved in the manufacture of this product, its cost is prohibitive for general crops; hence it is used for the more remunerative crops and those that do not respond well to chloride, such as tobacco, citrus, and pineapple. If the cost of sulfate were reduced, mixtures of the chloride and sulfate would be used for most crops.

Manure Salts. — These are mixtures of crude salts enriched with enough refined KCl to give the desired K_2O content. Generally, these salts contain from 20 to 30 per cent K_2O. Manure salts contain appreciable quantities of common salt and, if large quantities of K are to be supplied from this source, there is danger of incorporating too much NaCl. However, 5 to 10 per cent of the total K applied in the form of manure salts may often be an advantage. The impurities they carry may serve as stimuli, supplying some elements not found in refined salts. Besides, as pointed out in the discussion on saline soils, a mixture of salts is always more efficient.

Other Potash Carriers. — 1. *Greensand marls,* found in New Jersey, Delaware, Virginia, Maryland, and North Carolina, represent huge resources of K_2O. The K bearing mineral *glauconite* (a K, Fe silicate with some P_2O_5) is greenish in color, hence the name. The marls of New Jersey analyze 5 to 7 per cent K_2O and 1 to 2 per cent P_2O_5. In the 70's and 80's this material was utilized for soil improvement. The author used greensand marl experimentally, with marked success, in the Lebanon forests of New Jersey. No economical method of extracting the K_2O from the greensand marls has been developed. 2. *Kelp*, a seaweed of the Pacific Coast, when burned, gives an ash containing about 30 per cent K_2O. 3. *Ash*, from burning the following waste products: *a*, the distillation of alcohol from cane sugar molasses; and *b*, sugar-beet molasses in the refining of sugar. The ash from these products analyzes more than 30 per cent K_2O. 4. *Flue dust*, a by-product of iron smelting and cement manufacture. As the hot gases containing the volatilized K_2O are led through flues they cool; the potash then precipitates in the dust. It contains from 3 to 13 per cent K_2O.

There are many waste products rich in K which are utilized only locally because of the nature of their distribution. Thus, ashes of *banana skins* contain close to 42 per cent K_2O and more than 3 per cent P_2O_5; of *grapefruit rinds*—30 per cent K_2O and 5.5 per cent P_2O_5; of *potato peelings*—close to 28 per cent K_2O and 5 per cent P_2O_5; of *corn cobs*—17.5 per cent K_2O; ground *tobacco stems* and waste tobacco in the manufacture of cigars and cigarettes—from 4 to 10 per cent K_2O and 2 to 3 per cent N; *cigar* and *tobacco ashes*—about 17 per cent K_2O.

Complete and Mixed Fertilizer

A mixture of materials carrying NPK is spoken of as a complete or mixed fertilizer. The term *mixed* is sometimes referred to a mixture carrying two fertilizer elements, whereas *complete* refers to the mixture containing all three elements.

In the United States, the analysis of mixed fertilizers is usually expressed as per cent N, P_2O_5, and K_2O. In Europe and other parts of the world, the nutrients are reported as per cent N, P, and K, or NPK.

Fertilizer Laws. — To protect the farmer against frauds by unscrupulous dealers and manufacturers, fertilizer laws have been passed and enforcement agencies to implement these provided for. While these laws are not uniform, the variations are generally very minor. Practically, all states make it mandatory to furnish on the fertilizer package the following information: 1, name and address of manufacturer; 2, number of net pounds of fertilizer to the package; 3, brand or trademark; 4, chemical composition (known as the guarantee) in terms of percentages of N, P_2O_5 and K_2O. Some states require a statement of the ingredients which make up the mixture. This is known as the *open* or *public formula*.

Fertilizer Grades. — The guarantee, or analysis, is expressed by three figures which represent the composition of the fertilizer. A 5-10-10 fertilizer grade contains 5 per cent available N, 10 per cent available P_2O_5, and 10 per cent water soluble K_2O. These figures are known under several names: *fertilizer analysis, formula,* or *grade*. Strictly speaking, the analysis guarantees the percentage composition of the ingredients; the grade tells the percentages of the respective ingredients in the mixture; and the formula tells how the mixture is made up. In daily parlance, however, these names are used interchangeably.

The fertilizer grades have been developed over a period of years of experimentation. No one of these is adapted for all crops and not even for the same crop in different parts of the country. Thus, legumes, as a rule, need no N in the mixture, and a 0-10-10 is, therefore, used for alfalfa. Agronomists versed in soil productivity problems prefer a little N in the grade used for newly seeded stands. For sweet potatoes, the common grade is 3-9-12; a high N content causes luxuriant growth of vines and prevents tuber formation. For white potatoes which require a high K_2O content, a 4-8-8 is used. Local conditions occasionally dictate slight variations in grade to be used. One should look for advice from the local Experiment Station or good farmers of the neighborhood.

As the demand for fertilizer has increased and competition has become keen, the number of grades on the market has also increased. This comes about in the following manner. In any particular area, one dealer sells a 5-10-10 and another a 4-8-8 grade for potatoes. If the farmer was advised to use 1600 pounds of the 4-8-8, it is easy to see that in both cases the total quantity of plant nutrients was the same, namely, 80 pounds of N, 160 pounds of P_2O_5, and 160 pounds of K_2O. If a third dealer comes into the locality he can not very well offer either one of the two grades, so he introduces a 5-8-7, claiming it to be best for potatoes. And so on down the line for different crops and different localities. In 1937, there were 118 grades listed in the State of New Jersey.

Experiment station workers have been advocating the reduction of grades for a number of years. In 1943, because of war conditions, the Government stepped in and forced a reduction in grades. In all, New Jersey was allowed about 18 grades. None of the crops suffered in the least because of this drastic change.

The Mechanics of Making Up Grades. — Fertilizers are sold on the ton basis. The manufacturer uses a formula just as a cook uses a recipe. To make up 2000 pounds of a 4-8-8 grade, the manufacturer has a choice of materials. For the 80 pounds (4x20) of N, one may take 500 pounds of $NaNO_3$ which analyzes 16 per cent N; or 400 pounds of $(NH_4)_2SO_4$ carrying 20 per cent N; or 250 pounds of $NaNO_3$ and 200 pounds of $(NH_4)_2SO_4$. Combinations of other carriers, such as urea, dried blood, and cyanamide, may be introduced. For 160 pounds (8x20) of P_2O_5, one may take 800 pounds of superphosphate carrying 20 per cent P_2O_5 or 500 pounds of the 32 per cent superphosphate. For 160 pounds (8x20) of

K_2O, one may use about 260 pounds of the 60 per cent K_2O grade KCl; or 320 pounds of the 50 per cent K_2SO_4; or about 520 pounds of manure salts carrying 30 per cent K_2O. The determining factor in selecting the carriers is price. If the law does not require to state on the bag the source of the N, the manufacturer may use either $NaNO_3$ or $(NH_4)_2SO_4$, whichever is cheaper. From the point of view of the farmer, however, it is better to have a mixture of carriers, especially of N. Thus, the choice would be:

250 pounds $NaNO_3$ = 40 pounds N
200 " $(NH_4)_2SO_4$ = 40 " N

Total...... 80 " N
800 " 20% superphosphate = 160 " P_2O_5
260 " 60% KCl = 160 " K_2O

Total....1510 pounds of materials

To make up a ton of 4-8-8, one would have to add to the 1510 pound mixture 490 pounds of extraneous material, known as *filler*. The filler improves the mechanical condition of the fertilizer by preventing caking or lumping of the mixtures. The choice is somewhat determined by their functions as conditioners. Again, the cost of the conditioner is important. Sand, soil, sawdust, ground peat, ground limestone, ground tobacco stems, and any other material available are being used.

If the lower grade materials for K_2O were used, less filler would be necessary. On tbe other hand, if the 32 per cent superphosphate were used still more filler would be necessary. It is simple to see that if the 1510 pounds of material would make a well conditioned mixture, why should the farmer pay for adding a filler, for more bags, more labor, more freight, and more power to handle the fertilizer? And why add 490 pounds of filler to improve the mechanical condition of the fertilizer? Perhaps 190 pounds would do? Indeed, it is possible to have a mixture without a filler, especially if the fertilizer is to be used immediately. The point is that the farmer has been trained to buy fertilizer on the ton basis guarantee. In the early days of fertilizer trading, long before laws were introduced to protect the buyer, the odor and color of the materials were criteria by which many sales were made. Under such conditions, the volume and weight of the fertilizer meant a lot. And even now, there is the practice of making low grade fertilizer, such as 3-6-4, which the uninitiated will buy without knowing that most of the product consists of worthless filler. In some states, no fertilizer containing less than 15 units of NPK in the mixture may be sold, i.e., the percentages of the grade must add up to at least 15. In the trade, a unit of fertilizer means one per cent of a ton, or specifically 20 pounds of either N, P_2O_5, or K_2O. Thus when a unit of N is quoted at $1.50, the cost per pound will be $\$1.50 \div 20 = 7.5$ cents.

Fertilizer Ratios. — To eliminate the system of grades which lends itself to unscrupulous practices, the European system of applying plant nutrients according to crop and soil needs is being advocated. Thus, the European farmer has been taught that for a potato crop he needs 75 pounds of N, 150 pounds of P_2O_5, and 150 pounds of K_2O per acre. Whether it will take 1000 pounds, 1200 pounds or 1500 pounds of total material to supply these nutrients is not very important. The 75:150:150 figures when reduced to the simplest ratio will be 1:2:2. Now, in making up the fertilizer mixtures to suit the needs of certain crops and soils, the manufacturer will have a half dozen ratios to offer. There is no need for selling, let us say, 1200 pounds of worthless filler with 800 pounds of good fertilizer. To get these 800 pounds in good mechanical condition, the dealer who sells these on the basis of nutrients adds just enough filler to give the mixture the required conditioning. The farmer pays for 800 pounds of fertilizer, and not for mixing a lot of filler, bagging superfluous material, etc. The selection of ratios to get definite quantities of plant nutrients is the system that will eventually be adopted in this country.

Home Mixing. — It goes without saying that the cost of mixing fertilizer, such as the actual labor involved and other cash expenditures, must be charged against the buyer. By buying the raw materials, the farmer may save this cost, since he can prepare the mixtures at a time of the year when he has little to do. Besides the saving, the farmer has the opportunity to choose the materials he knows are best suited for his conditions. In this respect, he may take advantage of the expert advice of the State Experiment Station. Another point, if the farmer wants a special mixture, he may do so without paying the extra charges to the dealer. Mixing his own fertilizer is a worth while education for the farmer; it brings him closer to the problems of his soil and crops.

The disadvantages of home mixing are associated with difficulties of a mechanical nature. For example, the mixture might set and cake, requiring machinery for crushing it. Odds and ends of fertilizer materials may be wasted. However, the farmer should learn how to overcome these difficulties, and the advice of the Experiment Stations is always at his disposal. It should be stated, that from an economic point of view it hardly pays to mix less than 10 tons of fertilizer. In the buying of large quantities of raw materials lies the advantage of home mixing. By pooling the buying power through a cooperative association, the individual farmer may realize considerable financial benefit.

High Analysis Fertilizers. — The introduction of urea, ammonium nitrate, ammo-phos, triple superphosphate, and metaphosphate carrying high percentages of N and P_2O_5 made it possible to make fertilizer grades containing large quantities of nutrients; for example, 10-15-10, 10-20-10, 10-20-20, 8-24-16 or 8-16-16. Such fertilizers are designated as *high analysis* mixtures. If we take 600 pounds of ammo-phos analyzing 10.7 per cent N and 48 per cent P_2O_5, 300 pounds of urea analyzing 46 per cent N, 250 pounds of triple superphosphate analyzing 45 per cent P_2O_5, and 650 pounds of KCl analyzing 60 per cent K_2O, the mixture of 1800 pounds contains 202 pounds of N, 400 pounds P_2O_5, and close to 400 pounds K_2O. If 200 pounds of some conditioner—a 100 pounds of dolomitic limestone and 100 pounds of castor bean meal or peat—are added, this fertilizer formula will represent the grade 10-20-20. Many other formulas of high analysis grades can be suggested. It is clear, that if one is to change from a 5-10-10 to a 10-20-20 grade he has to use one half the quantity of the latter grade of fertilizer.

On the face of it, high analysis fertilizers have these economic advantages: reduced costs of manufacturing, transporting, and distributing these on the land. A 10-20-20, in comparison with a 5-10-10, should theoretically cut the above costs by one half. Actually, however, the farmer does not enjoy all of these benefits, the manufacturer and some middlemen down the line also gain something. Nevertheless, high anlysis fertilizers do result in a definite saving of money.

There are, on the other hand, definite disadvantages. *First,* small quantities of materials are difficult to distribute uniformly and thoroughly. A smaller volume of soil will come in contact with the high analysis fertilizer giving less feeding ground to roots. *Second,* distribution of small quantities of materials involves more expensive machinery. *Third,* the safety and effectiveness of the high analysis material has not yet been fully established. The problem of *fertilizer burning* (actually an injury caused by contact with salts causing plasmolysis of plant tissues or seeds) becomes doubly dangerous with the "high powered" fertilizer. *Fourth,* with the lower grade of fertilizer one gets the accompanying substances, such as S and Ca in gypsum and S in ammonium sulfate, and other ions which were discussed earlier.

Of course, many of the objections raised may be met by introducing proper fillers, diluting the concentration of salts at any one point, and distributing the fertilizer with a greater volume of soil. It is also possible to add gypsum to take care of the Ca and S which are important. However, with these additions and operations involved, the initial financial gains made in using high analysis fertilizer are quickly wiped out.

FERTILIZER PLACEMENT

Two universal methods of applying fertilizer are in vogue: 1, broadasting and 2, placing the ingredients in proximity to the seed or plant.

Broadcasting and Plowing Under. — By and large, the method of roadcasting fertilizer has been found to be the safest and most effective n terms of yields. Besides going after the ingredients supplied by fertilzers, plant roots roam the soil in all directions for other nutrients. Plants xtend their root systems deep into the soil (provided the physical and hemical conditions are favorable) in search for water. By placing the ertilizer at one point, as in band applications, the tendency is for the roots o concentrate at this point. This limits the supply of nutrients other than hose of the fertilizer and curtails the water supply. These limitations may ften invalidate, at least in part, the effectiveness of the fertilizer. Because f these facts, it is preferable to broadcast and plow under fertilizer.

Plowing under of fertilizer is also important because leaving fertilizer n the surface or even working it just into the surface 2-4 inches means nefficient utilization of nutrients. The cations of the fertilizer ingredients nd the phosphate anion are retained or adsorbed by the soil; they are not ffected much in their distribution in the soil by upward or downward novement of moisture. Nitrates, however, may be placed at the surface, ince they work with the water downward. This means that most of the ertilizer ingredients, except nitrates, are of little value to the plants when ncorporated in the first 3-4 inches of soil.

Plants or seeds treated with transplanting or starter solution (see . 294) send out roots to depths of 5 inches and more within a few days. Jnder such conditions, plants begin to make good use of the nutrients disributed in a large volume of soil by broadcasting and plowing under of ertilizer.

In the case of meadows, pastures, and sod in general, where surface pplication is the only means of getting fertilizer to the plants, the time actor is important. If applied in the spring, the fertilizer ingredients, exept the nitrates, will concentrate at the surface. Drying and wetting the oil causes the fixation or immobilization and concentration of K and P t the surface. In the fall, the drying effects are not as acute and the soil s more open for mechanical movement of fertilizer ingredients. Thus, fall pplication of P and K carriers and topdressing with a complete fertilizer arrying extra nitrates in the spring are the most rational methods of ferlizing sods, meadows, and pastures.

In Proximity of Seed or Plant. — A fundamental consideration in ferlizer placement is to avoid contact of seed or plant roots with the fertilizer alts. This is particularly important in the methods of: 1, band application;

2, placing fertilizer in the hill; 3, mixing the fertilizer with the soil in th row. If the weather stays dry, there is danger of seed or plant injur Such injury is more frequent in sandy soils. On the other hand, in w years these methods have proved to be effective in increasing crop yiel of certain crops with less fertilizer than by other methods of applicatio However, even with all the precautions, such as applying the fertilizer i advance of planting and placing it at safe distances and depth away fro the seed or plant, the success of the proximity-to-the seed methods depen on the weather.

Potato growers generally favor placing fertilizer in a band on a lev with, and 2 to 3 inches to either side of the seed piece. It is pointed o that because of its limited root system, the potato cannot reach out for fe tilizers broadcasted. Many other plants, such as corn, tomatoes, sna beans, cabbage, and sweet potatoes have been tested with proximity-to-th seed methods of fertilizer placement and in many cases have given satisfa tory results. In general, the favorable results obtained with this metho of fertilizer applications may be explained by a poor physical and chemic state of these soils. The fertilizer salts eliminate some of the poor co ditions and permit the plants to utilize the nutrients at their disposal.

Fractional Application. — The method of fractional application of fe tilizer represents a combination of broadcasting and placing the fertiliz in proximity to plants or seed. The most common of the many variatio of this method is broadcasting and plowing under one to two thirds of t intended amount (it would be better to use a fourth) and sidedressing definite time intervals after planting. A better way of sidedressing is t apply the fertilizer as the plants need it.

Summary. — In the zones of laterization and podzolization, where fe tilizers are used most extensively, broadcasting and plowing under the fe tilizer is the most efficient method, especially in dry years. Roots exten into large volumes of soil where the fertilizer salts are incorporated. I that way the roots also have an access to more moisture. The locall tested methods of placing the fertilizer in proximity to the roots may b followed for a limited number of the so-called cool-season crops that a planted early in the spring, when the soil is generally well supplied wit moisture. Under such conditions, the root system may concentrate at th points where the fertilizer is located, without getting burned.

Generally, mixed fertilizers are used in the initial applications. It very likely that in the future the initial broadcast applications of fertiliz will consist primarily of PK carriers, with only small amounts of N a NO_3 and NH_3-salts preferably $NaNO_3$ and $(NH_4)_2SO_4$. Small quantitie of transplanting or starter solution will be placed in proximity to seeds o ts at planting time. The bulk of the N, about two thirds as NO_3 and third as NH_3, with small quantities of PK will be sidedressed as the ts will need it. This type of fertilization reduces the danger of high entrations of soluble salts in the zone of seed or plant placement. Of se, this method requires extra operations, but in the end it will pay.

Fertilizer for Different Crops. — No specific recommendations can be n for individual crops. Soil texture, previous crop and fertilizer and treatments of the soil, pH, the use of manure, and drainage condition il determine the quantity of fertilizer to be applied.

As a rule, the extensively grown crops, such as grain, forage and hay s, pastures, meadows, and fruit trees (in the zones of podzolization and ization or anywhere in the regions of intensive agriculture under stand- irrigation practices) may be fertilized with a 4-12-4 or 5-10-5 grade. rates used are determined by the returns per dollar invested. For crops the applications generally fluctuate from 200 to 800 pounds per . For intensively grown crops, such as vegetables, cotton, tobacco, etc., the same grades may be used at higher rates which may go up to a ton or even more per acre. For crops that need extra K, such as potatoes, beets, tobacco, and celery, the grade 5-10-10 or 4-12-8 is recommended. Under conditions of continuous culture, a 4-8-8 may be just as good as a 4-12-8.

In special cases, such as sweet potatoes, a grade with only 3 units of N is preferred; for alfalfa and other legumes no N is used, although experiments are on record showing that to start the legumes 1 or 2 units of N may be beneficial; for lawns and leafy vegetables an extra unit or two (above the 4 or 5 in the grades noted) have been found to be beneficial. These cases brought out on the market the grades 3-12-9 or 3-9-12; 0-10-10 or 2-10-10; and 7-7-7.

A good rule to follow in choosing a fertilizer grade, besides the general rules suggested, is to consult with a competent soil specialist at the State Experiment Station and local successful growers.

Minor Elements in Fertilizer Practices

By definition, minor elements are those which are quantitatively low in the plant or in the soil. Outside the elements C, O, H, N, Ca, Mg, K, P, and S which are present in appreciable quantities in plants as well as in the soil (the C and N comes from the air), any other element appearing in the plant ash may be considered as minor. However, there are plants that contain large quantities of Na, SiO_2, Cl, or Al. It is natural that more attention should be paid to the elements that are generally deficient in intensively cropped soils. Of the 86 possible minor elements, only a few have thus far been demonstrated to require attention in fertilizer practices: B, Mn, Cu, and Zn. Mn is generally not deficient in the soil, but becomes immobilized temporarily upon liming, and additions of manganese sulfate are necessary (see Ch. XI). The other 3 elements are found in soils in traces only (see also Ch. V).

Boron. — As a rule, this element is found in the soil in trace quantities. The lower limits of total and water soluble B for different crops have not been fully established. Plants vary considerably in their B requirement and their sensitivity to B deficiency in soils. Plants also vary in their sensitivity to B toxicity. It is very likely that the rate of supply in the soil dominates the situation. Some plants, such as the sunflower and turnip, have been found to be very sensitive to B deficiency and are used as an indicator plants. If the sunflower or turnip shows symptoms of B deficiency, additions of borax must be made. Lettuce, soybeans, oats and alfalfa have been found to have a high B requirement; corn and timothy, a low requirement.

Dry rot of beets, celery rot and cracked stems of celery, internal cork and corky apple cores, dieback of terminal buds of tobacco, browning of cauliflower, and brown heart of turnips are abnormal conditions resulting from a deficiency of B in the soil. A number of abnormalities in alfalfa culture, such as poor setting of seed and certain types of leaf bronzing, has been traced to the paucity of B. Citrus in California have benefited from the addition of borax. Apparently, there are many sections of the country especially the zones of podzolization and laterization, where B is deficient in the soil. Additions of borax have, therefore, become a common practice in many localities.

Whenever soils are limed, B deficiency is apt to appear. The bad effects wear off with time. Some investigators claim that microbes, stimulated by the Ca, use up the available B and leave little for the crop. It is also probable that temporarily the excess of Ca keeps the borate ions unavailable to the plants. Additions of borax are, therefore, advisable whenever heavy liming is practiced; it is a must with spring liming (see p. 237)

Boron is generally applied in the form of borax, $Na_2B_4O_7.10H_2O$ containing 11.44 per cent B. Boric acid, H_3BO_3, containing 17.5 per cent B may also be used, but it is more expensive. The quantities added vary from 10 to 40 pounds of borax per acre, less on light soils and more on heavy soils. On mucks one may use as much as 100 pounds. Since a slight excess of borax may cause serious trouble, it should never be placed in the row; it should be broadcasted. Some crops require more B than others, and the application of borax has to be made accordingly. If the borax has to be applied separately, a cyclone seeder may be used in disributing it. When mixed with the fertilizer and broadcasted, better disribution may be attained. For effective reaction, borax should be disked n.

Boron may be applied to the soil by way of manure. Borax at the ate of 2 to 3 pounds to the ton of manure, spread in the gutters of the ow barn, helps to control the breeding of flies. When used for that purose, the farmer should gauge his applications of manure, lest he supply oo much B and injure the crops. One should be impressed with the fact hat slight excesses of B are very toxic to plants.

Copper. — Muck and peat soils have been found to respond very favorbly to additions of copper sulfate. Premature dying of onions on muck oils in New York has been prevented by the application of $CuSO_4$. In he Florida Everglades, 75 to 100 pounds of this salt have been used in rowing sugar cane and other crops. Similar quantities of $CuSO_4$ have een found to be very effective against dieback of citrus trees in California nd Florida. The author obtained very good responses to applications of o to 50 pounds of $CuSO_4$ per acre on Portsmouth soils in North Carolina or lettuce and onions, and 100 to 150 pounds for celery on muck land in ergen County, New Jersey.

Zinc. — *Rossette* of pecan, *white bud* of corn, *bronzing* of tung oil ees, *yellows* of walnut trees, *mottle leaf* of citrus, and *little leaf* of the one fruits have been traced to a deficiency of Zn in the soil. Zn is sually added as the sulfate, either as a spray or to the soil mixed with he fertilizer. The applications vary from 5 to 40 pounds per acre, heavier oils and muck and peats taking the higher amounts and the light soils the naller amounts.

Manganese. — As a rule, soils are not deficient in Mn. Its availbility varies with the zonal soil types. In the zone of podzolization, Mn aches from the A horizon and accumulates in the B horizon. In virgin oils, the A_0 layer, upon mineralization, supplies sufficient Mn to satisfy he needs of the native flora. In cultivated soils, the drain on the Mn ources through harvested crops may exceed the rate of supply, especially hen lime is added to short season growing crops, such as spinach. oxicity of Mn has been reported on acid soils, but these cases are not ommon.

Additions of lime to neutralize acid conditions seem to immobilize emporarily the available Mn. Apparently, the sudden change in pH prepitates the Mn and causes a deficiency. Good growers have learned to apply this element in the form of manganous sulfate, 25 to 50 and 100 ounds per acre whenever *heavy liming* is resorted to.

In the zone of laterization, Mn may accumulate in the A horizon in the form of the oxides which go into solution only with difficulty. Additions of lime to these soil also immobilize the Mn and cause deficiencies.

There is apparently no paucity of Mn in the pedocals. The local action of nitrifying organisms and the formation of other acids seem to release enough Mn, as it does in the case of Fe, to supply the crop needs.

Other Minor Elements and Their Effects. — Deficiencies of Fe, Cu and possibly Co in the sandy Florida soils were found to retard the development of cattle feeding on plants grown in these soils. Lack of Co in certain New Zealand soils causes the *bush sickness* of sheep. The cause of a fatal alkali disease among animals, characterized by the loss of hair and hoofs, lameness, liver lesions and dropsy, has been traced to the consumption of grain and other vegetation grown on soils of arid regions containing available Se. Only one part of Se per million parts of soil may produce poisonous vegetation.

The importance of I in the diet as a measure of controlling certain types of human goiter is now well established. Soils near the seacoast get appreciable quantities of this element from the ocean water spray. In these sections of the country, the incidence of goiter is low, as compared with the regions removed from the seacoast.

In regions of intensive cultivation, arsenical sprays are used in combating diseases and insect pests. Cases are on record where the spray residues caused serious trouble to some crops. Vegetable growers in New Jersey found out that lima beans failed on land formerly in peach orchards which were heavily sprayed with lead arsenate.

Arsenic in soils is fixed in a manner similar to P. However, some of it moves downward into the profile. To overcome the injurious effects of As, an application of 1000 pounds of limonite or ground bog iron ore is recommended. Plowing under the surface layer to a depth of 10-12 inches is another way of meeting the problem. As to the Pb, it seems to he fixed in the soil, and is apparently not much of a prohlem from the point of view of its residual effects.

In general, plants are sensitive to soluble As and Pb, but the quantity taken up by them is not high enough to be injurious to humans or animals. Experiments at New Jersey with an array of vegetables (radishes, potatoes, squash, corn, peppers, tomatoes, cabbage, beets, beans, lettuce, eggplants, carrots, broccoli, and onions) have proved that onion tops retain the highest quantity of As, about 2.3 parts per million, and even these are below the tolerance limits set by the Government in connection with the removal of spray residues from fruit.

Fertilizing Organic Soils

Mucks and peats are fertilized very heavily and they produce huge crops. It is not uncommon for celery growers on muck in New Jersey and other states to apply 2500 pounds of a 5-10-10 fertilizer and 2500 pounds of $NaNO_3$ for sidedressing, besides 10 tons of manure, frequently poultry manure. Following early celery, some other crop, such as carrots, beets, or spinach, is grown. Again a heavy application of fertilizer, 2000 pounds or more, is made. As a rule, these applications are excessive and infrequently cause trouble.

Potassium. — This element is in the first minimum in organic soils. It should receive the highest priority in fertilizer grades for crops grown in muck or peat, especially those that have a high K requirement, such as potatoes, beets, and celery.

Any fertilizer grade for organic soils should contain not less than 7 per cent K_2O. In the author's experience, as much as 12 per cent K_2O was sometimes necessary for celery. In such cases, the low analyses grades have to be supplemented with muriate or, better yet, with sulfate of potash.

Phosphorus. — Even though P is fairly abundant in the upper layer of organic soils, liberal applications of phosphates have proved beneficial. They seem to retain the divalent and trivalent bases that are essential for the crop and which would otherwise be washed out.

Nitrogen. — This element is present in large quantities in organic soils. If limed properly, these soils are capable of supplying sufficient N released in the course of the decomposition of the organic matter. These soils also fix large quantities of atmospheric N. In the experience of the author, a grade of fertilizer containing as low as 3 per cent N may suffice. A careful check on the nitrate content during the growing season should be helpful in deciding on N applications.

Sulfur. — Some mucks having a high lime marl content may require additions of S to reduce the alkalinity and to introduce badly needed sulfates. From 500 to 2000 pounds of S were used. One should exercise great care in applying S. Unlike lime which may be added far in excess of need with no ill effects, just a few hundred pounds of S above the requirement may ruin a crop. One should always keep in mind the fact that one pound of S makes 3 pounds of concentrated H_2SO_4. A competent soil expert should be consulted in such cases.

Boron. — Organic soils suffer more than upland soils from a paucity of B. More borax has, therefore, to be added to mucks and peats. As much as 50 pounds and more per acre per season have been applied with marked beneficial results. Whenever these soils are limed, an extra 10 pounds of borax should be added.

Copper.—Copper sulfate is more effective in acid than in neutral or alkaline mucks and peats. It is of interest to note that the quantity of Cu taken up by a crop of lettuce or celery, for instance, may not be more than 15-20 grams, and yet 50 pounds have been found to be better than 25 pounds, and improvements have been noted with applications up to 150-200 pounds of $CuSO_4$ per acre. It is clear that in the case of Cu, it is not solely a question of the deficiency of a nutrient element, although it is possible that large quantities of $CuSO_4$ give a better distribution. However, from experience by the author with muck soil, it *appears as if the beneficial effects of $CuSO_4$ are due in some measure at least, to the precipitation of crenic and aprocrenic acids and, perhaps, other toxic substances.* Limed mucks and upland soils treated by the author with mixtures of gypsum and lime, did not respond to $CuSO_4$. This was probably due to the immobilization of the toxic substances by the lime-gypsum mixture and the increased pH. To play safe, some $CuSO_4$ should be added even to limed areas.

Manganese. — The usually low Mn content of organic soils makes it mandatory to add this element with the fertilizer. As much as 500 pounds or more of manganese sulfate have been added with no ill effects. In general, 50 to 150 pounds of this compound is sufficient to take care of the crop needs and to satisfy the capacity of the exchange complex of the soil.

Magnesium. — In discussing the liming of organic soil, it was pointed out that additions of Epsom salt are essential. It has been observed by the author that in addition to the Epsom salt applied with the lime, 100 to 150 pounds of Epsom salt mixed with the original application of fertilizer (broadcast) and 25 to 50 pounds with the fertilizer used for sidedressing have proved to be very beneficial.

It is very probable that in the near future more Epsom salt (or sulfate of potash-magnesia) will be used on organic as well as on upland soils. It has been reported from England that as much as 4000 pounds of Epsom salt have been applied on tomatoes with excellent results. Anyone who has had anything to do with tomato culture and sweet potato culture is well aware of the importance of Mg salts. These facts have been brought out in surveys of the tomato and sweet potato industry made by the New Jersey Experiment Station in 1938-1942.

There is a possibility that one of the beneficial effects of soluble Mg salts in fertilizer mixtures is the formation of magnesium phosphate, as shown in the following equation:

$$CaH_4(PO_4)_2 + 3MgSO_4 \longrightarrow Mg_3\ (PO_4)_2 + CaSO_4 + 2H_2SO_4$$

The Mg phosphates (undoubtedly some $Mg_2H_2(PO_4)_2$ is also formed) are more soluble than the corresponding Ca salts and more available to plants. It is of interest in this connection to note that prior to World War II Mg phosphates were used experimentally in France and Russia in place of Ca phosphates. It has been reported that this form of phosphates is being manufactured in California.

Conductivity Measurements, Guide in Fertilization. — Specific conductance measurements are a general orientation guide in fertilizing organic soils (see Chapters X and XIV) whenever the crop shows lag or is in distress. If the specific conductance of the plowed layer and of the 4-6 inch layer below it is less than $20x10^{-5}$ reciprocal ohms (mhos), the picture is clear: there are not enough nutrients of one kind or another. In case the figure is higher than 150, there is either an excess of some particular fertilizer salt, or of a number of these. If irrigation is available, flushing the soil is the best method of handling excesses of salts.

A lack of one or more nutrients may be overcome best by the addition of a mixture of ingredients than with a single ingredient, even if tests show no lack of most of these. One should apply 600 to 800 pounds of a complete fertilizer, a 4-8-12, 100 to 150 pounds dolomitic limestone, 50 to 100 pounds gypsum, 50 pounds Epsom salt, (or an equivalent amount of sulfate of potash-magnesia) 20 pounds $CuSO_4$, 25 to 40 pounds $MnSO_4$, and 5 pounds borax.

Newer Methods of Applying Fertilizer. — In a number of cases with muck and upland soils where irrigation was available, the best procedure was to incorporate first the insoluble ingredients, such as acid phosphate, gypsum, and limestone; these were followed by the soluble ingredients in solution. The $NaNO_3$, NH_4NO_3, $(NH_4)_2SO_4$, $CO(NH_2)_2$ (urea), KCl, K_2SO_4, Epsom salt, $CuSO_4$, $MnSO_4$, and borax were dissolved in 100 gallons of water. Ten gallon aliquots or an equivalent quantity of salts were diluted with 40-50 gallons of water and, by means of a siphon or an injector, applied through the irrigation water and washed into the soil to a depth of 5 to 6 inches. This method of applying fertilizer salts is still in the experimental stage, but it is very promising. If the preliminary trials are substantiated, much less fertilizer will be required as compared with an all dry method of application (see section on *Fertilizer Solutions*).

Animal Manures in Fertilizer Practices

As fertilizer, animal manures are generally appraised on the basis of their availability and total NPK. Manure also affects favorably the soil structure which is advantageous to the moisture and air components of the soil; manures introduce into the soil sex hormones which are claimed to be beneficial to crop yields; and lastly, manures supply minor elements. (See also Ch. VI).

The value of manure is influenced by the variability in its composition, which is determined by the type of feed, the class and age of animals, the kind of bedding used, and the method of keeping the manure. However, in discussing the fertilizer value of manure, its average composition may well be taken as a standard.

The bulk of farm manure comes from dairy and beef cattle. Horse and mule manure is rapidly vanishing from the farm. Because of its open structure, horse manure decomposes rapidly and is known as a hot manure, in contrast to the cold cow manure. This property makes horse manure a highly prized material for mushroom beds and cold frames and hotbeds. Sheep and poultry manures are a local rather than a general source of farm manures.

Bedding Material. — In table 22, the average daily amounts and composition of excrements produced by different classes of animals are given. It is to be noted, that the liquid portion of animal excrements contains more N and still more K_2O than the solid portion, but less P_2O_5.

In choosing a bedding material, one has to consider, in order of importance, the following factors: absorptive capacity for liquids, nutrient content, ease of decomposition, and effect on the physical condition of the manure.

In table 23 are given the moisture absorptive capacity and the NPK content of a number of bedding materials. Peats rank high in meeting the qualifications for good bedding. However, peat has nuisance qualities; it is dusty and soils the animals and stalls. Sawdust is an excellent material, but its low N content and slow decomposition are liable to disturb the nutrient balance in the soil. Straw is the most common bedding material. For best results, manures bedded with straw should be composted before using. Heavy layers of peat on the bottom and some straw on top are an excellent combination under conditions where the manure is removed periodically.

AVAILABILITY OF MANURE

On the average, farm manures, as hauled on the land, contain 0.5 per cent N, 0.25 per cent P_2O_5, and 0.5 per cent K_2O. A 10 ton application of manure supplies 100 pounds N, 50 pounds P_2O_5, and 100 pounds K_2O per acre. In terms of mineral fertilizer this is equal to 1000 pounds of a 10-5-10 grade. However, no close comparison can be made. In the case of manure, only a portion of the N is available, whereas in mineral fertilizer all of the N is available.

Nitrogen. — The N availability of manure depends on many factors, such as the source of origin (horse, cattle, or poultry), the stage of de-

TABLE 22

Average daily amount and composition of solid and liquid excrements of mature animals

(From U.S.D.A. Yearbook for 1948, p. 450)

Kind of animal	Daily production per animal		Composition of fresh excrement									
			Dry matter		N		P_2O_5		K_2O		CaO	
	Solid	Liquid	Solid	Liquid	Solid	Liquid	Solid	Liquid	Solid	Liquid	Solid	Liquid
	pounds	*pounds*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*
Horse	35.5	8.0	24.3	9.9	0.50	1.20	0.30	Trace	0.24	1.50	0.15	0.45
Cattle	52.0	20.0	16.2	6.2	0.32	0.95	0.21	0.03	0.16	0.95	0.34	0.01
Sheep	2.5	1.5	34.5	12.8	0.65	1.68	0.46	0.03	0.23	2.10	0.46	0.16
Hogs	6.0	3.5	18.0	3.3	0.60	.30	0.46	0.12	0.44	—	0.09	0.00
Hens	0.1	—	35.0	—	1.00	—	0.80	—	0.40	1.00	—	—

composition, and soil conditions. Aeration, temperature, moisture content, and pH of soil influence very markedly the process of decomposition and hence the release of N. The availability figures quoted by different investigators vary from -13.8 to as high as 60 per cent for the first year. The negative number means that in some cases (such as a high straw content) the manure gave a decrease in yield.

TABLE 23

Properties of different bedding materials

Material	Moisture absorption capacity	Composition		
		N	P_2O_5	K_2O
	per cent	*per cent*	*per cent*	*per cent*
Straw-grain	180-280	0.3-0.9	0.2-0.3	0.5-1.1
Oak leaves	160	0.8-1.4	0.2-0.3	
Beech leaves	400	0.8-1.4	0.2-0.3	0.2-0.4
Pine needles	150-200	0.8-1.4	0.2-0.3	
Sawdust	400			
Wood shavings	300			
Peat	300-700-1000	1.0-2.0	0.1-0.3	0.2
Sphagnum moss	300			

The availability of N of sheep manure is 48 per cent; of horse manure —29; and of cow manure—26 per cent. It is evident that sheep manure (its N content is usually twice that of cow manure) offers a better source of N than the manure of other animals. In practice, it has been found that 2 tons of sheep manure is more effective than 4 tons of cow manure. The availability of the constituent parts of animal excrements varies. A comparison of the effects on crop yields of N from $NaNO_3$, urine, solid excrements, with and without bedding, and bedding alone showed the urine to be almost as good as the $NaNO_3$, the standard of comparison in availability studies. Solid excrements alone were next to urine, and bedding alone decreased the yield, i.e., the coefficient of availability had a negative value. It is thus clear that the accessory substances of manure have a positive or negative influence on the N availability.

The major part of available N of manure consists of NH_4 salts, such as sulfate and phosphate. There is also available some organic N, chiefly as bacterial proteins. The so-called unavailable N consists of certain proteins and other nitrogenous organic substances which the animal could not digest readily. These substances, however, are gradually decomposed, and they are the ones which give manure the residual value, i.e., the beneficial effects of manure over a period of years. In heavier soils and in cool climates, these effects last more years than in light soils and in warm climates. In view of the gradual release of N from manure, it is asonable to assume that long season crops make greater use of manure l than short season crops.

Nitrates are present in well rotted manure protected from leaching; lso around the edges of the manure pile at the point of contact with the oil. In general, however, very little nitrate is present in farm manure.

Phosphorus. — The P of organic compounds and of the NH_4 and robably Ca phosphates that form in the process of decomposition of maure is easily available. This P is considered even more available than hat of mineral phosphates. It is to be remembered, however, that the P_2O_5 content of manure is low.

Potassium. — Practically all the K in manure is soluble and is just s available as the K mineral fertilizer. Manure is, therefore, highly esteemed as a source of K in potato and beet culture among the farmers in Europe where manure is still plentiful. In reinforcing manure for other crops, its high K content should be kept in mind.

In general, manure should be reinforced with phosphates and sometimes with N salts, but seldom with K salts. In dairy barns and in quarters of other animals, such as roosts of chickens, in sheep barns, and in other animal shelters, the practice is to incorporate 18 to 20 per cent pulverized acid phosphate, 50 pounds per ton of manure, to absorb the ammonia and to reinforce the manure with P.

POULTRY AND SHEEP MANURE

In centers of concentrated poultry industry and sheep raising, a steady supply of manure is available. It reaches market gardeners and florists in dry form. These manures are used locally for various crops.

Poultry and sheep manure vary in composition for reasons similar to those of manures of other types of animals. The manures are, however, inherently richer in the NPK, especially N. Fresh poultry excrements contain 55-60 per cent moisture, 1.0 per cent N, 0.8 per cent P_2O_5, and 0.4 per cent K_2O. Sheep manure (urine included) contains 65 to 68 per cent water, 0.95 per cent N, 0.35 per cent P_2O_5, and 1.0 per cent K_2O. Poultry manure protected from the elements, fortified with 50 to 100 pounds of 20 per cent superphosphate to the ton, to retain the ammonia, contains 2 to 2.5 per cent N and corresponding increases of PK. Commercially dried and pulverized poultry manure may contain 4.5 per cent N, 3.2 per cent P_2O_5, and 1.3 per cent K_2O; sheep manure 2.5 per cent N, 1.5 per cent P_2O_5, and 1.5 per cent K_2O.

Poultry and sheep manure are excellent fertilizer materials, but the tendency is to use too much of these. The result is an oversupply of N, with the consequent succulence and vegetativeness of the plants. In areas where these manures are available, many a failure in potato and tomato culture may be traced to excessive applications.

MANURE AS FERTILIZER—A SUMMARY

Mineral fertilizers have been compared with manure. However, some difficulties have arisen in making these comparisons. It is easy enough to match the NPK applications, but the other effects of manure, such as its influence on the physical properties of the soil, the lasting nutrient residues, and presence of accessory substances, cannot be duplicated with mineral fertilizer. Nor is the overall composition of manure constant from year to year. *In spite of these difficulties, comparisons have been made, and* the results obtained in the humid temperate regions show that *mineral fertilizer can take the place of manure.* A redeeming feature of mineral fertilizer is the stocks of organic residues that result from increased yields. A well fertilized crop of rye contributes more than a ton of dry matter in the form of roots and stubble. Legumes, except soy beans, contribute still greater residues. By properly manipulating the most favorable crop for a locality, by fertilizing heavily with phosphate and sulfates to a considerable depth, and by making conditions of aeration and pH conducive to deep rooting, *the residual organic matter content of the soil may be increased to the maximum natural limits for that environment without resorting to manure applications.*

In localities where manure is scarce, it is advisable to cover the cultivated areas successively at a lighter rate rather than to concentrate on only a portion of the cultivated land. There are always exceptions, such as the specificity of certain crops to respond to manure. Cucumbers, for example, must get more manure, as they respond to it much more than other crops.

Manure cannot serve as the sole source of NPK. A concrete example will clarify the point. For tomatoes, the application of 1500 pounds of 5-10-10 fertilizer per acre supplies 75 pounds N and 150 pounds each P_2O_5 and K_2O. If 10 tons of manure, analyzing 0.5, 0.25, and 0.5 per cent of N, P_2O_5, and K_2O respectively, were added in place of mineral fertilizers, the *available* nutrients would amount to 50 or 33 pounds N (since ½ to ⅓ of the N in manure is available the first year), 50 pounds P_2O_5, and 100 pounds K_2O. To make up the balance of nutrients for the tomato crop, we need an additional 25 pounds of N (160 pounds of $NaNO_3$), 100 pounds P_2O_5 (500 pounds of a 20 per cent grade of acid phosphate), and 50 pounds K_2O (100 pounds of the 50 per cent grade muriate). Of course, if acid phosphate has been used in preserving the nitrogenous substances of the manure at the rate of 50 pounds to the ton, no supplementary phosphate need be added.

HANDLING MANURE

In days gone by, when manure was the only supplemental source of plant nutrients, methods of storing it had been devised to prevent losses of valuable ingredients, such as the ammonia and the liquid portion. We continue to speak of these losses, even though their preservation is very laborious and expensive and they can be made up easily and cheaper with mineral fertilizers.

Under the old livestock system of farming, the general belief was that no rational soil management was possible without manure. With the improvements made in the manufacture of mineral fertilizer, with the advancement of knowledge in their uses, and with the reduced cost of fertilizers, the question of the feasibility of farming without manure has been raised. The replacement of beasts of burden by motor power and the increased specialization in agriculture have been responsible for the disappearance of manure from the farm. Farming without manure and with mineral fertilizers replacing the nutrients supplied by manure is the order of the day. There is no way out of it.

There are some sections of the country where manure is still obtainable and a brief discussion of methods of handling it may, therefore, not be out of place.

Losses in Handling Manure. — The most common losses are leakage through wooden floors in stables or seepage into the earthen floors in feeding pens and in stalls. It is generally accepted that about one half of the urine is lost under the circumstances described, even if ample bedding is provided. Manure kept in a pile unprotected from the elements, or manure in a pit not of concrete loses the urine and the substances that go in solution as a result of the decomposition of manure.

Some of the NH_3 from the urea, forming soon after the manure is voided, is volatilized. The high concentration resulting from the initial flare of NH_3 formation causes the loss of N by volatilization. Soon, however, the organic acids, formed in the process of decomposition, reduce the pH. Any NH_3 subsequently formed in the decomposition of the proteins is neutralized by the acids; it is either retained in adsorbed state or is utilized by the microbial flora. Some of the NH_3 may be neutralized and retained by sprinkling acid phosphate in the gutters, about 1.5 to 2 pounds of 20 per cent pulverized acid phosphate per cow per day. It has been reliably estimated that, in spite of precautions, 10 to 20 per cent of the NH_3 is lost. In the summer time, the loss may be even higher. These losses seem to be unavoidable.

Losses by leakage and seepage in barns may be eliminated by constructing concrete floors and gutters. Very little can be done against seepage in feeding pens and stalls having earthen floors. Losses by leaching in storage may be prevented by storing the manure under cover.

One of the losses in storage is the decrease in organic matter resultin from decomposition. Under average farm conditions, about 50 per cen of the organic matter is lost after 3 to 5 months of storage. Thus 200 pounds of fresh manure containing about 500 pounds of dry matter will after 3 months, be reduced to about 750 pounds containing about 25 pounds of dry matter.

The organic matter in the form of fresh manure when *added weeks o* *months in advance of planting* (and this is the proper way of applyin fresh manure) is undergoing a process of decay in the soil instead of i the pile or in the pit. In the final analysis, the result, as far as the majo effects on the plants are concerned, is probably the same as if well rotte manure were added. Besides, the latter is easier to handle and has a mor favorable influence on the physical properties of the soil. The well rotte manure also has the advantage of having the ideal C:N ratio, from 10 t 12:1. There is less available N in rotted manure than in fresh manure One should remember, however, that fresh manure added in advance, whe incorporated into the soil, has the same value as well rotted manure by th time the plants are ready to use the nutrients. Thus, the loss of organi matter of manure in storage is not as serious as might appear upon superficial examination.

Storing Manure. — Where animals are fed for beef, the system o bedding them with sufficient litter and allowing them to tramp the manur is one of the most efficient methods of preserving the manure. Unde these conditions anaerobic decomposition sets in and causes a favorabl change in the composition of the manure, with a minimum of loss of constituents. A concrete floor will prevent the loss by seepage. The syste of accumulating manure in the pen or in the stall is still practiced by dai farmers in many sections of the Old World and in some parts of the Ne World. Shed storage is one of the most common methods in up-to-dat dairies. A trolley carrier removes the manure daily to a covered place There it is dumped in a pile under cover on the bare ground, or into pit where it is preserved.

When manure is to be kept in the open, it should be piled in the for of a mound so as to shed water and reduce leaching by percolation. I Europe, some farmers have arrangements for the liquid portion of th manure to drain into a cistern. A thin layer of oil on the surface of th liquid prevents loss of ammonia. The liquid manure is pumped from th cistern into barrels and taken to the fields. In recent years, machines hav been developed which deliver the liquid into the soil a few inches belo the surface.

By separating the liquid from the solids and compacting the latter, the loss of N from manure is reduced to a minimum. This method, however, is expensive. Assuming that a dairy cow is kept in the barn 200 days per year, it would take about 75 to 80 cubic feet of tank space to store the liquid, if emptied once a year. Pumping, carting, and applying the liquid, add to the cost of the manure. Besides, the solids have to be handled separately.

In recent years, drying of manure in mechanical driers has been receiving considerable attention. The manure is hauled from the barns directly to the drier, where it is dehydrated to the moisture content of well cured hay. By this method, only small quantities of NH_3 are volatilized. The product is easy to handle and can be stored indefinitely. However, this method is too expensive for the average farmer.

Manure in Different Zonal Soils. — As a general rule, manure may be utilized most efficiently in the soils of the zones of podzolization and laterization. As one enters the zone of chernozem, the efficiency of manure decreases. In the semiarid regions, where the typical deep chernozem prevails, manure is no longer effective and may even be injurious.

In the zones of laterization and podzolization, where aeration is frequently a limiting factor, the better method of incorporating manure is to disk it in instead of plowing it under. This is especially important if fresh manure has to be used in the spring. In general, it is safer to use well rotted or at least partly composted manure in the soils of these zones. In the case of early fall plowing, fresh manure may be used and it can be plowed under. At that time of the year, the soil is usually well aerated. In general, it is not advisable to incorporate fresh manure, even in well drained soils, close to planting time.

In the southern sections of the zone of podzolization and in the zone of laterization, spring application of manure is preferred. Of course, in the tropics manure applications are timed with the crop planted. In the regions with severe winters, fall applications of manure have been found to be just as efficient as spring applications.

In chernozem soils (especially the subdivision of the degraded chernozem, such as the prairie soils) which respond to manure, it should be plowed under. Aeration is no factor in these soils. Moisture is the more important factor. When plowed under to a depth of 6-8 inches, moisture is available for the decomposition reactions. The much needed P_2O_5, as well as other nutrients, become available to the crop.

Residual Effects of Manure. — As pointed out earlier, the N availability of manure is about 50 per cent (in heavy soils it may be even as low as 30 per cent) for the first year. After that, the N becomes available gradually, and the residual effects of manure may last for several years As a rule, these effects last longer in heavier than in light soils. In th latter, oxidation goes on at a faster pace than in heavy soils, and the organic matter naturally disappears faster. In England, residual effects hav been noted for 30 years on leavy limestone soils which had been manure consecutively for 20 years prior to the experiment. In warmer climate the manure disappears faster, and the residual effects last less than in coo climates. In the chernozem soils these effects show up better on the secon than on the first crop. This is especially true in the case of a dry season

Some Objectionable Features of Manure. — 1. Manure serves as breeding place for house flies and other insects. This is especially tru for horse manure. Keeping the manure in a pit tramped down and covered greatly reduces the chances for breeding.

2. Diseases and parasites have been known to infect hogs and chicken that work over cattle manure. Chicken manure harbors parasites, an yards and runs have to be changed off, for fear of infection. Plowing th areas in the fall should overcome the danger of infection within one season especially on light soils where oxidation is intense.

3. Manure is a carrier of weed seeds, and infestations of these i lawns, meadows, pastures, and sod crops in general may be traced to th practice of topdressing with manure. It is questionable whether the goo one gets out of manure on sod is not offset by the harm it does by introducing weeds.

Fertilizer Solutions

None of the few innovations in crop production have thrilled th imagination of the layman as did hydroponics, known as nutriculture. Thi is now a matter of historical record. The enthusiasts settled down to th tasks of the limited application of hydroponics. Beds of pebbles, gravel, sand, crushed stone, or cinders are successfully used as carriers of nutrient in dilute solutions, applied when needed by the plants. Solution culture in shallow tanks properly aerated are gradually gaining favor in greenhouses and even in open air culture of flowers, tomatoes, cucumbers, and other vegetables.

Another innovation, somewhat related to hydroponics, is the method of fertilizer solutions for crop production. As yet, this method has not startled the world with spectacular claims as hydroponics did. There is this to be said: ***less nutrients will be needed and better results will be obtained when fertilizer solutions replace dry fertilizer.***

Historical. — Long before anything was known of plant nutrition, tillers of the soil appreciated the value of the liquid portion of animal anures. With the introduction of mineral fertilizers, solutions of these ere tried. As a matter of fact, $NaNO_3$ in solution is well known to eenhouse men. Ammonia N in solution has been experimented with tensively, and now NH_3 gas is successfully applied as a source of N rectly into the soil. The practice of applying fertilizers in solution with igation waters is well established and is gaining popularity. In recent ars, fertilizer solutions have been applied on a field scale in growing matoes, sweet potatoes, peppers, and eggplants in New Jersey.

The term *liquid fertilizer* was probably patterned after *liquid manure*. he latter term however, differentiates two distinct portions of animal anure: liquid and solid. There is no liquid state of fertilizer salts under tural conditions of temperature and pressure. There can be *fertilizer lutions*, just as there are nitrate solutions, ammonia solutions, salt solu- ns in general, gold sol solutions, or gelatin solutions.

THEORETICAL CONSIDERATIONS

Every soil particle in contact with water is subject to solution re- tions. Because of the low solubility of soil constituents, the concentration the soil solution is almost always low. In exceptional cases, it is pos- ole for the nutrient salt concentration of the soil solution to increase. n increase takes place invariably after a prolonged drought, or during e spring awakening, when the native flora is just emerging from its rmant stage while the microbes have been active for some time. What- er the concentration of the natural supply of nutrients is, their distribu- n within the genetic horizons is uniform. This provides an extensive lume of soil for the native flora to root and to "feed" on.

For cultivated plants, the rate of supply of natural nutrients is in- fficient, as pointed out earlier. Artificial fertilizer has to be added. It ems sensible to follow nature's way of uniform distribution of the sup- ementary nutrients through the entire volume of soil. This condition ay be attained with fertilizer solutions. Some of the theoretical high- hts on fertilizer solutions versus dry fertilizer applications may be mmarized as follows:

1. Under the most ideal distribution of dry fertilizer, broadcasting d disking in or plowing under, the salt crystals distribute themselves local nests. At some points in the soil, the concentration of salts may very high and at others very low. This is a definite hindrance for rmal distribution and functioning of roots. They are at a greater handi- p when the fertilizer is placed in bands or in the hill, since the roots ill tend to concentrate at local points. The dry method of fertilizer acement, therefore, limits the supply of moisture, air, and minor elements

to the volume of soils in immediate contact with the fertilizer. Fe solutions, on the other hand, bring about *a diffusion of nutrients tl large volumes of soil;* and what is most important, the distributic concentration of these nutrients will tend to be uniform througho soil. Under this system of fertilization, plant roots may utilize the of air, moisture, and minor elements of a much larger volume of so under the system of dry fertilization.

2. Since low concentrations of salts are used in fertilizer sol the chances for losses by leaching are meager as compared with possible by water channels striking nests of dry fertilizer salts.

3. The low concentration of the fertilizer solution is conduc greater adsorption and hence more efficient utilization of nutrie exchange reactions.

4. It is much simpler to gauge the application of nutrients in s than dry fertilizer, as plants indicate hunger signs.

5. Fertilizer solutions tend to approach conditions of a plant p logical medium. In such a system of fertilization, the crop is fe directly, whereas with dry fertilizer the soil is fertilized and plants indirectly.

USING FERTILIZER SOLUTIONS

Fertilization with solutions on a field scale is still in the experi stage. Technical difficulties of applying fertilizer solutions have overcome. Some farmers in New Jersey have improvised machi apply fertilizer solutions. They found by this method a saving of as as 35 to 50 per cent in their fertilizer requirements. These trials a fragmentary and can not serve as a basis for general recommend They are, however, very significant and further developments sho watched.

Transplanting Solutions. — When plants are transferred from o habitat to another they are usually watered. In recent years, it wa covered that additions of some nutrients to the water make the trans ing solution far more effective.

The effectiveness of the transplanting solution is due to the fe trients which carry through the transplant the first few days or In the transplanting operation, plants lose a lot of feeding roots, a general root system is weakened. Having at their disposal the nu of the transplanting solution, the roots easily recover, giving the p chance to start off. Half a pint of solution per plant of 0.5 per c pounds of the salt in 50 gallons of water) solution of either of the tures recommended, will give satisfactory results. A number of sal tures for making up transplanting fertilizer solutions are available on the market.

A very common mixture is the fertilizer grade 13-26-13, made up of the following: 1092 parts ammo-phos, analyzing 11 per cent N and 48 per cent P_2O_5; 440 parts muriate of potash, the 60 per cent K_2O grade; 100 parts sulfate of ammonia, analyzing 20.5 per cent N; 120 parts nitrate of soda, analyzing 16 per cent N; and 248 parts urea, analyzing 42 per cent N.

Another mixture used successfully by the author is the grade 18:26:12, made up of the following: 1000 parts $(NH_4)_2HPO_4$; 100 parts KNO_3; 150 parts $NaNO_3$; 200 parts $(NH_4)_2SO_4$; 100 parts NH_4NO_3; 100 parts urea; 150 parts KCl; and 200 parts K_2SO_4. For best results, the transplanting solutions should be adjusted to pH 7.6—8.0 by adding sufficient sodium *carbonate (washing soda)*.

When soluble salts are not available, one may make up a transplanting solution from any regular mixed potato or tomato fertilizer, 4 pounds to 50 gallons of water. The mixture is thoroughly stirred and allowed to stand for a few hours. The supernatant solution is poured off; enough washing soda is added to bring the pH to 7.6—8.0. A half pint of solution per plant is applied. The sediment that settles out consists of gypsum and calcium phosphate; it may be incorporated in the soil along the rows or broadcasted.

No transplanting solutions should be used when dry fertilizer is applied in the row. There is the danger of dissolving too much of the salts and causing an injurious concentration of the soil solution in the immediate vicinity of the roots of the transplants. This injury is known as burning and is a more common occurrence than a good many farmers seem to realize.

Starter Solution. — This is similar in its functions to transplanting solutions. It is used in getting seeds off to a good start. In many parts of the Old World, peasants soak some seeds, such as peas and beans, before planting. In later years, the addition of some chemicals, primarily nutrients, was advocated as a stimulant for germination.

The reasoning advanced on the beneficial effects of transplanting solutions in setting out plants is valid also for seed treatment. It should be remembered, however, that seeds can not make use of nutrients in the same manner as do roots of transplants. Nutrients applied with seeds have to linger in the soil until roots are sent out by the germinating seeds. Because of that, it has been found that a higher salt concentration has to be used for a starter solution. Instead of 2 pounds of the salts per 50 gallons of water, as recommoned for the transplanting solution, three to five times that quantity has to be applied for a starter solution. It is very probable that by the time the roots of the germinating seeds become active through the soil medium, the solution has already been diluted to the concentration of a transplanting solution. A pint of starter solution to 25 feet of seeding is sufficient.

Booster Solution. — For market garden and other cultivated crops such as sugar beets, cotton, and tobacco, sidedressing with a single or a mixed dry fertilizer salt is practiced. To avoid ripping up feeder roots the salts have to be applied not deeper than within the depth of the usual cultivation, 2 to 3 inches. By applying fertilizer solutions, by way of feeder tubes in the back of the cultivator teeth, deeper penetration of the nutrients (and far superior distribution) is attained. Because of these advantages less fertilizer has to be applied, as pointed out earlier. A fertilizer solution used for sidedressing purposes is called *booster solution.* The desired quantity of salts is applied with 200 to 400 gallons of water per acre.

A desirable invention would be a machine to inject solutions into the soil to a depth of 4 to 6 inches without causing much damage to the feeder roots. It should be possible to have some form of injectors working with up and down strokes, making holes 3 to 5 inches deep, 4 or 6 inches apart and delivering the quantity of solution desired.

Bulk Application of Nutrients. — Sometime soon, engineers will build a machine which will deliver, by means of nozzles following in back of the disk or cultivator teeth, any amount of fertilizer solution wanted. Such bulk applications of fertilizer should be incorporated 5 to 6 inches below the surface of the soil. In this manner, the nutrients could be distributed (by diffusion) through the soil from a point 2 to 3 inches from the surface to a depth of 8 to 10 inches. In some European countries machines are available that deliver liquid manure a few inches below the surface. Where overhead irrigation is available, the nutrients may be introduced into the feeder pipes before the water enters the sprinkling pipes.

GENERAL REMARKS ON FERTILIZER SOLUTIONS

Theoretically it should be possible to substitute fertilizer solutions for dry fertilizer and by virtue of their distribution and other properties economize on the fertilizer bill. It should be possible to apply soluble nutrients to the bottom of the furrow at any depth desired. However, it would be necessary to supplement the fertilizer solutions with other constituents, such as Epsom salt, manganese sulfate, and sometime zinc and copper sulfates. All of these can stay in solution as long as phosphates are kept out. *Fertilizing crops with fertilizer solution will necessitate the application of lime, borax, acid phosphate, and gypsum in dry form at the time of plowing and later during cultivation.*

CHAPTER XIII

WORKING THE LAND

Introduction. — In working the land, farmers have developed practices and methods of handling the soil. Of these, plowing, harrowing, cultivating, manuring, irrigating, draining, fallowing, burning the sod, and soil conservation measures, such as terracing and contour plowing, are of ancient origin. Other operations and practices, such as disking, listing, rototilling, subsoiling, crop rotation, liming, and mineral fertilization, are of more recent origin.

With the advent of modern science, some qualitative and quantitative aspects of the problems of working the land have been established. Some operations and practices have been refined and modified.

In the economy of a country, first consideration is given to the tillable land. Without a sufficient acreage of this kind of land, no modern state may exist, and no nation can survive and develop. It is, of course, advantageous to have a reserve of pasture and woodland, as we do in the United States, but the basis of agriculture is the land in use for the production of cultivated crops.

An understanding of the whys of tillage operations is a prerequisite for implementing them. Specifically, the intelligent tiller of the soil must ask himself the questions: What is the purpose of the particular operation? Why must it be done in this or that way? Why plow in the fall or spring? And how will the methods used influence the soil conditions in relation to the four principal factors of plant growth: *moisture, aeration, temperature, and supply of nutrients?*

Plowing

Purpose of Plowing. — The fundamental overall purpose of plowing is to keep the soil from reverting back to its natural flora. Plowing attains this purpose by turning under brush, stubble, and any vegetation that may obstruct mechanically the culture of farm crops. Every farmer knows that he must first plow before planting standard cultivated crops on cut-over forest land, prairie sod, virgin peat or muck, or any land that has become overrun with weeds after abandonment for several years. By removing mechanically the native flora, plowing eliminates the element of competition for nutrients and water.

In some of the grain sections of the chernozem zone of Russia, fields badly infested with weeds are plowed to depths of 15 to 18 inches with the furrow slice turned close to 180°. This method smothers most of the weeds. A few may survive and reappear years later. Then a deep furrow is turned again to bury the new infestation.

Turning the furrow was inaugurated with the introduction of the moldboard plow[1]. The angle it will turn depends on the length, height, and curvature of the moldboard. Seldom does the entire furrow slice turn the full 180°.

The purposes and effects of plowing that have been described are applicable to all soil zones. There are, however, some effects which are specific for certain soil zones. Thus, turning the furrow in the zones of podzolization and laterization may bring to the surface colloids that have accumulated in the B horizon. These colloids, mixed with the 4 to 6 inches surface soil, bring into circulation nutrients held by them. The colloids also contribute to the improvement of the structure of the surface soil. Besides, the toxic substances frequently found in materials of the lower portions of the furrow slice, when exposed to the surface, become oxidized and harmless. At the same time, the surface soil material, placed at an angle towards the bottom of the furrow, offers a favorable medium for root penetration, since it is, as a rule, lighter in texture.

When the furrow is turned, there is a shattering effect; the soil is loosened and mixed. Loosening the soil increases its volume. This in turn allows more aeration, greater ease of water movement, faster drying and warming of the soil. These improved properties lead to an intensification of microbial activity. In the enhanced decomposition of organic matter, more mineral nutrients are released and more nitrogen is fixed. Thus, loosening the soil favors the four factors of plant growth mentioned earlier in this discussion.

Mixing makes the soil more or less physically homogeneous. Mixing tends also to distribute the nutrient elements more uniformly. This is especially important when fertilizer has been applied in bands to the previous crop. Uneven stands following such crops may be eliminated by thorough mixing of the soil.

Rototilling. — This operation mixes the soil thoroughly. Simultaneously, rototilling pulverizes the soil instead of loosening it, as the plow does. The difference between the two effects lies in the nature of physical change brought about. In the case of loosening the soil, the action is a natural cleavage along the surface of the structural units. No mechanical breakdown or change takes place in these units as the furrow is turned and

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[1] It may be recalled that Thomas Jefferson made a scientific study of the plow with the purpose of getting one that would turn over the furrow slice.

the soil is loosened. This type of physical change increases the non-capillary pore space and facilitates aeration and movement of water. In the case of pulverization, the structural units are very often broken down to a powdery state. This decreases the non-capillary pore space and impedes movement of moisture and hence aeration. Besides, the tendency for the finely divided (pulverized) particles is to coalesce and to form anew the broken structural units. The result is a caking and crusting effect, followed by compaction, first on the surface, and then all through the pulverized material. This condition becomes acute if heavy rains alternate with dry spells.

Depth and Time of Plowing. — As a general rule, depth of plowing is regulated by the natural attributes of the zonal soils. Thus, *chernozem soils do not require deep plowing.* They are naturally well aerated to appreciable depths. Aeration is promoted in the A horizon by the stable granular and crumb structure of the soil. In the B horizon, lime accumulations flocculate the soil particles and prevent compaction. Water and air, therefore, readily penetrate the profile to considerable depth. Roots follow the downward path of the water and air, thereby producing channels which enhance the drainage and aeration still further. Roots of alfalfa and of other plants have been traced in these soils to depths of 10, 20, and more feet down in the C horizon. Plowing these soils to depths greater than 4 to 8 inches (the former in spring, the latter in fall) is a waste of power by which nothing is gained. Deep plowing of chernozem in spring causes a loss of moisture which is the primary limiting factor in the production of crops in this zone. Fall plowing affords better penetration of fall rains and retention of snow in the winter. All in all, fall plowing tends to increase the store of moisture for the ensuing crop.

Chestnut brown, brown, and even the gray semidesert soils need not be plowed deep (somewhat deeper in the fall for the purposes of taking in the rainwater) for reasons similar to those advanced for the chernozem. For spring sowings, these soils are best left in the rough, after fall plowing, in order to catch all the moisture possible.

For the soils of arid, semiarid, and subhumid sections of the grass country, frequent plowings and diskings are not desirable, because they tend to pulverize the soil and make it vulnerable to blowing. As a remedy against this curse, the so-called *stubble mulch* system was introduced at the turn of the present century. The soil is loosened and mixed by a middlebuster, duck foot cultivator, V-shaped sweeps (some as much as 4 feet wide), or just a disk. The last is to be avoided because of its deleterious effects on structure. Actually, the operations mentioned are a type of plowing without turning the furrow. The stubble remaining on the surface protects the soil from wind and water erosion and from surface caking and crusting caused by the beating of rain drops. While this type of soil preparation is well adapted for grain culture, it can not be used for intensive vegetable gardening in the humid temperate regions or in the arid regions under irrigation. Stubble mulching (the stubble serves as a mulch, hence the name) or subsurface tillage, as it is called, cannot be maintained for years. Some noxious weeds manage to establish themselves in the stubble after a few years. Besides, some insects, sucb as the corn borer, become a menace under conditions of stubble mulching. To overcome these difficulties, occasional plowing of the soil is imperative.

As a general rule, *soils in the zones of laterization and podzolization* respond to deep plowing, 8 to 12 inches. However, early spring plowing has to be shallow, 4 to 6 inches, to avoid puddling of the soil that is usually waterlogged this time of the year. For spring grains, ripping up the soil with an implement on the order of the John Deere spring tooth tillage cultivator, model CC, is sufficient. For late spring and early summer crops, plowing 6 to 10 inches deep gives better results than shallow plowing.

Green manure crops and heavy applications of fresh barnyard manure need not be plowed under deep, and the operation should be carried out as much in advance of planting as conditions permit. As was pointed out in Chapter VI, tremendous quantities of O are required to decompose organic matter, and the deeper it is buried the more acute becomes the aeration problem.

Whenever a green manure crop has reached an advanced stage of growth (for example, rye beading out), it might be a better plan to harvest the crop and plow under the stubble only. If not removed, such a crop should be ripped to pieces in the manner described for preparing the soil for spring grains. The land should then be left exposed to the elements for a few days, allowing the easy access of air which is essential for the decomposition of organic matter. After that, no difficulty should be experienced in burying the residual organic matter by shallow plowing. Of course, green manure crops and barnyard manure may be plowed under much deeper in the fall, when the soil is usually in a good state of aeration.

In general, it may be stated that *a soil in a high state of cultivation in the zones under consideration should have an Ap not less than* 10 *inches.*

Ridging of crops is tantamount to deep plowing. The ridges are sometime 10 to 12 inches high. This procedure, as well as growing crops on raised beds, is of ancient origin. Such practices probably first developed on poorly drained soils. Now ridging is very common in many parts of the world, even on soils which do not actually need it. In wet seasons, a carefully manipulated ridge is often helpful in relieving the crop of a condition of poor aeration.

With reference to plowing, *reclaimed saline soils under irrigation* are in a class by themselves. As a rule, these soils are dispersed and tend to be poorly aerated. The infrequent development of solonetzic properties in such soils aggravates the problem of dispersion and aeration. Deep plowing is, tberefore, imperative. *Normal (none-saline) soils of the arid and semiarid regions,* when irrigated, gradually approach the physical conditions of reclaimed saline soils, and they should be handled as such.

For the soils just described, fall plowing is best. Salts that might have accumulated at the bottom of Ap, as well as the colloids that usually have moved downward, are returned to the surface. The colloids supply some nutrients and serve as binding material for structure formation. The salts tend to coagulate the colloids, thus facilitating percolation of fall and winter precipitation. Toward the spring, the salt concentration is reduced all through the profile, and the excess salt is driven to the lower depths beyond the reach of the rhizosphere.

Spring plowing of fields that have not been fall plowed should be shallow in order to avoid bringing undesirable salts to the surface. It is much more difficult and uneconomical to wash out excess salts with irrigation water in the summer.

Depth of Plowing and Plow Sole. — Plowing the same depth year in year out causes the bottom of the furrow to become sleek, compact, hard when dry, resembling the beginning of a hardpan in consistency. A layer is formed, 1 to 1.5 inches thick, darker in color than the soil overlying and underlying it, relatively impervious to water and air. This layer is known as *plow sole.* It is a condition formed by the movement of the plowshare over the surface of the bottom of the furrow. Plow sole formation prevails in soils of the zones of podzolization and laterization. It is also very common in saline soils under irrigation, or soils subject to salinization because of irrigation. Plow sole often gives rise to glei (see p. 146) and all that goes with it. Specifically, plow sole affects the growing plants and soil in the following manner:

1. Roots flatten out at the plow sole, not being able to penetrate it. In dry seasons, the roots are killed.

2. In attempts to penetrate this unfavorable formation, plants are wasting energy that would otherwise be used in enlarging the yield.

3. In wet seasons, or after heavy rains in normal seasons, waterlogged conditions ensue at the plow sole. The result is reduction of organic and inorganic compounds. Sewage and hydrogen sulfide odors make their appearance. At the same time, the soil below the plow sole may maintain its normal musty odor. Such an environment is unfavorable for roots; they become brown and die back.

4. At higher points in fields plagued with plow sole, seepage waters move horizontally along the surface of the impermeable layer towards the low spots. The result is desiccation of the soil at the high spots in the field at any provocation of drought, and surface swamping at the low spots. Plow sole may thus become the cause of pond formation.

5. Plow sole in soils under irrigation prevents the storage of water in the B horizon. Frequent irrigations of the surface soil must follow, resulting in a high loss of water because of the rapid evaporation rate from the surface soil.

Amelioration of Plow Sole. — In the case of plow sole formation, prevention is easily attained by varying the depth of plowing. Never should land be plowed the same depth year after year.

The treatment of plow sole requires a mechanical operation followed by chemical correctives. Turning a furrow to a depth beyond the plow sole breaks it up mechanically and brings to the surface poorly oxidized materials. Exposed to the elements and mixed with well aerated surface soil, these materials lose their cementation and toxic properties. Another way of breaking up a plow sole is to *subsoil* the bottom of the furrow beyond the depth of the plow sole.

Whichever method is used in breaking up the plow sole mechanically, it should be followed up with an application of 2500 to 3000 pounds per acre of a mixture of dolomitic lime and gypsum, in the ratio of 3:1, for soils in the zones of laterization and podzolization, and gypsum alone for soils under irrigation in the arid and semiarid regions. Two thirds of the liming materials should be broadcasted before plowing and the rest after plowing.

Subsoiling and Pan Breaking. — Of these terms, subsoiling is the older in use. To the farmer it means deep plowing whereby the light colored material below the Ap (among the uninitiated the Ap is known as *surface* or *topsoil*) is turned up to the surface. It should be stated, however, that, historically speaking, the operation of bringing up soil from below to the surface is not subsoiling but deep plowing. *Subsoiling is an operation of shattering and loosening the soil at the bottom of the furrow* without bringing up raw subsoil to the surface. In this manner the Ap may also be deepened without turning a deep furrow.

In recent years, the terms pan breaking and subsoiling have been used interchangeably. As a rule, pan breaking operations are restricted to hardpan and claypan. Here also the terminology is often confused. By hardpan we mean a cemented and stone-like formation. Whenever the hardpan is of the hard ironstone type, no chisel used in the pan breaking operation will be effective. Dynamiting might then be warranted. Frequently, dynamiting and chiseling are used on compacted layers or claypan. In most cases, these operations are a waste of energy and money. Shattering effects produced on claypan or compacted layers (erroneously called hardpan) sometimes give temporary relief, until the layers in question become saturated with water. After that, the cut made by the chisel or the cracks produced by dynamiting disappear, because the clay runs together and, upon drying, the original poor condition sets in. It is far better, in the case of claypan and compacted layers, to subsoil and incorporate a ton or more per acre of a 3:1 ratio of dolomitic limestone-gypsum mixture. A surface application of the same mixture should be made every other year, over a period of 5 to 6 years, at the rate of 1200 to 1800 pounds per acre.

Additional Pointers on Plowing. — A great many specialized problems pertaining to plowing and plowing implements may be discussed. These are beyond the scope of this hook. Publications on soil management and special bulletins issued by the U. S. Department of Agriculture may be consulted. A few pertinent pointers on plowing follow:

1. The structure of the surface 1 or 1.5 inch of soil in the pedalfer group is poor because of the heating of raindrops. When this surface soil is thrown into the bottom of the furrow by means of a skim coulter, jointer, or combination of these, a layer of soil material of good structure is exposed.

2. Plowing in fall and exposing clods of soil, with or without a cover crop, to frost action is conducive to structure formation and to killing grubworms, corn borer, corn rootworm, and other insect pests.

3. If the soil is plowed at a time when shattering takes place, as the furrow slice follows the operation of the jointer, there may be no need of auxiliary tillage operations, such as disking, harrowing or rolling, except for small seeds that require the so-called fine seedbed.

Harrowing

Two general types of implements are generally used for harrowing. First, the disk (disc) harrow; and second, the spike-tooth or spring-tooth harrow.

The Disc. — If the furrow slice, upon leaving the moldboard, does not shatter and stays in the form of clods, large voids appear between the furrow slices and between these and the bottom of the furrow. This condition is more likely to happen upon plowing under a cover crop or sod. The voids cut the horizontal (between the furrow slices) and vertical (between the furrow slices and bottom of furrow) capillary movement of water.

Disking breaks, crushes, and cuts the clods and clumps, with the result that loose material fills the voids. Unfortunately, the cutting action of the disks tends to reduce the structural aggregates to a powdery consistency, in a manner similar to the performance of the rototiller. This is definitely a negative effect on the physical condition of the soil. Farmers, as a rule, are prone to disk too much. Not only do they waste power and precious time, but they also damage the soil and reduce its productive capacity. Of course, the ideal way of handling the soil is not to plow when it is in the plastic state.

In working land, there are many other operations for which the disk harrow has been used to advantage:

1. To incorporate, without plowing, into the surface 3 to 4 inches of soil either manure, peat, sewage sludge, a cover crop, or crop residues.

2. To rip and cut up a heavy crop, sod, or coarse crop residues, such as corn stalks, preparatory to plowing.

3. To break up rough land abandoned to weeds and light brush, preparatory to plowing.

4. To break up a hard compacted surface into which the plow could not penetrate to do an efficient job of turning the furrow. The operation is similar to that of the skim coulter or jointer on the breaker plow. Damage done to the surface 3 inches of soil by disking is repaired by the plowing operation. By being shoved into the furrow bottom, the pulverized surface soil undergoes a regrouping to form new structural aggregates.

5. *Intended originally as a supplement to plowing, disking* has been developed to become a substitute for it. By using disks of a certain size and turning the gangs at a sharp angle, the operation of plowing is imitated, except that the soil is pulverized instead of loosened, and no furrow is turned. As pointed out in the discussion on rototilling, this is not desirable. For heavy soils, the so-called disk plow is not to be recommended. For the structureless sandy soils the disk plow is as good as the moldboard plow.

The Spike-Tooth or Spring-Tooth Harrow. — In place of the disk harrow following the plow, either one of the tooth harrows may be used. These implements do less damage to soil structure than the disk harrow. They can not take the place of the disk whenever the plow turns up plastic clods.

In general, the tooth harrows have been designed for the following two purposes. First, to level and smoothen the surface of the soil for a seedbed. This is especially important for fine seed which would otherwise lodge too deeply and smother before the seedlings could reach the sun. Second, to stir the surface of planted fields before and even after the plants have come up, in order to destroy weeds. This operation is inimical to shallow seeded crops.

Because of poor structure, soils heavier than sandy, in the zones of laterization and podzolization, tend to form a crust on the surface. This may be broken up with a light spike-tooth harrow. A mulch is thereby formed, and it allows air and rainwater to come in.

Rolling

When soil clods are in condition to be crushed, the roller is to follow the plow. Under favorable conditions, after rolling the soil surface may be smooth enough even for fine seeds.

Rolling helps to press down the furrow slices that have not been shattered and thereby promotes uniform air and moisture distribution in the soil. The corrugated roller, or cultipacker, rather than the smooth roller is preferable.

In spring, rolling is a common practice on lawns, golf courses, and sods that have heaved. Care must be exercised when the soil is wet, since a compact plastic mass may result from untimely rolling. Generally speaking, rolling of lawns is overdone and frequently causes more harm than good.

A smooth roller is used in the preparation of a seedbed for fine seed. It is argued that in this manner fine seed gets in close contact with the soil, and that capillary moisture facilitates seed germination. A light rain followed by drying winds may result in the formation of a crust that will smother germinating seed. This danger is especially true for legume seed which are very sensitive during the germination period. Heavy rains on such crusts may just run off and sometime cause gullying.

Cultivating

Cultivating crops grown in rows is an old established practice. Generally, however, it is overdone and frequently carried out improperly because of failure to appreciate the fundamental principles involved in this operation.

The objectives of cultivation are: First, keeping out weeds that compete with the cultivated crops for moisture and nutrients. Second, maintaining a soil mulch that serves the following desirable functions: *a*, reduces evaporation by breaking the capillary rise of water; *b*, produces an air-cushion in the surface inch or two, keeping thereby the soil more effectively aerated and cooler; *c*, rainwater or irrigation water can enter more freely into the rhizosphere. The last mentioned function of the mulch permits the utilization of small rains which otherwise would evaporate or run off the baked and caked surface.

Cultivation should not be done early in the morning when the turgidity of the plants is high and they are, therefore, easily injured.

Cultivation must not interfere with the roots occupying the soil between the rows. One should examine the extent of spread of roots before cultivation and cultivate accordingly. *In general, in the early stages of growth, cultivation should be deep in the middle of the row and shallower at points closer to the plants, 3-4 inches in the middle, with a gradual reduction of depth, to about 1 inch, near the plants. As the season advances, the depth of cultivation in the middle must be reduced.*

After sidedressing, or whenever the soil is compact, the center of the middle should be disturbed with the rear tooth of the cultivator to a depth of 3-4 inches, so that the entire middle is shattered. Away from the center of the middle, the cultivator teeth or sweeps should not go beyond 1-1.5 inches. This type of cultivation assures least root injury and maximum aeration. There are on the market many types of cultivators, with adjustable teeth, shovels, or sweeps to suit every purpose.

Cultivation should not aim at pulverizing the surface soil, a common faulty practice. A rough, loose, shattered surface will maintain the mulching properties much longer than a pulverized surface, which has a tendency to flow together and cake.

SYSTEMS OF AGRICULTURE AND LAND USE

In the evolution of human society, three stages in the development of agriculture, and consequent land use, may be charted. In the first stage, man emerged as master over wild beasts by perfecting the art of hunting. He tracked the beasts in the forests, ran them down in glens and caves and killed them, used their meat for food, and their pelts for clothing and shelter. He supplemented his diet with fruits, herbs, and roots.

In the second stage man learned to domesticate animals. This moment ushered in the nomadic form of agriculture. Man left the forests for the wide spaces of the grass country, to return later to the forests to destroy them in search of pastures for his herds and flocks.

The third stage is known as that of organized farming, or settled existence. It is estimated, that the practice of land cultivation is 10,000 to 20,000 years old.

The transition periods in the evolution of agriculture were marked by a series of dramatic struggles which culminated in our modern civilization. In every stage, the old order with its institutions did not give way voluntarily to the new. The nomads looked down upon settled agriculture and waged war against it. The epic of the long war is dramatized in the Bible story of Cain and Abel. "And Abel was a keeper of sheep, but Cain was a tiller of the soil." For the Bedouin of Transjordania and Desert Arabia and for the marauders of the Gobi desert the struggle is not yet over. Nomad hordes of the desert still cling to the economy of grazing and continue their belligerency against cultivated regions.

Fallow. — In permanent settlements, man learned that soils become exhausted and have to be abandoned. To his delight, man had also discovered that land left to nature recuperates after a few years and produces again. The principle of resting land was incorporated in the basic laws of the Israelites on entering the Promised Land. "And six years thou shalt sow thy land and gather in the increase thereof; but the seventh year thou shalt let it rest and lie fallow." Thus came the system of fallowing.

With the introduction of fallowing, the cropland area has decreased. Strange as it may seem, an expedient designed to alleviate the consequences of soil exhaustion brought about the element of land hunger. Organized states in search of food for their ever increasing populations embarked on a program of conquest. Weaker neighbors were subdued and enslaved; the conqueror enjoyed the loot until a still stronger State engulfed him. Thus, empires grew, developed, aged, and disappeared, leaving behind relics for the archeologists and historians. The Roman Empire went into oblivion because of its decadent agriculture.

Julius Caesar forced the system of clean fallow on Italy, Gaul, and England. From there it spread to Germany and Russia. It is still popular in many sections of Europe. In the United States, however, it is not practiced except in dry farming regions.

Clean fallow consists of plowing in the fall and leaving the land in the rough. This facilitates the intake of water in the soil and the retention of snow. In the spring, the soil is smoothed and worked up into a mulch to conserve moisture. A clean fallow is also an enemy of weeds which dissipate three times as much water as when the soil is free of them. King, the outstanding American soil physicist, showed that the fallowed part of a certain field contained 203 tons more water per acre in the spring succeeding the fallow than the part that was not fallowed. Even after large crops of grain had been taken from the land, it contained 179 tons of water more than the unfallowed land.

Burning Surface Vegetation

The nomads of all ages have fired the grasslands after the grazing season was over. They found this practice increased the grazing capacity of the land. Burning of pastures and meadows is practiced by many farmers as an effective measure for eradicating weeds. Undoubtedly, the ash added by burning contributes to the improvement of the soil.

In the tropics, the practice of burning the brush (assartage) destroys huge quantities of vegetation. This system is used in clearing the jungle for the primitive type of agriculture to which the natives in some of the tropics are accustomed.

Recent reports of the United States Department of Agriculture on the status of grazing in the range country indicate that judicious burning of grazing land is definitely beneficial. Noxious weeds are destroyed. Not only may desired grass species be seeded, but also a good many of these come in voluntarily.

Controlled burning of the forest floor as a means of decreasing the hazards of forest fires has brought out the paradox of the possibility of increasing, by this method, the organic matter content of the soil. Burning the A_0, the dead wood, brush, leaves, and dry herbaceous vegetation returns to the soil large quantities of ash. In areas of controlled burning of the pine barrens of New Jersey, the pH of the profile increased perceptibly. It has been shown in Florida that this practice has increased the grass cover and the number of grass species. Through their root system, these grasses in turn have increased the organic matter content of the soil.

In golf courses, lawns, and closely grazed pastures of the humid regions a condition known as *sod bound* is not uncommon. Here and there, patches of turf dry up and become detached, leaving behind blank spots. The exact nature of the phenomenon is not known. It is very probable that bitumens (see p. 82), forming at the stems immediately below the surface of the soil, shut off the air from the roots and impede the entry of water into the soil. Bitumens accumulate slowly, and this is perhaps the reason why sod bound conditions prevail in old sods. It is probable that some benefits of burning pastures and meadows in the humid regions are the result of the destruction of the bitumens. No experimental data are available on this point. It is suggested that light burning of turf in the late fall or early spring might prove an effective measure against sod bound conditions.

As a rule, the practice of burning is looked upon with disfavor and it is anathema to the soil conservationist. However, the trained pedologist is ready to defend judicious burning of land as outlined above. It may be well to reiterate at this point a fundamental principle of pedology, that *organic matter accumulation in the soil results not from surface vegetation but from the root system and other subterranean parts of plants.* If burning contributes to the health and thrift of sod, the little loss of surface vegetation is more than offset by gains in root development.

In summarizing, it may be said that properly handled burning of surface vegetation has a place in land management, especially on sod. Burning should not be undertaken on an extensive scale before local effects have been watched and proved beneficial. In carrying out a program of burning, care is to be exercised not to set on fire forests and farm buildings. Burned heaps of vegetable matter leave behind an ash containing alkali and alkaline earth carbonates which are apt to injure or kill the succeeding crop. Such heaps should be scattered over a larger area before burning, to avoid a local concentration of carbonates.

CROP ROTATION

Crop rotation is the system of growing different crops in a definite sequence instead of growing one and the same crop continuously. Any rotation is associated with a more or less definite time period. A clover sod followed by corn and then by tomatoes is a 3 year rotation. If the soil is kept for two years in clover, it is a 4 year rotation. There are 5, 6, and 7 year rotations. In the course of generations, the system of crop rotations has developed as one of the means in maintaining the productivity of the land.

When clean fallow began to lose favor, cover crops or interfilled crops, like beets or corn, were introduced. The substitutes for clean fallow became known as *cover crop fallow, occupied* or *cultivated fallow*. In developing the new cropping system, the fact that all crops do not put the same demands on the soil stimulated experiments in choosing the right rotation. Crops that are hard on the land would naturally be avoided. On the other hand, crops that add to the fertility of the land would be favored. It is, for instance, well known that wheat and cereal grains in general take more P and more K from the soil than fruits do. Legumes, such as alfalfa and the clovers, remove huge quantities of Ca, K, Mg, P, and S. At the same time legumes add N to the soil.

In the 19th century, practical farmers in England divided farm crops into two groups: soil exhausting and soil improving crops. The former includes the grains and industrial or technical crops, such as flax. The latter includes the legumes and root crops. It was then considered sound practice to have crops that are hard on the land occupy not more than 50 per cent of the land. To fit these qualifications, the 4 year Norfolk rotation was introduced: clover, winter wheat, turnips, barley with a clover seeding. This rotation was adopted in Prussia and Bavaria with slight modifications. Instead of wheat and turnips, rye and beets were introduced.

Advantages of Crop Rotation. — Crop rotation is credited with a series of advantages, some of which are not clearly defined.

1. Crops vary in their nutrient requirements. Some place a he demand on the soil for P, others for K, still others for P and K. T variability holds true also for Ca, Mg, Na, S, P, and the many ot nutrients. In rotation, the amounts of nutrients used by the differ crops are somewhat balanced. It should be stated that this argument favor of crop rotations might have been valid in the prefertilizer days. can not be defended now, when any element may easily be supplied in form of commercial fertilizers.[2]

2. Crops vary in extent and depth of penetration of their root s tems. Alfalfa and clover penetrate deep into the soil. Corn has a m intensive root system than oats. Mangels and sugar beets root dee than turnips or table beets. With deep rooting, a larger volume of s is exploited. Extensive and deep root systems result in the accumulati of organic matter to greater depths, thereby improving the structure the soil. Rotations of deep and shallow rooted crops keep the soil in bet physical condition.

3. Crop rotations are helpful in combating weeds. In general, c tivated crops following grain are very efficient weed exterminators. the northwestern states, for instance, wild carrot and plantain are eas controlled in a two year rotation of wheat and clover. As the clover cut, these weeds throw up their flower stalks. These may then be mow or buried when the clover is plowed under for the winter grain.

4. Growing the same crop continuously favors the establishment soil borne diseases or insects common to this crop. Potato scab and cl root of cabbage are difficult to eradicate, unless these crops are kept the land. Cutworms thrive in sod and in fields left to weeds. By rotati the crops, the living conditions of the specific diseases or insects are i periled. However, with more advanced methods of combating insects a diseases and with the development of better varieties, growing the sa crop continuously is not a major problem.

5. Crop rotations are economical in the sense that diversity allo the distribution of labor over a longer period. Different crops, howev require a greater outlay of capital for the various implements essential producing them. The one crop system is like putting all the eggs in o basket.

It took 3000 years of experience to reach the Norfolk rotation a its later modifications. In our times, attempts are being made to dep from or eliminate some of the uneconomical rotations. With the aid chemistry, physics, and biology some progress has been made in ov

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[2] As a matter of fact, all cultivated perennials, such as fruit trees, berry shru and plants, asparagus, and alfalfa, represent the system of monoculture, the oppos of crop rotation.

coming the shortcomings of continuous culture of one and the same crop on the same land. There are areas where potatoes have been grown successively for more than two decades without decreasing yields. A number of other crops are beginning to enter the field of continuous cropping. It should be noted, however, that in most of these continuous culture crops some sort of a cover or green manure crop, of a longer or shorter duration, is used. This may be regarded as a short duration rotation.

In practicing some system of rotation, problems of fertilizing, manuring and other soil management and cultural practices have arisen in the different areas of the country. Local authorities of the Agricultural Experiment Station and progressive farmers should be consulted on these matters.

SOIL EROSION

> "*Les forèts prècèdent les peuple et les deserts les suivent.*" (Forests antedate peoples, and deserts follow them). Chateau-Briand, historian, rhetorician, poet (1768-1848).

Soil erosion connotes removal of soil by water and wind. A large share of water-carried soil reaches the rivers. A portion of the suspended load settles in the stream bed, clogs the channel, and interferes with navigation. The accumulation of sediment also causes a rise of the stream level and results in extending the flood plain. In this manner the silt[3] load either enriches the flooded area, as in the valley of the Nile, or it covers cropland and ruins the area. A large share of erosion material carried by the river reaches the seas and oceans. Murky and muddy waters of streams after rains in all parts of the world and the dirty brown waters of the generally blue-green oceans and of the azure Mediterranean at the mouth of such rivers are grim reminders of the phenomenon of soil erosion.

It has been variously estimated that the annual silt discharge of the Mississippi River into the Gulf of Mexico amounts to from 400 to 730 million tons. While the wide variation in this estimate depreciates the value of the figures, they are impressive nevertheless. Since on the average an acre of soil, 6⅔ inch deep, weighs about 2 million pounds (1000 tons), the 400 million ton silt discharge signifies the annual removal of 400,000 acres of top soil. According to official figures of the Soil Conservation Service, U. S. Department of Agriculture, about 3 billion tons of soil are removed annually by wind and water from the croplands and associated pastures of the United States. This amounts to 3 million acres

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[3] When used in connection with the sediment carried by rivers, the term silt embraces all mechanical separates—sand, silt, and clay.

of land being stripped annually to a *depth of 6⅔ inches by erosion*. These staggering figures are questioned by some authorities in the field.

The 400 million odd acres of cropland in the United States are appraised, from the point of view of erosion, as follows. About 50 million acres have been ruined for cultivation; 50 million acres have been severely damaged; 100 million acres have lost from one half to all of their topsoil and their productivity reduced one half to one tenth of normal; and 100 million acres are beginning to suffer from erosion. Thus, only 100 million acres are free of the ravages of erosion. These figures should be looked upon as rough estimates.

Geologic Erosion. — In evaluating sources of silt discharge, the contribution of geologic erosion has to be considered. By geologic erosion is meant the detachment of rock and mineral particles by the forces of weathering through the agents of water and wind. Ever since the earth could hold liquid water and the rains moved into the cavities along indentations and carved channels in the earth's surface, stream action has been one of the potent factors in carrying loads from one place to another. As a river moves in its bed, it cuts the banks, undermines them, and causes huge masses of rock to break away. In its course, the river receives material from talus slopes of the valley and boulders and rocks that become detached from the mother rock. All of these are worn away by their impact against the bed rock and by striking against each other. In mountain streams, angular fragments become rounded while being moved by the water before they have been carried a mile. It has been estimated, that as much as one foot in 9000 years is denuded from the surface of the earth by geologic erosion. Were it not for that, peaks rising to heights of 6 to 7 miles would still be in view in the Appalachian and other mountain chains. They have been eroded, the region has been peneplaned, dissected by rivers with broad valleys, and the mountains finally reduced to their present size and appearance.

Water Erosion. — Water and wind remove and transport surface soil. The action of water and wind is similar in some respects and different in others. A brief analysis of the two forces of erosion will bring out the difference.

Water erosion is conditioned by topography, soil texture and structure, system of farming, and intensity of rainfall.

The steeper the slope, the greater the velocity of the water flowing over the field and the more destructive is its erosive force.

The finer the particles, the more extensive is the erosion. It takes less carrying force to move clay in its ultimate unit particle size than silt or sand. As the texture gets finer, less water enters the soil; this promotes more runoff and leads to increased erosion.

Soil aggregation or structure, conditioned by the binding action of clay and stabilizing action of organic matter coatings, is a bulwark against erosion.

Erosion (not including geologic erosion), as we know it now, may be traced to the time when the nomads settled down and turned the first furrow. The farther methods of cultivation have advanced, the more acute became the problem of erosion. The old system of general farming included an appreciable area of land in pasture and meadow. Animals used for power on the farm have supplied sufficient manure to cover the land and in that way protect it from the ravages of erosion. With the modernization of agriculture following the industrial revolution, mechanization and specialization have changed the picture on the farm. Animal power was replaced by machines — tractors, combines, etc. Specialization has eliminated the home utility animals, such as the family cows for milk and other dairy products, the beef animals, and the porker for the meat supply and needs for fats. Former land areas in hay and pasture have been plowed up, thereby increasing the area for the devastating forces of soil erosion.

Quantity of precipitation is not as much a factor in erosion as is the intensity of rainfall. A gentle type of rain in regions of heavy total precipitation causes less erosion than a low total annual precipitation of the torrential type. Slow rains soak in and cause no surface runoff. Torrential rains trap the air in the soil and little water percolates through the soil. Instead, most of it runs off causing heavy erosion.

Three types of erosion are generally recognized: sheet, rill, and gully.

Sheet Erosion. — Removal of soil in thin layers uniformly from the entire surface is known as sheet erosion. It goes on even on slightly sloping[4] land and is least conspicuous. One may recognize the extent of this type of erosion by measuring the depth of the A horizon in various parts of the field. As a rule, the depth of this horizon is fairly uniform, unless eroded. The departure in depth of the A horizon from the normal is an accurate measure of the degree of erosion.

Rill Erosion. — Small incisions made in the land surface by the cutting action of flowing water is known as rill erosion. It does not exclude but rather complements sheet erosion. Besides uniformly washing the surface of the soil, some of the water concentrates in streamlets of sufficient volume and velocity to cut into the land and leave behind tiny gullies. This type of erosion is severe on fallowed land. Considerable rill erosion

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[4] Steepness of slope is expressed in percentages. A 5 per cent slope means a vertical drop of 5 feet in 100 feet of horizontal distance.

is caused by heavy rains on bare soils at a time when the frost is coming out of the ground. Exposed B horizons are vulnerable to rill erosion. This condition is common in the soils of the zones of podzolization and yellow soils.

Gully Erosion. — This is an accentuated case of rill erosion. Constant cutting of the land in the same groove eventually opens a deep gully with small terraces and falls which cut back the land and form gorges. Gully development is common in furrows that run up and down the slope. Often, these gullies get their start in ruts made by farm machinery and by tracks of animals.

Gully erosion is more common on land of considerable slope. There are, however, some soils which erode more easily than others, and these may be gullied even on gentle slopes. Some land areas may become so cut up with gullies as to make them useless for crop production. In some sections of the Piedmont and rolling Coastal Plain in the South, many farms have been abandoned because of gullying. It has been reported that some gullies have attained a depth of 50 to 100 feet or more in 50 years.

Wind Erosion. — Unlike water erosion, removal of soil by wind is independent of slope. Whereas soil blowing may occur in every climatic zone, it is most severe in the arid and semiarid regions where the sweep of the winds is unbroken by irregularities in topography or by forests.

Wind erosion may cause disturbances ranging from dust squalls to huge dust storms. In the great dust storm of 1934, clouds of soil were carried from Texas, Oklahoma, and Kansas eastward to the Atlantic seaboard and for hundreds of miles over the ocean. A dust storm in 1937 originating in the Texas-Oklahoma Panhandle country traveled across five states and on into Canada.

Forests and Erosion

Deforestation in general and especially of steep slopes and hilltops has been known to be a contributing factor of soil erosion. Conversely, it is being generally recognized that in a sound program of land utilization and soil conservation, reforestation of hilltops and steep slopes is the order of the day.

Forests and Floods. — Besides the protection forests afford to the land against erosion, they also mitigate the dangers of floods. The factors involved in this connection are as follows:

1. The canopy of a mature stand of conifers intercepts 40 to 50 per cent of the precipitation, and the canopy of a deciduous stand of the same age intercepts 15 to 30 per cent. Records of a forest project in the sand-

hills of Nebraska show that a 36 year old jackpine plantation intercepted 26 per cent of the precipitation. This water never reaches the ground and does not contribute to erosion or flood waters.

2. The A_0 layer of forests has a high capacity for moisture absorption, thereby reducing surface runoff, the most dangerous type of water movement from the point of view of erosion. Besides, the infiltration of water through the A_0 is greatly enhanced by the damp condition of the organic materials of the forest floor. Cultivated land has to get wet before infiltration can begin. Until then, surface runoff carries water to the stream bed.

3. Soil structure in the A horizon under forest is more highly developed than under conditions of cultivation. Water enters the soil body with ease, proceeds slowly into the ground waters and finally to the streams. Under such conditions of water supply, the stream bed is capable of taking care of the inflowing waters. It is the sudden rush of surface waters that the stream channels can not accommodate.

4. Runoff from forests carries practically no sediments. The stream bed is therefore deep and offers no obstructions. With silting, the channels fill and the result is flooding. In the Mississippi watershed, army engineers are constantly deepening the channels by removing the silt, clay, and sand brought in by erosion. The disastrous floods of the Yangtze River in China are caused by the silting of the channels of the rivers in the watershed. The dikes and levees have been raised higher and higher. At certain points, the boats navigate on a level far above the surrounding landscape.

5. In forests, the mechanical obstruction of the surface vegetation retards the speed of the surface runoff, thereby decreasing the rate of inflow into the stream bed.

6. Snow in forests thaws out much more slowly than in open cultivated land. This means a retardation in the rate of supply of water to the rivers. The heavy uniform snow blanket in forests reduces the depth of freezing of the soil. More water can, therefore, seep through the soil body of forested areas during the critical flood season of the spring.

7. Root channels in forests facilitate movement of water through the soil body.

Summary of Damage by Erosion

1. The outstanding damage to soils by erosion is the removal of the Ap. This necessitates the constant renewal of the depth of the Ap, which can be accomplished by bringing up material from the lower part of the A and sometimes of the B horizon. In some soils, the domestication of this

material may take a year or two. During this time crop yields may be low. By proper methods of fertilization and liming high yields can be obtained even the first year.

2. Areas eroded, because of poor soil structure, do not take in water readily and therefore suffer more from droughts.

3. Soils badly damaged by gully erosion often have to be abandoned.

4. Silt and sand blown by low sweeping winds may smother a crop.

5. Silting of stream channels increases the danger of floods.

6. Silting of reservoirs reduces the value of these as water storage and as sources of hydro-electric power.

7. In preparing the case against the crime of soil erosion, it is necessary to remember the contributions geologic erosion makes to the silt load of streams. Neither should we forget the positive contributions of erosion, both geologic and soil, in building of delta lands, pushing of shore line into the sea, extending and enriching the flood plains, and in filling of swamps and marshes and regenerating these to dry land for cultivation.

Soil Erosion Control

Historical. — Terracing is one of the oldest measures of erosion control, traceable back thousands of years to various parts of the world. In the Middle-East, Israel, Lebanon and Syria, rock walls were built on the contour; the impounded soil which was washed down from the slope made up the terraces. Relics of such terraces are still found in the vicinity of Jerusalem. A highly developed system of terracing in the Republic of Georgia, one of the Federated Republics of Soviet Russia in the Caucasus, was the object of the author's admiration during a visit in that country with a group of soil scientists in 1930. It was pointed out to the visitors that terracing has been known to the Georgians and other mountain peoples for more than 1500 years. The Incas of Peru farmed the steep Andean slopes with the aid of terraces. It is claimed that the stone hedges found on some of the sloping land of Ireland were built 5000 years ago. Evidence of terracing as a measure against erosion may be found in many other parts of Europe, as well as in the ancient Asiatic centers of civilization, such as China and the Near Eastern countries.

George Washington experimented with soil conservation practices at Mount Vernon. Among the writings of Jefferson, (U. S. Department of Agriculture (1943), Agr. History Series No. 7, *Jefferson and Agriculture*, pp. 46-7), we find: "A method of plowing over hillsides horizontally, introduced into the most hilly part of our country by Col. T. M. Randolph, my son-in-law, may be worth mentioning to you. He has practiced it a dozen or 15 years, and its advantages were so immediately observed that it has already become very general and has entirely changed and renovated the face of our country." Jefferson goes on to describe terrace building as a measure against erosion. Patrick Henry is said to have declared that "since the achievements of independence he is the greatest patriot who stops most gullies."

The rank and file of the American farmer failed to heed the warnings of far-sighted leaders. Land was aplenty. In settling the country the farmer moved from the poor land of the Atlantic Coast to the richer slopes and valleys of the Appalachian range and the still riches chernozem of the prairie and Plains country. Why worry about land deterioration? Why make the effort and invest capital in control measures against erosion when it was much simpler to acquire new good land? Gradually, however, this wasteful practice had to come to an end. American agriculture and land settlement became stabilized; then erosion was one of the various problems that arose. State and Federal agencies, such as the State Agricultural Experiment Stations and the Soil Survey Division of the United States Department of Agriculture inaugurated programs for soil erosion control. A more aggressive policy in this direction has been pursued with evangelical zeal ever since the establishment, in 1933, of the Soil Erosion Service and the Soil Conservation Service in 1936. These Federal Agencies inaugurated a large number of projects all over the country to demonstrate the standard time-tested methods of erosion control. In close cooperation with the farmers, the various methods have been popularized and improved. This program has been followed by research projects aimed at developing better and still better methods of erosion control.

Methods of Erosion Control

It is practically impossible to give hard and fast measures of erosion control. They have to vary with physiographic conditions, climate, soil type, hydrologic elements, and all the other factors involved in soil erosion, as discussed earlier. Only general principles and discussion of the methods in vogue may be presented here.

The best method of erosion control is to keep land in forest and in grass. These means are resorted to only when ordinary expedients of erosion control prove unavailing. Indeed, in the forest zone, badly eroded hilltops and steep slopes may just as well be turned into forest. Wherever grass may be established, it is, as a rule, more economical than forest. If properly managed, such areas may be grazed or mowed for hay. In the grass country, sod is, of course, the only alternative.

For land in cultivation, a series of erosion control measures have been worked out. These are: 1, contour tillage; 2, strip cropping; 3, grassed waterways; 4, terracing; 5, diversion ditches; 6, dams; 7, stubble mulch;

8, system of farming; 9, windbreaks. Measures 1 to 7 are designed for the control of water erosion; 7 and 8 apply to both water and wind erosion; 9 is exclusively a wind erosion control measure which also helps to conserve moisture. Strip cropping also aids against wind erosion.

Contour Tillage. — Land of sloping topography should never be plowed, disked or harrowed up-and-down the slopes. Rather, these operations should be done on the contour. While it is not easy to follow the natural contours in tillage and planting operations because of the absence of permanent markings, the help of the experts of the many Federal and State Soil Conservation Service agencies may be enlisted by any farmer who wants to master the practice of contour tillage and planting.

The advantage of contour farming lies primarily in the mechanical obstruction that ridges and depressions of the furrow offer to the movement of water. Each ridge serves as a dam and each depression as a diversion ditch with a very mild grade. These conditions allow water to enter the soil body and to percolate through it, rather than to run off the surface and carry away the precious Ap material.

Strip Cropping. — When the author asked an old farmer in the Tiflis region, the Caucasus, where he had acquired the art of contour plowing and strip cropping a mountain side with a 30 to 40 per cent slope, his answer was: "I do not know, I guess I was born with that knowledge." To the question, as to how old this practice was in his country, he replied: "I suppose it is as old as the hills and probably originated soon after Noah's Ark landed on our Mount Arrarat." Strip cropping systems have been practiced on many farms in the rolling country of Pennsylvania, Ohio, W. Virginia, and Wisconsin for more than half a century.

In Farmers' Bulletin No. 1919, U. S. Department of Agriculture, by Tower and Gardner (1943) four general types of strip cropping are recognized: 1, contour strip cropping; 2, field strip cropping; 3, wind strip cropping; and 4, buffer strip cropping.

1. In contour strip cropping the crops are arranged in strips or bands on the contour at right angles to the natural slope of the land. Usually the strips are cropped in a definite rotational sequence, although all of the crops in the rotation need not be in the same field or field unit in the same year. This type of strip cropping is used generally for the control of water erosion; however, it is also used effectively on sloping land in areas where wind erosion may be as serious as water erosion.

2. In field strip cropping, the strips are of uniform width and are placed across the general slope but do not curve to conform to any contour. It is recommended only in areas where the topography is too irregular or undulating to make contour strip cropping practical.

3. In wind strip cropping, the strips are uniform in width, usually straight and laid out across the direction of the prevailing winds. It is recommended on level or nearly level land where erosion by water is unimportant.

4. In buffer strip cropping, strips of some grass or legume crops are laid out between strips of crops in the regular rotations. The strips may be wide or narrow

and of even or variable widths. They may be placed only on steep, badly eroded areas of a slope, or they may be at more or less regular intervals on the slope.

Grassed Waterways. — The removal of surplus water from cultivated fields of sloping topography has always been a most serious problem. Rivulets tend to concentrate in the depressions giving rise at times to torrential streams which cut deep into the land causing severe gullying. Farmers have learned that sometimes these gullies may be repaired by dumping into them stumps, brush, straw, and rocks, thereby cutting the force of the moving waters. In the end, the area has to be abandoned. Left to nature, the area is taken over by the native flora in the form of creepers, shrubs, and grasses. It was just this natural phenomenon that gave the soil conservationist the idea of protecting such depressions with grass over which water is carried away. Such strips of grass are known as grassed waterways. They are used for pasture or meadow. At present, waterways are used in connection with the diversion of water in the strip cropping system and from terraces.

Sod strips may become a source of insect infestations, and the good they do to the soil is frequently offset by the damages these insects might cause. A trained entomologist should be consulted in such situations.

Terracing. — As stated earlier, terracing is one of the ancient erosion control measures known. Terraces are nothing more than ridges on slopes, constructed on the contour. The primary function of terraces is interception of water, either to be absorbed or to be diverted along a channel on the terrace to some waterway. By building several terraces on a long slope, the diversion of water in an orderly fashion, and hence control of erosion, is much simplified. With strip cropping, terraces are especially effective. A number of types of terraces are known. Some of these are named after their inventors, such as the Mangum terrace, developed by P. H. Mangum of North Carolina in 1885.

Diversion Ditches or Channels and Dams. — No matter what system or systems of erosion control are applied to any specific area, channels or ditches have to be provided for runoff. In the case of pastures on steep slopes, contour furrows serve as water diversion channels. Woodlots and pastures at the bottom of slopes or on the hillside may serve as outlets for various channels. Grassed waterways are the most ideal channels for the diversion of water. In the case of large accumulations of water, concrete channels are built.

In areas where waters flow most of the time, as is the case in hilly sections where the headwaters of rivers begin, checking of undesirable channel cutting is done by means of dams at strategic points. These dams impound waters and control the direction of the stream. In some areas, temporary dams serve as barriers until the depression is stabilized by means of sod and other vegetation that will reduce the cutting action of the rushing waters. The sides of the depression are planted to honeysuckles, wild blackberries, elderberries, and other ramblers. Sometimes, the entire waterway is taken over by this type of vegetation.

Stubble Mulch. — As pointed out (p. 299), plowing the soil without turning the furrow and leaving the stubble on the surface is known as stubble mulching. The lister, one way harrow, duckfoot cultivator, or similar implements break up the soil underneath the stubble, while the latter serves as a protective shield primarily against wind erosion and in some measure against water erosion. The lister, and more so the harrow, are used when the stubble is heavy. These implements mix the trash with the soil more than the duckfoot does.

In spring wheat regions, where the land cannot be kept covered in the winter, this method is one of the best for the protection against soil blowing and soil washing. It has been practiced in the spring wheat sections of North America for several decades.

System of Farming. — Crops vary in their protective capacity against erosion. There are the close growing crops and clean-tilled crops. To the former, as the name suggests, belong first in order the grasses that produce stolons or underground rootstalks, followed by any sod forming vegetation, hay crops, and grain crops. If land is subject to erosion, it should be kept in these crops rather than in clean-tilled crops (potato, cotton, corn, and most vegetables). At least, the rotation should be arranged in such a manner that the land will be in grass every so often. Whenever possible, the land should be in a cover crop. Clean fallow aids erosion and should be avoided.

Mulching of crops is another effective measure of erosion control and should be practiced whenever possible; it has been used with success in orchards.

Windbreaks. — This would-be-exclusive measure against wind erosion, when properly managed, may serve as one of the very important moisture conservation measures possible. Breaking the force of the wind by trees cuts down blowing of soil, allows the snow to settle uniformly over the surface of the land, and decreases evaporation.

In the steppe region of Russia, forest strips, known as shelter belts, have been used for more than a half a century. Records were kept of the moisture and temperature of the soil and air in the open steppe, in the forest strips, and in the steppe areas between the strips. The results show that even in the arid steppe some favorable hydrothermal changes may be brought about with as low as 3 to 4 per cent of the area in forest plantings. An important consideration in establishing shelter belts is finding the forest species that would give most protection for the longest period of years.

In 1934, forest strips were introduced in the arid region of the United States, from North Dakota into the Texas Panhandle. A total of 16,105 miles of belts have been planted, with 187,905 trees on 26,375 farms. The success of this project may be judged from the fact that by 1941 only 744 miles of belts were abandoned and only 1012 farmers discontinued their cooperation.

CHAPTER XIV

SOLVING PROBLEMS OF SOIL PRODUCTIVITY

Introduction. — In the middle of the 19th century, it looked as if the advances made in chesmistry in solving riddles of nature would also solve the problem of soil productivity. The refined methods of analytical chemistry have been engaged to make up the balance sheet on the nutrients in the soil and the requirements of the particular crop. It was common to argue that a soil analyzing 0.1 per cent N in the first 6 to 8 inches and 0.04 per cent in the next 6 to 8 inches should provide for about 70 crops of wheat at the rate of 20 bushels per acre, without resorting to any outside sources of N. Similar calculations have been made for other plant nutrient resources of the soil.

Value of Total Analyses. — It was soon discovered that total analyses of soils did not provide the information looked for. Soils with a low N, P, or K balance were not necessarily poor yielders and vice versa, soils with a high content of these nutrients were not necessarily high yielders. Total analyses as criteria of soil productivity turned out to be a failure. With the advent of pedology, analyses on the profile basis have been found to be useful for general orientation on the inventory of plant nutrient resources of the soil. The distribution of the elements in the profile have uncovered the processes involved in making up the specific features of the different zonal soil types. To the trained pedologist, such data are helpful in interpreting the physical and physico-chemical reactions that might take place in the different soils as a result of soil management practices, such as deep plowing, manuring, liming, fertilizing, irrigating, and cover cropping.

Available Nutrients.—From the middle of the last century, agriculturists had divided the soil mass into *active* and *passive* components. The former represents substances which plants may use potentially; the latter represents substances which are of limited use to the plant and serve merely as mechanical support. Later, the term *availability* came into use. It was recognized that the capacity of soils to produce does not depend exclusively on the available nutrients. Some physical property, such as a dispersed condition of the clay, the action of cementing agents, or a waterlogged state, may become the limiting factor in the productive capacity of the soil. Some chemical property, such as poor balance of water soluble or exchangeable nutrients, might also be a limiting factor in soil productivity. Barring hese limiting factors, availability of nutrients has been accepted as the determining factor of soil productivity.

Acid Extracts. — Since plant roots are responsible in a large measure for the mobilization of soil nutrients, it was thought that some reagent may be found to resemble root sap in extracting from the soil the available nutrients. The methods of acid extraction, inorganic and organic, have then been introduced.

Among the inorganic acids, 10 per cent HCl, 0.2 *N* HCl, or HNO_3 have been used extensively in Europe and in the United States. Fifty grams of soil would be extracted with 500 milliliters of acid for 10 hours on the steam bath. The acid soluble constituents would supposedly represent the active or available portion of the mineral constituents of the soil. Especially promising was the correlation between the available soil P (as shown by field experiments) and that extracted by this method. Many cases have been found where a high P content in the acid extract corresponded to a highly productive soil; a medium P content in the extract corresponded to soils of medium productivity; and a low P content in the extract corresponded to soils of low productivity. A scale of soil productivity on the basis of P extracted with the respective acids was then suggested. This method is still being used by some investigators. Generally, however, it is not considered of value in differentiating the available nutrients.

Concentrated acid extracts have then been tried. As shown in table 24, these extracts offer as much information on the composition of the soil as total analyses, except for SiO_2, Al, K, and Na which do not go fully in solution.

The search for a reagent giving an insight into soil productivity has been shifted to extracts made on soils with organic acids, such as citric, acetic, and tartaric. These acids have been found to be almost equal in their power of extracting plant nutrients from the soil as the acids of plant sap and those that are exuded by the plant roots. Dyer, of the Rothamsted Experiment Station in England, has shown that a 1 per cent citric acid extract comes closest to the aims outlined. He was, in some measure, successful in correlating the P extracted by the citric acid with the requirements of a number of crop plants. Thus, if the citric acid extract gave a 0.01 per cent P_2O_5 content, such a soil was sufficiently supplied with P for the normal yield of the average grain crop. For root crops, a higher P_2O_5 content was found necessary. A soil with 0.03 per cent citric acid soluble P_2O_5 was considered well supplied with P for any crop. Similar correlations have been reported by Dyer for K extracted with citric acid. Others have obtained similar results with acetic and tartaric acid.

TABLE 24

Comparison between total and 10 per cent hydrochloric acid extract analyses

Soil and type of analyses		Per cent of dry soil									
		SiO_2	SO_3	P_2O_5	Al_2O_3	Fe_2O_3	CaO	MgO	MnO	K_2O	Na_2O
Clay chernozem	Total	66.86	0.022	0.257	15.192	4.712	1.794	1.215	0.020	2.002	1.130
	10% HCl	17.09	0.022	0.248	6.587	4.055	1.694	1.101	0.010	1.002	0.173
Loam gray	Total	76.84	0.009	0.145	11.319	1.888	0.559	0.469	0.026	2.432	0.639
	10% HCl	6.04	0.009	0.123	3.332	1.810	0.506	0.306	0.021	0.245	0.040
Loam podzol	Total	80.22	0.043	0.081	9.985	2.252	0.481	0.563	0.011	2.197	1.235
	10% HCl	4.95	0.043	0.073	2.062	1.171	0.341	0.371	0.010	0.242	0.053

More thorough and extensive investigations with various organic acid extracts on many soils in the United States and Russia have disproved the findings of Dyer. It has been shown, that the correlation between extracted P_2O_5 and K availability of these to plants is applicable only to a limited number of soils.

POT, CYLINDER, PLOT, AND LYSIMETER EXPERIMENTS

Introduction. — While chemical tests have been developed, tried, used, discarded, and tried again, other approaches in the solution of soil productivity problems had a similar history.

As early as 1757, the British scholar Home undertook, at the request of the Edinburgh Society for the Improvement of Arts and Manufacture, a chemical study of the principles of agriculture. He placed soils in pots, grew plants, and followed their development. The idea was that in pots it would be possible to control the moisture and temperature conditions of the soil. Since then, pot experiments have been used in studying soils. Later, cylindrical tubes buried in the open and filled with soil, known as cylinder experiments, were introduced in soil studies. Rothamsted Experiment Station in England and the New Jersey Experiment Station in the United States have attained some of their world wide fame through experiments of this type. As a later development and supplement to the other methods, plots have been introduced in many Experiment Stations in Europe and in the United States. To get an insight into the losses of plant nutrients by natural leaching, lysimeters have been installed.

Pot Experiments. — At present, pot experiments serve the purpose of evaluating the need of soils for fertilizer, to test various fertilizers, to trace general nutrient deficiencies, and to demonstrate minor element deficiencies. For testing fertilizers, pot experiments have been set up according to the following original basic pattern:

Five pots are filled with the soil under investigation. Into one of these, the salts of all three usually deficient elements, NPK, are added; to pot two—NP; to pot three—NK; to pot four—PK; nothing is added to pot five, which serves as the control. Plants grown in such pots invariably show whether or not the soil was supplied with these nutrients and which one of these gives most response.

Objections raised against pot experiments are many. Most serious is the artificial situation of the soil in the pot. If surface soil is used, it is detached from the many possible influences of the layer immediately below and of the B horizon. For instance, if toxic substances should form in the pot, they must stay there, unless the soil is flushed. In the pot, there is no B horizon to receive and neutralize the toxic substances. On the other hand, soil material in pots is not affected by injurious toxic substances that are occasionally found in the B horizon of soils in the zones of podzolization and laterization. Thus, plants thriving well in a pot might not do the same under field conditions, or vice versa.

Sieving soils, discarding debris, pebbles, and other odd size particles, and drying them create in the pot artificial conditions not encountered in the field. Drying has a profound effect on the microbiological activities of the soil and on the availability of nutrients. The watering of pots, keeping the optimum moisture, and favoring temperature requirements of the different plants add to the artificial condition of pot experiments. As a rule, plants show up better in pots than in the field. There are, however, cases on record where the reverse is true. In general, results of pot experiments can not be duplicated in the field. The hope to solve productivity problems by means of pot experiments has not been fulfilled.

Many pot experiments conducted by uninitiated soils men are modified plant physiological studies. A critical analysis of these experiments would show that they furnish neither plant physiological nor soil information.

Cylinder Experiments. — These experiments are nothing more than pot experiments in the open. Cylindrical tubes, varying in area from 10 to 25 square feet, 20 to 30 inches deep, are set into holes with the rim slightly above the outside soil surface. They are made usually of galvanized iron and coated with tar or similar products as a protection against rusting. They are filled with the excavated soil material up to 8-10 inches from the top; the rest is filled with Ap material. Fertilizer formulae trials, availability of nutrients, and testing old and new materials (such as different forms of lime, sources of organic matter, by-products of industrial processes, waste products, and inoculants) are some of the experiments carried out in cylinders.

The advantage of cylinder over pot experiments is that they are somewhat closer to natural conditions. Cylinder experiments do not eliminate the many objections raised against pot experiments. The relatively small quantity of surface soil in the cylinder cannot duplicate conditions of the soil in its natural setting. Subsoil effects from the soil of the cylinder area on the imported soil in the cylinder cannot be evaluated and compared with subsoil effects of the original soil body. Water entering the cylinder cannot run off; it must pass through the soil or evaporate. As a rule, the soil in cylinders dries out faster than that of the surrounding area. Crops in the cylinder may, therefore, be wilting and requiring artificial watering, whereas the crops outside the cylinders may thrive and prosper. Because of these conditions, cylinder experiments are of little value in appraising the capacity of soils to produce or to measure accurately the degree of response to treatment.

Plot Experiments. — Of the various methods thus far described, plot experiments (also known as field experiments) have been found most reliable in evaluating soil productivity. One should not construe from the aforesaid that plot experiments can furnish a solution to all problems of soil conditions in relation to plant growth.

Reduced to simplest terms, the basic procedure in field experiments is to have, as in pot experiments, 5 plots; the same line of treatment is followed: plot 1 receives all three elements, NPK; plot 2—PK; plot 3—NK; plot 4—NP; and plot 5—nothing, serving as the control. Plots vary in size from 1/80 of an acre and less to 1/20 of an acre and more.

In any modern outlay of field plots statistical methods are applied extensively. They are especially valuable in reducing the errors that might enter as a result of minor variations in the soil, contingencies of weather, insect and disease attacks, and other factors. For every variable in the experimental setup, the number of plots has to be duplicated or triplicated. Such a procedure makes plot tests expensive and tedious. Besides, it takes years of repeated tests to gain the information wanted.

In the final analysis, the results of plot experiments can be *fully* applied to a soil class only within a narrow geographic range. These results can be *less fully* applied to other soil classes of the same group within the same geographic range. Some of the results of plot experiments can be applied only *in a small measure* to the soil outside of its zonal range.

Lysimeter Experiments. — In plot experiments no provisions are made for tracing the natural and added nutrients and other soil constituents that leave the soil by leaching. A knowledge of these losses is important in evaluating the capacity of the soil to produce and in gauging quantity, kind, and time of application of fertilizer. For this purpose lysimeters are used.

At the end of the 18th century, Dalton (the father of the atomic theory) was asked by the Royal Society of England to investigate the movement of rainwater through the soil. The millers, the textile manufacturers, and others who depended on water power were interested in knowing in advance how much rainwater would reach the rivers by way of the ground waters. To answer this question, Dalton buried into the soil tanks with outlets at the bottom which led to receptacles located in a subterranian structure. The tanks, about 2 to 3 feet in diameter, 4, 8, and 16 feet deep, were filled with soil and left exposed to the elements. Alongside the tanks were standard rain gauges. From data on the quantity of leachings and rainfall, it was thought possible to estimate how much of the rainwater is retained by the soil and how much percolates to feed the ground waters. These tanks were originally called drain gauges and later given the name *lysimeters*. They did not solve the problem of the millers, but they were put into service by soils men for studying the composition of the leachings.

Lysimeters have been used for more than a century all over Europe, India, and in the United States. The widely quoted data on losses of nutrients by percolation have originated primarily from lysimeter installations at Rothamsted in England and at Cornell and at the New York State Agricultural Experiment Stations in the United States.

As our knowledge on the distribution and movement of soil constituents in the profile has advanced, it became apparent that data on leachings from soil columns in tanks were not too reliable. As in pot and cylinder experiments, the soil in the lysimeter tanks is detached from the soil body, has no contact with the water and constituents dissolved in it as these move horizontally and vertically by gravitational and capillary forces. Neither is there provision for runoff from the lysimeter tank. All in all, the lysimeter is an artificial creation, a cylinder with provisions for catching leachings. Losses of constituents from soils, based on lysimeter data, appeared to be too high. Hundreds of pounds of Ca have been reported percolating annually through fallow soils, less through soils in cultivated crops, and still less through sod. Correspondingly heavy losses of N and K have been reported.

In recent years, pedologists have introduced an improvement in the construction of lysimeters. In a pit exposing the profile, tunnels are dug under the respective horizons. Shallow funnels, 1 foot in diameter, 1 to 1.5 inches deep, with perforations leading to the stem, are filled with gravel and sand and inserted into the tunnels. The rim of the funnel is forced into the roof of the tunnel and the excavated soil packed around the funnel until the tunnel is closed. From the bottom of the funnel, a tube leads to a pit into a glass receptacle where the leachings are caught. In this manner, the leachings from the respective horizons are traced. Any fertilizer added may be traced and accounted for in its downward and upward movements.

A series of such lysimeter funnels were installed by the author at the New Jersey Station in 1928, and the data thus far obtained substantiate the suspicion against the old type tank lysimeters. It has been established, that under forest conditions the losses of soil constituents are relatively small. They are somewhat larger under cultivated conditions, but by far not as high as reported in the data of the tank type lysimeter.

SOIL TESTING

Many definitions and interpretations may be applied to the term "soil testing." To the farmer, home gardener, landscape architect, greenskeeper, florist, greenhouse man, and the lover of house plants, soil testing has an implicit meaning. It is expressed in the question raised by these people: "Will you, please, test my soil and tell me how and what I can do to raise bigger and better crops?" The real meaning of soil testing can only be appreciated in the light of its historical background and of what is being done now.

Historical Background. — At its inception, soil testing consisted in subjecting the soil to one or more of the methods of analyses, as outlined, and to prescribing a remedy. In the zones of podzolization and laterization, where acidity is the most limiting factor in crop production, an application of some liming material was, and still is, the first constructive ameliorative measure. This recommendation was, as a rule, followed by suggesting the addition of some kind of a fertilizer mixture. Another suggestion usually made has been to increase the organic matter content of the soil. On this last point, recommendations were neither clear nor practical, in the face of the dwindling supplies of barnyard manure and the elimination of meadow and pasture land.

With the rapid growth of the fertilizer industry and the widespread use of its products, a more definite attitude of the manufacturer or dealer of fertilizer and of the farmer towards the use of fertilizers had crystallized. The dealer was anxious to sell as much as possible within safe limits for the respective crops. The farmer was also willing to buy more, provided he was assured safe and economic returns. Out of these viewpoints, once more the question of soil productivity came to the fore. Specifically, information was sought by the industry on the maximum quantity of fertilizer one could use without injuring the crop; the farmers looked for a minimum quantity of fertilizer for maximum effect.

Exchangeable Bases in Evaluating Soil Productivity. — In the course of developments, the tests (except the cylinder and plot) for determining soil productivity and fertilizer requirements have undergone some modifications. New extracting reagents came into use, such as Na acetate at a certain pH, or different strengths of the old reagents. It was also realized that the exchangeable bases, particularly, K, Ca, and Mg, play a part in the productivity of the soil. Taking the available bases of soils of high productivity as the criterion, standards have been set up by which other soils may be judged. This information, however, does not give the true picture of the soil's capacity to produce, since crops make good use also of the non-exchangeable bases and anions. Moreover, the quantity of these bases varies from season to season, or even within any season, depending primarily on meteorologic conditions.

Other Elements Tested. — Other elements and radicals, besides the bases, are frequently determined by some "soil testers." Special stress is laid on NO_3, NH_3, and P. Again, comparisons are made, taking soils of high productivity as the standard. Al, Mn, ferric and ferrous Fe, and Na are tested. Sulfates, chlorides, carbonates, and occasionally the minor elements, such as B, Cu, and Zn are determined when the other elements do not divulge the trouble. When a soil comes from areas where sprays are used extensively, tests are made for As and Pb.

Fertility Level. — The bases and other nutrients in the soil tested are tabulated and compared with the standards, which consist of the quantities found in soils of known productivity. From these data, a fertility rating or fertility level is assigned to the soil tested. These fertility levels are designated as high, medium, and low; good, fair, and poor. Some tests report the quantity of the respective ingredient in pounds per acre. A number of colorimetric, turbidimetric, and electrometric methods have been developed for these tests. Most of these are microchemical in nature and can be made quickly. Thus the name "quick tests" or "rapid tests."

Status of Soil Testing. — For about 10 years, from 1930 to 1940, the rapid tests spread like wildfire, even though a number of Experiment Stations have not accepted them. These tests have not been indorsed by the highly trained chemists in the field of soil science in the United States and Europe. Their popularity may be ascribed to their appeal to the average layman who is looking for a prescription remedy. The extravagant claims made by the proponents of these tests have not materialized.

It took no time to find out that the so-called fertility levels have no real meaning. Soils testing high in P or K have been found to respond to P or K fertilization. The tests for nitrates have baffled the soil testers because of their variability in the soil, resulting from their ease of movement with the percolating waters and their utilization by plants.

The rapid soil tests are not used much more for the purpose originally widely advertised; namely, to advise the farmer on the exact quantity of fertilizer he is to use. Farmers have discovered that the recommendations of the "testers" did not vary from those of the pre-rapid testing days; and whenever there were some variations, the results have not justified the innovation.

The little reliable information soil testing does give, such as the base content, is not sufficient for the evaluation of the problem of soil productivity. In the hands of the uninitiated, this information is frequently misleading. Even the highly trained specialist can seldom apply this information for the purposes soil testing had been advertised for.

A serious error in the scheme of soil testing as practiced is that it does not take into consideration the dynamics of soil processes and weathering. No allowances are being made by any of the tests for the changes in the chemical system of the soil resulting from seasonal variations, meteorologic conditions, status of plants, and methods of tillage, liming, and fertilization. Any one of the factors mentioned (and there are many others) may throw off the test. For instance, any soil will test differently before and after a heavy rain, and more bases will be found in the soil in the fall than in the spring.

A more fundamental objection to soil testing as practiced now (irrespective of the accuracy of the test) is the total disregard for the condition of the soil in the profile. As a rule, surface soil only is tested. Pedologists know that the status of the first 6-8 inches of the soil does not reflect the true productivity condition of the soil.

Plants as Indicators of Soil Conditions

Having failed in establishing well defined and accurate criteria for measuring productivity of soils and in determining the correlation of soil composition to crop growth and response to fertilization, the "soil tester" has turned to plant testing.

For centuries, plants have been analyzed to account for the riddles of growth in relation to soil conditions. An example of this approach in historical perspective is the experiment of the Flemish alchemist Van Helmont in 1620 (see p. 61). He came to the conclusion that water alone was the "principle" of vegetation.

Plant Nutrient Deficiencies.—Hunger signs in plants have been known for a long time. Chlorosis of foliage is a sign of the lack of N, S, or Fe. Purplish color of tomato foliage, black spots spreading from the edges of beet foliage are sure signs of P deficiency. A low yield of grain with a high yield of straw is usually caused by a lack of available P. Yellow-brownish tinges of foliage followed by patches of deep yellow-brown which take on a whitish hue are definite signs of K deficiency. (These symptoms resemble scorch and are mistaken for burning or "firing.") Lighter green patches in the dark green foliage of sweet potatoes indicate Mg deficiency.

It would take us too far afield to discuss the many deficiency symptoms known. Some of these were noted earlier (pp. 65-71). Actual experience in the field is the surest way of learning these. Standard books on plant physiology and special publications may be consulted on the subject.

In appraising the value of diagnosing deficiency symptoms in plants as a guide for treating soils, it is well to keep in mind that the hunger signs described may be due to other causes, such as *ravages of insects or diseases, lack of aeration resulting from a temporary excess of organic matter which on decomposition robs the soil of its oxygen, waterlogged* *conditions, droughts, and paucity or excess of known and **unknown** elements.*

Chemical Composition of Plants. — This method of determining soil deficiencies is based on the assumption of a direct relationship between plant composition and the capacity of the soil to supply nutrients. Thus, if any of the nutrient elements were deficient in the soil, the plant composition would show it.

As far back as 1858, the French investigators Malaguti and Durocher demonstrated that the ash of turnips grown in soils rich or poor in Ca contained 28.0 and 13.6 per cent CaO, respectively; of black radish, 43.6 and 19.5 per cent; of red clover, 43.3 and 29.7 per cent. Red clover grown on soils rich or poor in K contained 27.6 and 9.6 per cent K_2O, respectively. The value of feed grown on soils rich in the various nutrients has long been recognized. The classical example cited is the preference animals show in grazing when placed on plots rich or poor in P. They invariably choose the phosphated plot. In the early records of cattle grazing in Florida, disease conditions have been often referred to in terms of grazing land, such as hill-sick and marsh-sick. Studies have shown the relationship of soil deficiences to the health and growth of animals.

A critical analysis of the mass of data available on this subject leads to the conclusion that the correlation between plant composition and soil deficiencies holds true only if all other factors of plant growth in relation to soil conditions, save the element discovered to be deficient, are uniform and normal. It has been shown repeatedly that time of planting may cause a difference in composition of plants. Differences in moisture content of the soil or abnormal variations in meteorologic conditions during the growing season may radically change the composition of the crop. By changing the osmotic concentration of the soil solution, the N content of wheat may be made to fluctuate from 1.5 to 2.5 per cent. The composition of plants varies with the stage of growth. Neither are the individual parts of the plant of the same composition. Thickness of stand, rate of seed used, poor or excessive supply of certain elements in the soil may be the cause of the deficiency of some particular element. Thus, an excess of Ca may cause a deficiency of Mg. Considering all the possible discrepancies involved in testing plants, one must come to the conclusion that this method is of limited value.

Plant Sap Analyses. — Hoffer in the United States was one of the first to examine plant tissue as a guide in detecting soil deficiencies. A definite procedure of expressing plant juices (sap) and testing these for plant nutrients was developed. It was reasoned that paucity of certain nutrient elements in the sap is definite proof of the deficiency of these in the soil. Other investigators used plant sap from guttation. Again, it was reasoned that nutrients found in this sap come from the roots and are, therefore, more representative of the capacity of the soil to supply these.

Criticism presented on plant analyses as a method of discerning soil deficiencies is applicable to the plant sap method in its several modifications.

Neubauer Method. — 100 grams of soil are mixed with 50 grams of sand in a glass dish and 250 grams of sand placed over the mixture. One hundred rye seeds are planted and, after 14 to 16 days, the plants, tops and roots, are removed and analyzed for P and K. It is assumed that the large number of plants is capable of taking out from the small quantity of soil, in the short period of 16-17 days, that quantity of nutrients which the plants usually obtain through their entire vegetation period. The PK found in the rye plants are compared with the quantities of these found in rye plants grown on pure sand. The difference represents the PK available in the soil. These are compared with standards worked out for various plants. Thus, for barley it is necessary that the 100 gms of soil should contain 19 mgs. K_2O and 5 mgs. P_2O_5; for rye the quantity is 16 and 4; for alfalfa—25 and 10. The rye plant is used as the test plant.

It was found that the limits of PK for the different plants vary with the soil. For some soils they are higher and for others they are lower. This makes the Neubauer test a difficult one, inasmuch as it has to be standardized for the various soils.

Considerable attention has been given to the Neubauer method in Europe and the United States. For a while (from 1923 to 1935) this method was valued for the determination of fertilizer requirements of crops. Soon, however, conflicting reports began to reduce the popularity of this test, and now very few use it.

Mitscherlich Pot Test. — Of the more widely advertised, especially in Central Europe, methods of testing soils for available nutrients and fertilizer requirements is one proposed in 1909 by Mitscherlich, a German soil technologist. He worked out an empirical formula (it was expressed in mathematical language by Baule) showing the possible maximum yield as the increments of plant nutrients are stepped up while all other factors of growth are ideal. In practice, the soil under test is placed into a Mitscherlich pot; it is a pot fitted with a false bottom to catch possible leachings which may be returned to the pot. All conditions for growth are standardized to approach the ideal except for the fertilizer ingredients. In testing for P_2O_5 for instance, pots are made up with NPK and NK, and crop yields are compared. The increase caused by the P_2O_5 is then compared with the possible maximum as indicated by the formula. The difference represents the available P_2O_5 of the soil tested and shows how much more P_2O_5 the soil needs.

A vast amount of work has been done with the Mitscherlich test all over the world. The reports are conflicting. In recent years, pedologists trained in mathematics have scrutinized the formula and proved it to be of little value.

Microorganisms as Detectors of Soil Deficiencies. — Aspergillus niger, Azotobacter, and other microorganisms and the reactions exhibited by these, such as increase in N fixed or rate of nitrification, have been used in detecting soil deficiencies. It has been argued that, if these organisms or their reactions do not fully develop on the soil tested, a deficiency of Ca, Mg, P, or some other element is indicated. One of the difficulties of these tests is that the organisms have a short life cycle and their requirements for nutrients are not fully comparable to those of cultivated plants. Activities of any group of microbes are frequently controlled by associated organisms and not by the nutrient supply. Toxic substances may also play a role in the life of microorganisms. If the soil is sterilized, as is the case in the pure culture method, conditions become still more complicated. None of the microbiological tests have been widely accepted.

THE PEDOLOGIST TACKLES SOIL PROBLEMS

Except for tests conducted with plot experiments, the various tests designed to unravel the secrets of soil productivity fall short of their aims because they fail to appreciate the soil as a body in nature. Data of plot experiments would mean much more, if the plots were studied and the experiments laid out in accordance with the profile characteristics of the soil. As stated repeatedly in part I of this book, *the reactions and behavior of any part or horizon of the soil body are so interdependent that a genuine evaluation of soil phenomena must be considered with reference to the entire soil profile and not to a detached part.* Any disturbance in a localized area of the soil body must be examined in relation to the entire body. In the human body, a headache is not necessarily local in nature. It may be caused by irregularities in the digestive system, nervous apparatus, glandular functions, hormone secretions, and other parts of the human organism. Similarly, an irregularity noted in the Ap may have its origin in the A_2 or B horizons.

The Soil As a Patient. — From the criticism advanced in the foregoing pages on methods of testing soil deficiencies and with the realization that at best the tests can, for the present, serve the purpose of trouble shooting, the author has developed and practiced successfully a pedologic system of diagnosing soil troubles.

A fundamental theorem of this system is: *soil troubles can not be rationally evaluated, either by examining a sample of soil by any rapid soil tests or by any one of the plant tests designed to trace soil deficiencies.* The entire soil body has to be examined by a trained pedologist on the spot. Like the physician, the pedologist can, now and then, prescribe a remedy without seeing the patient, the soil. We know, however, that in most cases the physician insists on seeing the patient. And likewise, the *pedologist insists on examining the soil in place.*

After a preliminary morphologic examination of the soil, definite clues may be offered on the possible causes of the poor condition of the crop. A preliminary diagnosis of the perplexing troubles is then made. To corroborate it, more thorough examination of the soil and a series of *tests on a soil-water extract* have to be carried out.

The new approach in tracing troubles in soils has been practiced by the author for more than 15 years. It rarely failed to give satisfaction. A discussion of the steps involved, the techniques employed, and the interpretations of the data will illustrate the theoritical basis and soundness of this approach.

Soil Examination

Drainage Features. — Any field presenting a soil problem should first be examined for signs of poor drainage. On plowed land, in the zones of podzolization and laterization, color is an excellent index of drainage conditions. Black or gray is a sure sign of poor drainage, due either to a high water table or to surface swamping. A tentative diagnosis may be made after questioning the owner on the behavior of the field as to the incidence and length of time water generally stands on the surface in late winter, spring, or after heavy rains during the summer, and of the presence or absence of tile drainage.

For early spring crops, such land should be plowed in the fall and left in the rough without a cover crop. In the temperate climate, frost adds to the improvement of the structure of the soil and hence to the drainage. Such land should receive well rotted manure and it should not be plowed under but disked in. Plowing again in the spring may or may not be advisable; if dry enough, it may be plowed again.

For late spring or early summer crops, poorly drained land should have a cover crop on the *plowed land left in the rough.* The crop should be fertilized heavily early in the spring to induce luxuriant growth. In this manner the land drains better and large quantities of water are removed from the soil. Shallow plowing, just to smother the cover crop; or better yet, removing the crop before plowing are the better ways of hand ling such land in the spring.

Ridging of crops, leaving an occasional dead furrow for drainage, timely use of lime and gypsum mixtures, judicious use of fertilizer, all of these operations will go a long way in overcoming poor drainage.

Profile Inspection. — Whatever the drainage condition of the problem field, a profile inspection is the next step in examining the soil.

Two or three holes, 15 to 20 inches in diameter, are dug with a round-point shovel in different sections of the field to a depth of 20 to 24 inches. Bent over the opening, the practicing pedologist makes, with a strong garden trowel, another stab, 6 to 10 inches deep, in the bottom of the narrowing hole. Tapping with downward strokes over the exposed cut with the point of the trowel, the presence or absence (the latter is the case in fluviogenic immature soils) of the various horizons and their depths are established. The following is to be observed:

Ap.—If the depth of plowed material (usually referred to as top soil) is greater than the average depth of plowing practiced in the locality, it is definite evidence that erosion has transported surface soil into the area. Generally, this type of erosion is advantageous to the area, since surface soil, as a rule, moves in. Depth of plowing should be determined, and one should be on the lookout for plow sole. If the depth of the Ap is normal, the following points are to be considered:

1. *Has the soil the typical musty odor?* If undecomposed organic matter, from plowed under barnyard or green manure, is present and putrefactive odors resembling sewage are noted, it is a sure sign of poor drainage. It may even be a temporary condition and not indicated by any well defined mottling symptoms. The author has encountered many such cases in heavy soils, where large quantities of manure have been added in the spring, and the season happened to be on the wet side. Neither soil testing, nor plant sap analyses can ever detect such cases.

Such soils should never have the manure plowed under. Disking in the manure into the surface 4 to 5 inches is preferable. The precautions outlined in the discussion on manures (p. 283) should be followed. For immediate relief, a mixture of lime and gypsum in the ratio of 3:1 (500 to 800 pounds per acre, besides the regular lime application), and 50 to 100 pounds of Epsom salt (or its equivalent of sulfate of potash-magnesia) plus 15 to 25 pounds of manganese sulfate and 3 to 5 pounds borax per acre (the smaller amounts for light soils and the larger amounts for heavy soils) will facilitate drainage. Ridging cultivated crops in areas of poor drainage is good practice. The source of N in fertilizers applied should consist of nitrates.

2. *How deep is the Ap and is there a plow sole?* The high absorptive capacity of the Ap for moisture and nutrients result in the concentration of

roots in the Ap layer. Deep plowing is, therefore, recommended in the zones of podzolization and laterization. In these zones, plow sole may often be encountered, especially in strongly acid soils. Plow sole may also result from dispersion caused by a high pH due to excessive and exclusive use of $NaNO_3$ or excessive amounts of K bearing salts. A plow sole condition is often the cause of temporary swamping, slow percolation of water, and poor aeration. Plow sole is most injurious to plants in *their active stages of growth. When a drought strikes, plants grown under* conditions of a plow sole begin to wilt early because the roots are concentrated in the Ap. With an abundance of rainfall, the plow sole holds back the water and drowns out the roots. Putrefactive decay sets in. On several occasions, when farmers complained about their soil which, in their words, "was tested and the report stated that there was nothing the matter with it," the author told them: "Put your nose to a freshly dug handful of soil from the plow sole, or bend down over the open hole and say whether something is the matter with the soil." It was not necessary to have a keen sense of smell to detect the foul sewage-like odor. In this and similar cases, the farmer had a heavy cover crop plowed under on top of a bad plow sole.

No examination or test of a surface soil sample, by any method of analyses made on plants, will ever give a clue to the presence or absence of a plow sole. Of course, the remedy is to change the depth of plowing from year to year and plow under some lime and gypsum mixture, ratio 3:1 (see Index).

A_2 and B. — The next step in examining the soil is to dig with downward strokes of the trowel into the horizons underlying the Ap (The A_2 and B horizons), noting the differences in texture in the profile, observing color changes, smelling for strange odors, and noting the structure and cleavage of the lumps of soil when crushed in the palm.

1. *What does the color of these horizons tell us?* A uniform gray brown, brown, to reddish brown or brownish red, with the color intensity increasing from A_2 to B is good evidence of effective oxidation, or aeration, and good drainage.

Streaks or patches of brown, gray, bluish or greenish gray (commonly known as mottling) through the mass of these horizons are evidence of poor drainage. Fields showing a discoloration on the surface, as discussed in section on *Drainage Features,* and mottling within the A_2 and B horizons substantiate the suspicion of poor drainage. A search for the depth of the water table should be made. Usually this information is furnished by the farmer. If the land is poorly drained, tile drainage is the only radical remedy. If surface swamping is the cause of mottling, the lime-gypsum mixture treatment, as described (see p. 212), should be recommended. The usual rapid soil tests, plant tissue tests, or sap analyses can never detect the cause of the crop's distress brought about by surface swamping.

2. *What is the condition of the roots?* Indeed, if the soil profile below Ap shows no apparent abnormalities and roots still refuse to go beyond the Ap, the trouble, with few exceptions, is high acidity in A_2 and B horizons, or a very sharp difference in the pH values of the Ap and A_2. Time and again, the author has seen fields that tested high for all the major and minor elements and yet did not support a good crop. Invariably, the cause was high acidity of the A_2 horizon. The crop was forced to thrive in the Ap only, thus limiting the *feeding grounds* of the roots, particularly for moisture. Of course, the remedy is a lime application, either plowing under or following the plow in the furrow by some implement to introduce extra lime in the horizons below the Ap (see Ch. XI).

Infrequently, roots in the Ap show signs of burning. The roots instead of being white are brown. Invariably, brown roots are associated with a high salt concentration resulting from the band method of fertilizer placement or excessive application of fertilizer salts. This condition is usually aggravated in the early stages of plant growth during a dry spell. Poor aeration and lack of certain elements also cause burning. A conductivity test will differentiate between burning caused by a high concentration of salts and other causes.

3. *Does texture offer clues to troubles?* Sandy soils with little or no B horizon development (the sandy to loamy sand classes) infrequently suffer from a lack of moisture, especially in dry years. There is nothing one can do about that, except provide supplemental irrigation. In wet years, crops on such land may suffer from lack of nutrients because of excessive leaching. Sandy soils should, therefore, be fertilized fractionally, applying at planting time just a few hundred pounds of the nutrients and sidedressing later.

Light sandy soils may be excellent for perennials, such as asparagus or fruit trees, which are deep rooting and may derive water from the lower layers. For these crops, liming the soil to depths of 2 or more feet will more than pay. Indeed, many orchards on light soils begin to suffer at a certain age when the root system reaches out deeper and deeper and meets increasingly unfavorable conditions of acidity.

In soils with a well developed B horizon, of the textural classes of sandy loams, loams and heavier, compaction may often be mistaken for a hardpan. An acidity test of such compacted layer would probably disclose a low pH, and the incorporation of lime and gypsum (see Chaps.

VII and XI) into the A_2 and B is the remedy for such a condition. Deep plowing and cutting 6 to 8 inches into the bottom of the furrow, and growing perennials, especially alfalfa and clovers, are means of improving soils of such profile makeup.

In examining the B horizon, careful notice is to be made of possible hardpan. Seldom is there a hardpan in well drained soils. It may be encountered where ironstone had formed in an earlier period in the development of the soils, or in the presence of gravel. Pan breaking with chisels and dynamiting are the remedial operations. Dynamiting is especially useful, if not imperative, in orchard plantings on soils having hardpan. As a rule, the C horizon of a soil having ironstone formations is open and well aerated. Here and there, a stab 10 to 15 inches deep into the C horizon offers some valuable information. Generally, however, not much may be inferred from the depths of the C horizon beyond the 10 to 15 inch depth below the B horizon.

A mechanical analysis of a suspicious soil profile or of some one layer in the profile may be helpful in detecting some disturbing physical factor. An excessive clay content of the montmorillonitic type in the soils of the humid climates (a rather rare phenomenon) or the presence of certain types of fine sands may bring about compactness, caking, baking, and brick-like constitution of the soil mass. Generally, such textural properties may be detected by the field test of mechanical analysis—the feel between the fingers.

Sampling the Profile. — With the information assembled by the system of morphological soil examination, as outlined, the diagnosis may be obvious in a great many cases. To corroborate the general diagnosis, the profile has to be sampled and some chemical and physical tests made.

The hole dug for the profile examination is cleaned out and the following samples taken: (1) the surface and (2) bottom parts of Ap; (3) the layer immediately below the Ap, usually a 4 to 6 inch layer of the A_2; (4) sometime, the next 6 inch, usually of the B_1. Sample B_1 is taken first. In this manner, digging with the trowel from a point below A_2 downward will not fill the hole and cover the A_2 which is taken next. The last samples are taken from the Ap, first from 0 to 4 inches and then down to the bottom. In most cases sampling of the B_1 horizon is not necessary.

In all, the digging, examining, and sampling the profile should not take more than 15 to 20 minutes. If the topography is rolling, it might be advisable to examine a number of profiles and take two or three profile samples. The soils are subjected to a definite procedure of analyses and tests, as described presently. How many of these samples one has to process depends on the information made available by the morphological examination and the ease with which the puzzles are solved.

Air dry soil samples are taken for a water extract. A 1:3 soil-water ratio is used for heavy soils and those high in organic matter[1]. A 1:2 ratio is used for soils lighter than sandy loams.

Dispersion. — If upon mixing the soil and water, mineral and organic substances remain in suspension after standing for 20 to 30 minutes, the soil is said to be dispersed. This condition reflects some irregularity in the hehavior of the soil colloids (see Ch. VII). Dispersion of the soil in the forest regions is generally due to the lack of electrolytes, a condition prevailing in soils during the late winter and early spring, or after a prolonged rainy spell. A conductivity test will tell the story on the electrolyte content. Dispersion of soils in the brown, chestnut brown, and chernozem soils is an indication of solonetzic conditions. In the zone of podzolization and laterization, dispersion indicates the effects of Na and sometime K, either residual, or of recent date added to soils, which have been fertilized heavily with $NaNO_3$, excessive amounts of KCl, or through the use of irrigation water containing some NaCl, and sometime bicarbonates. A recent application of liming materials—carbonates or hydroxides of Ca and Mg, may also cause dispersion. Cases like those mentioned have been met with by the author in the truck gardening sections where supplemental irrigation is a common practice. Additions of lime-gypsum mixtures with Epsom salt, manganese sulfate, and borax, as mentioned earlier, and replacing the bulk of $NaNO_3$ with other sources of N, such as $(NH_4)_2SO_4$, $CO(NH_2)_2$ (urea), and NH_4NO_3, have invariably eliminated the dispersion. Acid soils rich in organic matter, such as mucks, may also be highly dispersed. To these soils, the lime-gypsum mixture (more lime and more Epsom salt is used for mucks) with all the other ingredients and 100 to 150 pounds of $CuSO_4$ should be added. These ingredients will greatly aid the stabilization of these soils.

In making observations on the water extract, the color of the solution before and after filtering should be recorded. A brown color is an indication of the presence of soluble organic compounds. Some soils, especially those rich in organic matter, are frequently highly colored and turbid. As a rule, these soils show an appreciable content of crenic and apocrenic acids (organic acids that precipitate from an acidified solution only upon the addition of Cu-sulfate or acetate). This type of soluble organic matter is generally considered as undesirable. Additions of $CuSO_4$, recommended for the dispersed condition, and gypsum will precipitate these acids.

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[1] For genuine mucks and peats a 1:5 ratio has to be used.

A clear solution, even if slightly colored, is usually an indication of the soil being in good physical condition. As a rule, soils giving a clear solution filter much more rapidly than those that give turbid and brown solutions.

pH. — The pH value of the soil profile is by far the most important single diagnostic test. It reflects many reactions and conditions of the soil.

If the pH of the Ap is from 6.2 to 7.2, and the soil is dispersed, one should suspect recent additions of hydrated lime or limestone. If white specks can be picked out and they effervesce when treated with HCl, the suspicion is corroborated. A pH of the A_2 should be taken. If low, the cause of the disturbance may be due to the sharp variation in the pH readings of the respective horizons. For proper functioning of plant roots, the pH should be uniformly favorable throughout the profile.

If the pH is above 7.0, the soil is dispersed, and no free lime is apparent, chances are that this soil had been receiving excessive quantities of $NaNO_3$ or excessive quantities of K salts. If the soil had been irrigated, Na might have come in as the chloride or bicarbonate. In such cases, the entire profile, as a rule, has a high pH, even though there may be very little or no Na in the exchange complex. Generally, the addition of a lime-gypsum mixture and proper adjustment of the Ca:Mg ratio will speed up the recovery of such soils.

Low pH and High Base Content. — A relatively low pH (from 5.0 to 6.2) in soils rich in organic matter, such as mucks, peats, meadows, pastures, lawns, and turf, is not necessarily an indication of a low base (Ca, Mg, and K) content. These soils have a high cation exchange capacity. They may contain large quantities of exchangeable Ca and Mg, but the relatively high H-ion concentration keeps the pH down.

pH and Fertilizer. — Any soil, with few exceptions, showing a pH of 5.0 or lower rarely responds to proper management and fertilization unless limed. In these cases, testing for anything else is a waste of time and energy. Lime, fertilizer, and minor elements are to be recommended, the quantities being fairly well standardized for the respective crops in the locality. In appraising soil troubles, especially in the zones of podzolization and laterization, the pH determination stands out as the most important one.

Ca:Mg Ratio. — Liming with materials containing little or no Mg causes an undesirable widening of the Ca:Mg ratio (see p. 234). Large applications of superphosphate will cause the same thing. Under conditions of a high pH, a wide Ca:Mg ratio is especially dangerous, since some of the Mg is apt to become unavailable. Particularly may this take place in soils of the zones of podzolization and laterization. Some of the

Mg ions may unite with silicate ions, which become free in these soils, and remain unavailable as the insoluble silicates. There is also the possibility of the formation of the not too soluble hydroxide of Mg. Additions have to be made of 25 to 50 pounds MgO in the form of K and Mg sulfate (sulfate of potash-magnesia) or Epsom salt.

It is important to remember that sidedressing with one element, as is frequently practiced by applying acid phosphate or more often $NaNO_3$, *is generally not the best procedure.* It upsets the balance of nutrients and the results are not as good as they might have been if a mixture of salts were used. Therefore, when a source of Mg is added, it is best to supplement it with 200 to 300 pounds of dolomitic limestone, 100 to 150 pounds of a complete fertilizer, 7-7-7 grade, 15 to 25 pounds of manganese sulfate, and a few ounces of borax.

Water Soluble Constituents

With the pile of data assembled by examing the soil, as outlined, its physico-chemical system begins to unravel the favorable and unfavorable conditions in the soil. Its behavior and response to management and cultural practices become obvious and clear. To substantiate and corroborate deductions made and conclusions reached, a series of simple qualitative and a few quantitative chemical tests, which take but a few minutes, are carried out on soil water extracts. The novelty of these tests lies in the interpretation, *with the pedologic examination as a background.*

Specific Conductance. — In interpreting specific conductance measurements (see Ch. IX), we must remember that the conductivity of a solution depends on the number of active ions present. As the concentration of ions decreases, the specific conductance must drop. Any variation in the capacity of the solute for conducting electricity, which takes place with change in concentration, can not be directly determined, therefore, from a study of specific conductance. Neither does conductance give a clue as to the character of the salts in solution. However, *a high conductivity is an indication of an increased concentration of salts. A low conductivity is an indication of a low level of the rate of nutrient supply, or a complete lack of some of these.*

Whereas soils of a high productive capacity, as a rule, have a higher conductivity than poor soils, no direct relationship has been found between conductivity and the general state of fertility of soils.[2] Because of that, *con-*

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[2] Mhos, or Ks readings (a number, x 10^{-5} expressing specific conductance), of soils in the zones of podzolization and laterization devoted to general farm crops may vary from 3 to 50 or higher, depending on the nature of the soil. Low readings are typical for the winter and early spring seasons. High readings occur during droughts in the summer or early autumn. Readings as high as 400, without apparent injurious effects, were recorded by the author on leachings of soils in market garden crops in New Jersey. In pedocals, the readings are generally higher than in pedalfers.

ductivity measurements alone can not be used in diagnosing soil conditions. However, numerical values of conductivity offer a basis for comparing soils. These values also offer clues as to the causes of certain troubles.

In trouble shooting, or in determining the condition of the soil in general, two fields or two spots in the same field (*one where the crop is good and the other where it is poor*) should be examined.

Two fields (for all practical purposes of a similar soil type and similarly treated) may show wide variations in crop response. A conductivity determination will help in deciphering the source of these variations. If the field with the poor crop has a low conductivity value, a reading below 10×10^{-5} mhos, and the field with the good crop shows a much higher conductivity, a reading of 30 to 100×10^{-5} mhos, the picture is clear. The field with the low conductivity suffers from a lack of nutrients or a very low rate of supply, whereas the good field has an ample supply. A check on the texture of the respective fields may show that the poor field has a poorly developed B horizon which does not retain the nutrients. However, if the poor field shows a high conductivity, the cause of it has to be determined and it may be one of the following:

1. An excess of salts, chlorides, sulfates, and nitrates. Again and again has this condition been found by the author in greenhouse soils, in muck land, and sometimes in upland soils of the humid regions usually on light soils fertilized by the band method. The remedy is obvious; if possible, the soil should be flushed with water.

2. If the chloride and sulfate content is low and that of the nitrates high (50 to 100 p.p.m. or more), the picture is clear. The high conductivity is due either to excessive applications of mineral N or to a natural accumulation of it. The latter is a rare phenomenon in the humid regions, except in special cases, as pointed out presently. Under such circumstances, the poor condition of the crop is due to a general deficiency and unbalanced state of nutrients. Addition of a mixture of limestone, gypsum, Epsom salt, acid phosphate, muriate of potash, manganese sulfate, and a little borax (and copper sulfate to soils high in organic matter) should be made. The amounts to be used will depend on the soil texture. The quantities given for sidedressing in the section on the Ca:Mg ratio may serve as a guide for a loam soil.

3. If the sulfate content only is high, the high conductivity is due, as a rule, to the gypsum of the acid phosphate. In this case, there may be just a lack of one or more of the nutrient elements: N, K, Mg, and Mn. A combination of salts of these elements, rather than trying to pick out the deficient element, has been found to give the results desired.

It is to be noted that for a better interpretation of the conductivity data, tests are desirable on the chlorides, sulfates, nitrates, and ammonia in the water extract.[3]

Chlorides. — Chlorine is an excellent tracer ion. Soils heavily fertilized receive the Cl by way of the commonly used KCl. The absence of Cl in a water extract is an indication of the loss of K by leaching. Assuming this to be true, it is logical to conclude that other cations, especially NH_4, Mg, Mn, and Ca have also been subjected to the same fate as the K. In other words, a negative Cl test is a sign of a possible general nutrient supply deficiency. However, no final conclusion is to be made unless tests for nitrates, sulfates, and ammonia corroborate the suspicion provided by the lack of Cl.

Of course, the lack of water soluble K does not always indicate a lack of exchangeable K. However, there is no conclusive proof that the exchangeable K is sufficient to supply the plant at the rate it requires. Repeated tests made on soils practically devoid of Cl throughout the profile have proved them to be, as a rule, low in exchangeable K.

The presence of Cl in the profile, with a gradual increase of it (2, 3, and 4 on the scale of values) with depth, tells the story on the movement and translocation of plant nutrients. This story may also provide a useful hint on the behavior of the crop.

Excess of Cl (a reading of 5 on the scale) all through the profile in the soils of the zones of podzolization and laterization call for a quantitative evaluation of this element. In many cases, the author has traced these excesses to large applications of muriate, accidental entry of chlorides by way of irrigation water, or additions of NaCl. In one case, the sand used in a greenhouse has been contaminated with NaCl and $CaCl_2$ applied to the sand pit during the winter season to prevent freezing.

Sulfates. — The absence of water soluble sulfates throughout the profile serves as additional evidence of a deficiency of nutrients indicated by the negative Cl test. Since sulfates in the soil originate from the gypsum carried by superphosphate, a negative test for sulfates is an indication of a deficiency of available soluble phosphates. On the other hand, a high test for sulfates is good evidence of the presence of available phosphates, and may indicate a poor Ca:Mg ratio, as pointed out earlier. Invariably phosphate could be found whenever the sulfates were high.

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[3] The values for chlorides, sulfates and NH_3 are based on an arbitrary turbidity and color scale. No turbidity is designated by O; faint turbidity by "trace"; with an increase in turbidity, numerical values in the order 1, 2, 3, 4, and 5 are used. For nitrates, the quantitative phenodisulphonic acid test is used. For ammonia the Nessler test is used qualitatively. The operator, after a little experience, has no trouble in recognizing the arbitrary qualitative-quantitative values assigned.

A positive test for sulfates and chlorides is ample proof that the poor condition of the crop can not be ascribed to a deficiency of K, P, S, or Ca. Of course, there is always the possibility of a lack of Mg, N, or immobilization of minor elements caused by recent liming. Additions of Epsom salts or sulfate of potash—magnesia, a mixture of sources of N (if the NO_3 test is negative), and the minor elements will frequently be the right answer. The case of Mg might be not so much a deficiency as too wide a Ca:Mg ratio due to the Ca of the superphosphate and calcitic limestone.

Nitrates. — A quantitative determination of nitrates, if properly interpreted, is very helpful in determining why the crop is poor. One must keep in mind that nitrates are readily utilized by plants and microbes; nitrates, however, are constantly being replenished by the process of nitrification. It is, therefore, difficult to judge the significance of a low nitrate content. As a rule, it goes hand in hand with low conductivity and a low chloride and sulfate content, caused generally by excessive leaching.

From the case histories of hundreds of fields examined and treated successfully for deficiencies or other troubles, the author came to the following conclusions. *Whenever soils, heavier than a loamy sand, in general farm crops and orchards contain not more than 2 to 5 parts per million of nitrate N, or soils in market garden crops and in cultivated crops, such as potatoes, cotton and sugar beets, carry not more than 8 to 10 parts per million of nitrate N, it is time to sidedress.* This kind of treatment is to follow, even if the chlorides and sulfates do not show clearly a case of leaching (indicated by the presence of these in the A_2 and B_1 horizons). It is, however, possible that a low nitrate content is due to the low nitrifying power of the soil caused by acidity or more often by waterlogged conditions. Cases like these are associated with soils heavily manured or rich in organic matter. The treatment for these soils is: (1) not to plow under manure, but to disk it into the surface; (2) the cover crop should be light when plowed under; (3) the addition of some of the limestone-gypsum mixture, plus Epsom salt or sulfate of potash-magnesia, manganese sulfate, copper sulfate, borax, and 100 to 150 pounds $NaNO_3$ per acre. The quantities of the other ingredients are to be gauged as discussed earlier.

Whenever the water extract shows a high nitrate content, it may be due to the following:

1. A faulty practice of sidedressing with excessive amounts of "soda" (nitrate of soda); or from heavy applications of manure, especially poultry or sheep manure. Nitrates may also accumulate in the profile during prolonged droughts, when none are washed out, and plants are not capable of using these. As much as 80 to 100 parts of nitrate N per million pounds of soil, equivalent to 500-700 pounds of $NaNO_3$, have been found in many

fields of New Jersey during the summer droughts of 1942, 1943, and 1944. Crops grown in these soils have not suffered from such an abundance of nitrates, whenever the pH of the soil brought about by proper liming has been conducive to deep rooting. The roots reached the A_2 and B horizons, *where the concentration of nitrates was not high.* There, plants found the other nutrients and water necessary to meet demands caused by the stimulated growth due to the nitrates.

Large quantities of nitrates are frequently the cause of troubles in soils rich in organic matter, especially mucks when they are well limed and heavily fertilized. This condition is very common in greenhouse beds. In these cases, it is usually the total concentration of salts rather than the high nitrate content alone that distresses the crop. Flushing the soil with large quantities of water until the conductivity is reduced to a point below the critical for plants, as discussed earlier, is the remedy.

In fields where the B horizon is acid, roots stay in the Ap. With an excess of nitrates, or any other soluble salt in the Ap due to drought, the intake of water by plants is reduced. Besides, the roots suffer from a high salt concentration and turn brown. Flushing the soil and treating it with lime and the other ingredients necessary to give the plants a balanced diet will cure this condition. The radical remedy is, of course, liming the B horizon.

2. *Whenever extra "soda" is added, or sufficient nitrates are produced naturally in the soil, plants are stimulated.* This supply of nitrates puts a demand for a greater rate of supply of other nutrients which, if not available, cause the nitrates to stay in the soil. At the same time, the nitrates stimulate the microbial flora which also ties up other nutrients. If chlorides and sulfates are present in traces only, it is very clear that the soil is in need of nutrients except N. In such cases, sidedressing with a 0-10-10 or similar grade, depending on the crop, has almost always resulted in a marked improvement of the crop.

Ammonia. — A high NH_3 test may be due to a recent application of some ammonium bearing salts. If no ammonium salts have been applied, a high test for NH_3 is an indication of low oxidation, or poor aeration. Muck soils or heavily manured soils that tend to be poorly drained frequently show a high NH_3 content. As a rule, this phenomenon corroborates *the findings of the morphological examination. In such cases* treatments prescribed for poor drainage conditions (lime-gypsum mixture, Epsom salt or sulfate of potash-magnesia, manganese sulfate, and a little borax) are in order. These treatments have seldom failed.

A negative test for NH_3 with negative or low tests for Cl, SO_4, and NO_3 are conclusive evidence that the soil is deficient in nutrients. A negative test for NH_3 alone is no evidence even of a deficiency of N. The nitrate test has to be looked into.

Summary Statement. — The procedure of examining and testing soils to determine the cause or causes why they do not produce as they should is an evaluation of what is going on in the soil profile. Whenever possible, *the method of comparative analysis* which permits deductions by the process of elimination is to be followed. This involves the examination, sampling, and analysis of a good and a poor field or a good and poor area in the same field. The following are the steps involved in the search:

1. The morphological examination of the profile, down to the C horizon and sometime even deeper, is the first step in the search for a diagnosis of soil "ailments."

2. Information by the operator on soil management and cultural practices frequently furnish important clues on the reason behind the trouble plaguing the soil.

3. The dispersion and color of the soil-water extract and the turbidity and color of the filtrate of this extract reflect the physical condition of the soil.

4. A pH determination of the profile may tell the story of the physical and chemical conditions of the soil responsible for the troubles experienced.

5. Conductivity *is one of the most important single value tests* that offers general evidence on the chemical and physico-chemical condition of the soil in relation to plant growth. By themselves, however, conductivity data may be misleading.

6. Tests for the anions, chlorine, sulfate, and nitrate, and a test for ammonia reveal the status of the nutrient condition of the soil. These tests together with conductivity data clinch the final diagnosis of the soil conditions.

The various examinations and tests seldom fail to reveal the cause or causes of the failure of the crop due to the soil conditions.

The approach for trouble shooting, as outlined, is especially adapted to soils devoted to intensive cropping, such as truck gardening, and in general to soils heavily fertilized. This approach gives very illuminating information on the condition of the soil in greenhouse benches (in these cases samples are taken at 2 inch intervals through the entire depth of the bench) and pot cultures, i.e., for plants grown in pots permanently or temporarily until transferred to the soil in the open. This approach also gives much more information than any other in use for tracing troubles in field crops, orchards, meadows, and pastures.

Conclusion

The system of trouble shooting and the reasoning advanced, as presented in the foregoing pages, cannot and do not pretend to answer all the questions raised by farmers with reference to poor conditions of crops in the different soil zones. Essentially, this system has been worked out for and applied to problems of crops in soils of the zones of podzolization and laterization. However, the *basic principle of the system of trouble shooting stems from the inherent properties of the constitution of the soil body, the soil profile.* With slight modifications, these tests and procedures may be applied to any other soil zone with good chances for success.

In a nutshell: *an appreciation of the physical, chemical, and biological makeup of the profile, as presented in this book, is a prerequisite for the skillful use of the system of soil trouble shooting, as discussed in this chapter. Aided by a few simple tests, intelligently interpreted in the light of available information, one can generally find a satisfactory answer to the many queries perplexing the farmer, the landscaper, the gardener, the forester, or whoever else is working the land.*

CHAPTER XV

SOIL CLASSIFICATION AND SOIL SURVEY

Introduction. — Classification is a process of logical reasoning based on the properties and characteristics of representative units of natural bodies for the purpose of studying, identifying, and grouping them. Classification is not a science; it is just a tool in the workshop of scientists.

Variations exist between closely related individuals (there are no two leaves alike on a tree) and any object in nature having many variants does not lend itself easily to a system of classification. The multitude of characteristics involved in the variants makes it difficult to assemble these into groups. The soil is a typical representative of such an object. Its mode of origin and formation, widespread geographic distribution, and diversity of factors influencing the constitution of the soil body are the variants that complicate the problem of soil classification. A very disturbing element in building a new system of soil classification is the fact that prior to the advent of pedology, several systems were in use, and the tendency has been to mend the old ones rather than to build a new one. The aim of these systems was primarily utilitarian, with little reference to the internal characteristics of the soil as a natural body.

Among the very first systems of soil classification was the one designed for the purpose of taxation. This was a purely economic system, as was the one of classifying soils according to their capacity of producing the most profitable crops, such as wheat soils, potato soils, and cotton soils.

Geologic Classification. — This system of classification, based on the geologic history of the materials which make up the soils, recognized two broad groups: (I) *residual* and (II) *transported*. To group I belong the soils developed in situ: (A) from crystalline rocks; and (B) those developed from sedimentary deposits. In subgroup A we find a number of subdivisions; (1) soils developed from rocks poor in lime: granite, syenite, and quartz porphyry; (2) soils developed from rocks rich in lime: gabbro, basalt, and diabase; (3) soils developed from rocks poor in nutrients: mica-schist, slate, micaceous shales, and chlorite gneiss. In subgroup B, we find soils formed from sandstone, shale, and limestone. To group II (transported) belong the unconsolidated sands, silt, clay, and marls of various kinds.

The geologic origin of the parent material did not prove satisfactory in identifying soils and classifying them. The climate and biosphere, the two cardinal factors of soil formation, upset the geologic system of classification. It is not, for instance, difficult to see that a granite in Maine Georgia, or California does not produce one and the same type of soil A basalt in Alaska and Panama gives rise to two soil types that are as far apart in their properties as their geography. It is, however, well to remember that a knowledge of the geology of the parent material is of immense value in interpreting many important detailed features of the soil body.

Mechanical Classification. — This is also known as the physical classification because it is based primarily on soil texture which is a physical characteristic of soils. It is one of the early systems of soil classification, texture being a property easily recognized and associated with soil productivity. Such designations as loam, sandy loam, silt or clay soil have been used ever since the days of recorded history. In connection with this system, some other designations of a physical and chemical nature have been used, such as humus soils, peats, mucks, marl soils, limestone soils. This system of classification is applicable to all zonal soils inasmuch as soil productivity and soil management is associated with soil texture.

Chemical Classification. — As an independent system of classification, the characterization of soil groups by their chemical composition has not been used to any extent. It is obvious that data on soil analyses can not be classified according to any definite pattern. There can be some groupings, such as carbonate or limestone soils, silicate soils of Al and (less frequently) Fe, quartz soils (sandy), gypsum soils, acid soils, and alkaline soils. These characteristics, however, do not suffice to make up classification groupings of soils as distributed in nature. Some of the designations of the chemical classification have been incorporated in the geologic, mechanical, and genetic systems of soil classification.

Genetic Classification. — As the name implies, this classification springs from the characteristics of the various soils as fashioned by the natural forces. The broad aspects of it were discussed in chapters VIII and IX and need not be repeated here except in outline form.

The soils of the world are grouped into 7 climatogenic types, known as zonal soil types, and 4 climatogenically subdued soil types, also known as intrazonal types. The zonal soil types are: (1) Gray and red semidesert soils, grouped sometimes under the name *grayearths* (in the literature, the Russian term *serozem* is occasionally mentioned); (2) Brown steppe; (3) Chestnut brown steppe; (4) Chernozem; (5) Podzolic and podzols; (6) Tundra; (7) Laterites and lateritic soils.

The climatogenically subdued soils are: (1) Lithogenic; (2) Hydrogenic; (3) Orogenic; (4) Fluviogenic.

The zonal as well as the climatogenically subdued (intrazonal) soil types have subtypes and varieties, as discussed in chapters VIII and IX. Their morphological, chemical, and physical properties and biological characteristics and behavior serve the purpose of card-indexing or classifying these into some units of classification. As more information is gained about the less known soil varieties and departures from the normal become clarified, other subdivisions may become established.

In mountain regions, the climate and biosphere change with altitude, and correspondingly the soils change. Zonal soils distributed in a horizontal plane over vast geographic regions appear within a few miles in a vertical plane (see Ch. IX for a discussion of vertical zonation). Moving over brown and chestnut-brown soils from the foothills of the Rocky Mountains, a few miles outside Colorado Springs, towards Pikes Peak, about 15,000 feet above sea level, we pass through the zonal soils of the horizontal zonation, with the exception of the laterites. The soils in the vertical zonation resemble very much those of the horizontal zonation, and yet there are some distinctive differences which have to be classified in terms of mountain position. We thus have mountain chernozem, mountain podzols, and others. Specific mountain soil types, such as mountain meadows and mountain peat soils have no counterpart in the zonal or climatogenically subdued soil types of the horizontal plane.

In the genetic classification, the recognized variations in the properties and characteristics of the zonal soil types (conditioned by texture, parent material, microrelief, local climate, and sometimes changes in natural vegetation, such as the succession of forest species after a fire) are used in separating new groups of soils. We thus have clay or loam chernozem on loess, on granites, basalts, and limestones. We have podzols in a pine or fir association and podzolic brown soils in a beech association. These features give rise to an array of classification units which carry the broad fundamental features of the zonal soils and some specific features resulting from the other elements that enter in the constitutional makeup of the soil profile. In recent years, the types and quantity of colloids and minerals present in the soil are being utilized as indexing units in the genetic scheme of classification.

In the final analysis, the genetic system of soil classification embraces almost all other systems. The basis for this system is the development and expression of the characteristics of the soil profile and its component materials—water, air, mineral, and organic matter and their characteristics and properties.

The genetic system of soil classification is the only logical one, but the details of it have not been worked out fully. A thorough analysis of this system belongs to a more advanced study of soils.

Soil Survey in the United States

At the turn of the century (1899), the United States Department of Agriculture in cooperation with State agencies, usually the State Agricultural Experiment Stations, established the *Soil Survey*. In the beginning, the survey was engaged in taking an inventory of the soil resources of the country in relation to crop production. The Division of Soil Survey in the former Bureau of Chemistry and Soils and now in the Bureau of Plant Industry, Soils and Agricultural Engineering, United States Department of Agriculture, has published the results of the surveys in the form of maps and reports which attempt to give an idea on the soils of the country in relation to agriculture.

Soil Class. — In classifying soils, the units selected for identification purposes, particularly from the point of view of crop production, were those best known to the farmer. Outstanding among these was the texture of the plowed layer of the soil. It was, therefore, given first consideration in the early days of soil surveying. After years of work in the field, the soil surveyors have come to a textural classification which is based on prevailing mechanical composition. Sandy soils, clays, loams, silt loams, and other soil classes (texture) have been the principal soil characteristics in describing and mapping soils (see *Textural Classification* at end of chapter). It was soon discovered that soils of similar texture in different areas are not alike in their capacity to produce crops. Soil class (texture) alone as a unit of classification became inadequate, and other criteria had to be found.

Soil Series. — In Western Europe and in the United States, soils were looked upon merely as geologic formations designed by nature to serve as a medium for plant growth. Such characteristics as chemical composition and color were interpreted in terms of soil productivity. These characteristics have been gradually taken in by surveyors in grouping and classifying soils. As the work expanded, place names have found their way in referring to soils. Other names referring to geologic origin followed. Color was the first characteristic the surveyor has singled out in the scheme of naming soils of different localities. Color repeats itself over areas and districts, and it was convenient to place a series of soils of the same color under one name. In this manner the *series* as a classification unit came into being.

In 1904 the Marshall series was mapped in Marshall County, Indiana, on the basis of the black color of the surface soil. Soils of similar color were quickly established by the survey of Tama County, Iowa, of Cando area, North Dakota, and other places. All were named Marshall. By 1911, the Marshall series had been recognized on a number of geologic formations. Other names were then given to these soils, and Marshall remained as a black soil developed on loess (parent material as a characteristic). As the survey work had progressed, new characteristics within the series of one and the same geologic formation have been discovered. Thus, Marshall soils poorly drained are distinct in their features and behavior, and a new series, Grundy, was separated. With the recognition of the profile characteristics, some distinctive attributes common to some soils have been identified and more series have been separated. Thus, Marshall soils on parent material rich in lime retained the name Marshall, whereas soils that accumulated lime in the profile as a result of the soil forming processes were named Moody. At present, dark colored soils on loess grouped in 1911 as Marshall have been split into a dozen or more series.

Soil Type. — In the early days of the Soil Survey, the basis for new series was restricted to color of surface soil, later also of subsoil, and of geologic origin. It soon became evident that different soil classes (texture) in one and the same geologic province could have similar color characteristics of the surface and subsoil. A series could, therefore, embrace a number of classes. For example: the Sassafras series was recognized as one which developed on unconsolidated deposits of the Coastal Plain; its color is brown on the surface and reddish brown in the subsoil. Such a group of soils may be found on sand, sandy loam, loam, silt loam, clay loam, and other textural classes. The Survey, therefore, mapped Sassafras sand, Sassafras sandy loam, Sassafras loam, and so on. The combination of the series name and class designation was then recognized as the *soil type.*

With the crystallization of the *soil type* as a unit of classification, soil surveying got off to a good start in defining, identifying, correlating, classifying, describing, and mapping of soils. By 1930 more than 2000 series have been recorded, and now the number is probably 3-5 times that many.

Soil Survey Reports. — The distribution and position of the different soil types are charted by the field men of the soil survey on suitable base maps, such as of the U. S. Geologic Survey and in recent years of aerial maps. The data are then checked by Federal inspectors and, if satisfactory, they are published as a soil map, to a scale of one inch to the mile, in colors, and with suitable markings and legends. Besides soil data, the map gives other information, such as contour lines, rivers, brooks, lakes, reservoirs, railroad lines, roads, bridges, outstanding land marks, and occasionally plant cover. The map is accompanied by a bulletin that gives the geographic distribution and position of the area, its geology, climate, history of settlements, prevailing agriculture, and a detailed description of the soil types. Occasionally, soil management practices are suggested.

Dr. Marbut's Scheme of Soil Classification. — Ever since World War I, the survey reports have included pedologic data, thanks to the efforts of the late Dr. Curtis F. Marbut, then Chief in Charge of Soil Survey. In 1935, Dr. Marbut's monumental work *The Soils of the United States* was published by the U. S. Department of Agriculture as part III of *The Atlas of American Agriculture.* In this work, Dr. Marbut presented for the first time a systematic classification of soils in the United States from a pedologic point of view.

Soils are divided into two major groups on the basis of major characteristics resulting from soil forming processes: (1) *pedocals,* soils which show a zone of lime carbonate accumulation in some horizon of the soil profile, and (2) *pedalfers,* soils which have no such zone of lime accumulation (see p. 161). These two major groups are the starting point in Dr. Marbut's scheme of soil classification; they are designated as category VI; from it, other categories are branching off, as shown in the following table, reproduced from Marbut's publication.

Category V includes broad groups characterized by the colloids formed in the process of soil formation and products of weathering. The variations in the breakdown of the parent material under the influence of various agents in different climatic zones are taken as criteria for this category. In it, the variations in the types of clay minerals resulting from the reactions in the respective soil zones (such as montmorillonite, beidellite, halloysite, kaolinite, and the newly formed, known as *pedolites*) are to be included as criteria for classification. In this category we find:

(a) The soils from mechanically comminuted materials that result primarily but not exclusively from physical reactions. These soils are found in regions of low temperature.

(b) The *siallitic* products of subtropical weathering, whereby hydrated aluminum silicate approaching the composition of kaolinite coat the original rock.

(c) The *allitic* products which are hydrated oxides of Al with an admixture of SiO_2, Fe_2O_3, TiO_2, and H_2O.

The other categories are self-explanatory. More and still more detailed characteristic features, and properties resulting from the natural forces responsible in the processes of soil formation are included as we go from category IV, which includes the zonal soils, to category III which takes in the intrazonal (climatogenically subdued) and immature soils. Categories III, II, and I represent the specific contributions of the American Soil Survey, namely the concepts of *soil series,* and *soil types.*

In the opinion of the author, category V is somewhat artificial. It would seem that category VI, the pedocals and pedalfers, should lead to

TABLE 25

Marbut's scheme of soil classification

Category VI	Pedalfers (VI-1)	Pedocals (VI-2)
Category V	Soils from mechanically comminuted materials Soils from siallitic decomposition products Soils from allitic decomposition products	Soils from mechanically comminuted materials
Category IV	Tundra Podzols Red soils Yellow soils Prairie soils Laterite soils	Chernozems Dark brown soils (Chestnut: J.) Brown soils Gray soils Pedocalic soils of Arctic and Tropical regions
Category III	Groups of mature but related soil series Swamp soils Glei soils Rendzinas Alluvial soils Immature soils, on slopes (Orogenic: J.) Salty soils Alkali soils (saline: J.) Peat soils	Group of mature but related soil series Swamp soils Glei soils Rendzinas Alluvial soils Immature soils on slopes Salty soils Alkali soils Peat soils
Category II	Soil series	Soil series
Category I	*Soil units, or types*	Soil units, or types

the classification units of the zonal soils, category IV. The intrazonal (climatogenically subdued), immature, and other types of soils still unrecognized and unclassified should make up category III. Categories II and I may remain as they are.

As the work on the profile characteristics progresses and more information becomes available on the properties enumerated in category V and others, such as a mineralogical composition and new formations, points of contact of correlation may be found among the soil series. With that development, the burdensome increase of soil series names might be checked and simple subdivisions within the zonal types developed.

Other Groupings. — In recent years, soils of related series which have variations in topography, drainage, and erodibility have been grouped under the name *catena.*

Within the saline soil groupings, pedologists have recognized variations and departures from the standard type. For example, within an area of genuine solonetz, some solonchak, solodi, and different stages in solonetz development or mixtures of solonchak and solonetz soils may be found. Such a condition was designated as a *soil complex.* This term is now being applied in describing variations and departures from the standard type of soils in areas of other soil zones.

Soil Survey Summary. — There are close to 3 million square miles (about 1.9 billion acres) of land in the United States capable of producing some kind of a crop. Close to 850,000 square miles have been mapped and described in detail in the soil survey reports. This figure includes the surveys of Puerto Rico and Hawaiian Islands.

Poor lands are mapped on smaller scales than are good lands, and such a survey is known as a reconnaissance survey. It charts areas in which the finer divisions of soil types, series, and phases of these are omitted. There is still over 1.25 million square miles of land that has to be mapped in detail. It is estimated that the survey cost is 4 to 6 cents per acre.

With the expansion of the work of the Soil Conservation Service, a super-detailed system of soil mapping has come into use. The purpose of this is to supply information on *land use* from the point of view of soil conservation. Individual farms are being surveyed, and maps prepared on a scale of 8 to 12 inches to the mile, giving data on the degree of erosion, location of gullies, gradient and direction of slopes, location of fences, size of fields, and other details needed in planning a soil conservation program.

Textural Classification

Nowhere in the world has the concept of soil class been utilized as extensively as in the United States. It is probably due to the fact that the Soil Survey originally started out with texture as the unit of classification. To fix the proportion and limits of the three standard separates, clay, silt, and sand and the grades[1] of the latter for any one class was a perplexing problem. One may readily see that the number of classes that can be made up is infinite, since any change in the proportion may justify a new class. The one suggested by Mark Baldwin of the Bureau of Plant Industry, Soil and Agricultural Engineering is presented below.[2]

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[1] The sands are divided into the following grades: fine gravel: 2 to 1 mm.; coarse sand: 1 to 0.5 mm.; medium sand: 0.5 to 0.25 mm.; fine sand: 0.25 to 0.1 mm.; very fine sand: 0.1 to 0.05 mm.

[2] The + and — signs mean more or less. The dash sign when used between two figures represents range of content, e.g., 20-50 means from 20 to 50 per cent.

I. Soil material containing 0-10% silt and clay:

Coarse sand	25 + fine gravel and coarse sand and less than 50 of any other one grade of sand.
Sand	25 + fine gravel, coarse and medium sand, and less than 50 fine sand or very fine sand.
Fine sand	50 + fine sand.
Very fine sand	50 + very fine sand.

II. Soil material containing 10-20% silt and clay:

Loamy coarse sand	25 + fine gravel and coarse sand, less than 50 any other grade.
Loamy sand	25 + fine gravel, coarse and medium sand, less than 50 fine or very fine sand.
Loamy fine sand	50 + fine sand.
Loamy very fine sand	50 + very fine sand.

III. Soil material containing 20-50 silt and clay, with 30-clay:

Coarse sandy loam	25 + fine gravel and coarse sand, less than 50 any other grade.
Sandy loam	30 + fine gravel, coarse and medium sand or less than 50 any other grade.
Fine sandy loam	30 + fine sand, less than 30 very fine sand or less than 25 fine gravel, coarse and medium sand.
Very fine sandy loam	30 + very fine sand, 50 + fine sand and very fine sand.

IV. Soil material containing 50 + silt and clay, with 30-clay:

Loam	20-50 silt; 20-50 sand.
Silt loam	50-100 silt;—20 coarse, medium, and fine sand.

V. Soil material containing 30-40 clay:

Sandy clay loam	0-20 silt; 40-70 sand.
Clay loam	20-40 silt; 20-50 sand.
Silty clay loam	40-70 silt; 0-30 sand.

VI. Soil material containing 40 + clay:

Sandy clay	40-50 clay; 25-60 sand;—25 silt.
Silty clay	40-50 clay; 25-60 silt;—25 silt.
Clay	50 + clay.

The system presented is about the clearest thus far suggested. Other classes are frequently mentioned, such as stony loam, gravelly sandy loam, clayey sand, and others. Most soils, however, will fall in the scheme presented above.

GUIDE FOR TEXTURAL CLASSIFICATION

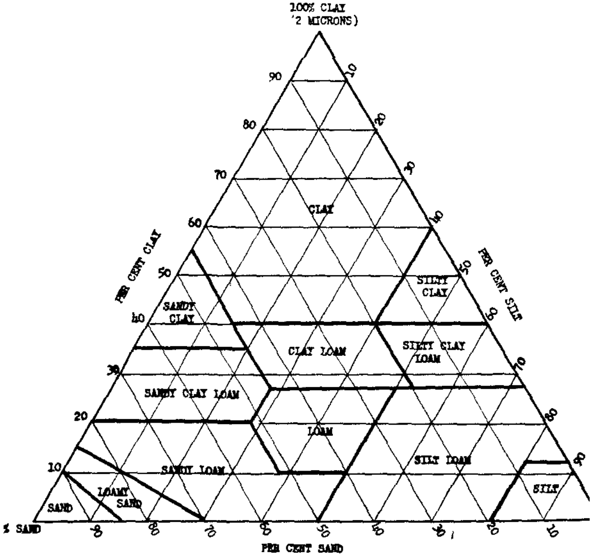

PLATE 12

(From United States Department of Agriculture, Bureau of Plant Industry, Soils and Agricultural Engineering, March 17, 1948).

To find the name of the soil class by the diagram, either two of the three seperates (determined by mechanical analysis) are shown on it as follows: the percentage of clay is indicated by the line parallel to the sand line; and the percentage of silt is indicated by the line parallel to the clay line. The name of the soil class can be read at the intersection of the lines.

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