

S
591
.W65

NOTES

—ON—

SOILS



Class 359/

Book W65

Copyright N^o _____

COPYRIGHT DEPOSIT.



NOTES ON SOILS

An Outline for an Elementary Course
in Soils

BY

A. R. WHITSON

Professor of Soils, The University of Wisconsin

H. L. WALSTER

Instructor in Soils, The University of Wisconsin

3
3
3
3
3
3
3

Published by the Authors
Madison, Wisconsin

S591
V65

Copyright, 1909,
BY
A. R. WHITSON AND H. L. WALSTER.



DEMOCRAT PRINTING COMPANY, MADISON

© Cl. A 253335

PREFACE

The aim in the pages that follow has been to present a brief outline of work in Soils, adapted to the needs of students pursuing short courses in Agriculture. The present volume has been hastily prepared, and therefore many errors may have been overlooked. Much valuable data, not included in these pages, will be found in the bulletins listed in the appendix, and in the larger text books upon the subject of Soils. Acknowledgment is due Mr. Stuart L. Clark for his careful preparation of the line drawings.

A. R. W.

H. L. W.

*The University of Wisconsin,
College of Agriculture,
December, 1909.*

CONTENTS

Chapter	Page
I. Conditions essential for Plant Growth.....	1
II. The Origin of Soil Material.....	19
III. The Supply of Chemical Elements.....	26
IV. Humus	32
V. Acidity and Liming.....	42
VI. Nitrogen	47
VII. Phosphorus and Potash.....	58
VIII. Mechanical Composition, Texture and Tilth....	68
IX. Water-Holding Capacity of Soils.....	75
X. Movements of Soil Water.....	79
XI. Temperature of Soils.....	83
XII. Ventilation of Soils.....	88
XIII. Tillage	90
XIV. Barnyard Manure	95
XV. Classification of Soils	101
XVI. Conditions of Climate and Soils Needed by	
XVII. Rotation of Crops.....	122
XVIII. Types of Sandy Soils and their Management....	125
XIX. Types and Management of Clay Soils of Humid Regions	131
XX. Marsh Soils	136
Appendix	140

NOTES ON SOILS

CHAPTER I.

CONDITIONS ESSENTIAL FOR PLANT GROWTH.

In studying the growth of the plant it is convenient to divide its life history into three periods: First, the period of germination; second, the period of vegetative growth, and third, the period of fruition. It is, of course, true that these periods shade one into the other or overlap to a certain extent, but it is nevertheless helpful to study the effect of conditions on plants from the standpoint of this threefold division. Some conditions are essential to the life of the plant at all times while others apply to only one or two of its periods of development.

CONDITIONS NECESSARY FOR GERMINATION.

(1) **Absorption of Water.** The first act in the germination of seed is the absorption of moisture. The factors which influence this process are: Temperature, closeness of contact between the soil and seed, amount of moisture in the soil and the amount of soluble salts in the soil.

(2) **Temperature.** By placing beans or peas in warm and in cold water the greater rapidity with which the warm water is absorbed can be readily determined. It is for this reason, in part, that seeds germinate in warm soil faster than in cold soil. But, besides influencing the rate at which water is absorbed, the temperature also influences the chemical changes which take place in the seed during germination.

The influence of temperature on germination has been studied by a number of experimenters and the averages of their determinations of the best and of the lowest temperatures, for the germination of the seeds of a few crops, are given in the following table.

	Wheat and Barley.	Red Clover.	Corn.	Rape.
Best.....	75 deg.	70 deg.	90 deg.	90 deg.
Lowest.....	40 deg.	40 deg.	48 deg.	40 deg.

There is usually little gained by sowing seeds in the spring too early and while the ground is too cold for the respective crops, although for some seeds, as for instance Red Clover, the moisture conditions may be better earlier.

The ways in which the temperature of the soil can be influenced will be studied in a later chapter.

(3) **Contact of Seed and Soil.** The ease with which water can be absorbed from the soil by the seed will also depend on the number of points of contact between the soil and seed. This will depend on the fine-

ness of the soil and on the firmness with which it is pressed down on the seed.

It is for this reason that so much depends on the care taken in the preparation of the seed bed and in firming the soil by rolling after the seed is planted. And the fineness depends very largely on the condition of the soil when cultivated, as will be shown in a later chapter.

The degree of fineness necessary for good germination depends also on the kind and size of seed. The smaller seeds, such as those of the grasses and clovers, require a finer seed bed than is essential for corn and peas.

(4) Influence of Salts. On account of the attraction between salts and water the presence of a considerable amount of soluble salts in the soil will prevent the seed from absorbing water. This can be shown by placing beans or peas in two cups of water—one of which contains a small amount of common salt while the other contains none. The salt will partly or entirely prevent the absorption of water by the seed. It is in this way that the large amounts of salts in the soil of arid regions often prevent the germination of seed. Some salts are actually poisonous to plants even in small amounts while others simply act to prevent the water from entering the seed and are not injurious except when present in considerable quantities.

(5) Oxygen. The work of constructing new tissues and of forcing the newly formed root into the soil is done by the energy resulting from oxidation of food stored in seed and therefore, the germinating seed requires a supply of available oxygen, just as the energy

which a man uses in doing work comes from the food which he consumes when oxidized in the muscle tissue.

It is therefore necessary that the soil in which the seed is germinating allow the air to reach it, otherwise the seed will rot without germination. The access of air to the seed is frequently prevented by too much water in the soil and by puddling of the soil as will be described later.

(6) Mineral Elements not Needed for Germination. It is often noticed that seed will germinate and grow for a short time better in poor, sandy soil than in fertile soil and even better in sawdust or other loose material. This shows that nothing but water and air need be taken in by the seed in germination and in the early growth of the seedling.

The amount of growth made by the seedling developing in sawdust or in the air alone under suitable conditions of moisture, temperature and light depends on the amount of material stored in the seed. Small seeds such as those of most grasses will allow but little growth while larger seeds such as those of pea and bean may allow the seedling to attain considerable size; in some cases half the size usually attained in ordinary soil, and even produce flowers.

Conditions Essential for Vegetative Growth.

(7) Mineral Elements Taken from the Soil. While the seed will germinate readily and the seedling grow rapidly for a short time in pure sand or sawdust it soon begins to lose its healthy green color and finally stops growing. On the other hand, while the field soil

may not allow the seed to germinate as rapidly as the pure sand or saw-dust, it does allow it to continue its growth to maturity.

The reason for this is that it furnishes material which is necessary for continued growth although not necessary for germination.

When plants are analyzed the following elements taken from the soil are usually found: sodium, potassium, calcium, magnesium, iron, silicon, chlorine, sulphur, phosphorus and nitrogen. With the exception of the nitrogen these are almost entirely left in the ash on burning. Besides these elements there are a number of others which are often found.

Part of the above list of elements are not entirely necessary to growth, as has been shown by growing plants to maturity in a solution not containing them. Those which do not seem to be essential are sodium, silicon and chlorine. All of the remaining ones must be present or growth will cease before maturity.

(8) The Amount of Salts Taken up by Plants.

The amount of the various elements taken up by plants depends on three factors: first, the relative amount present in the soil in a form which can be taken up by the plant; second, on the combination it makes in the plant, and third, on the kind of plant.

More salts will be taken up from a soil rich in soluble salts than from one poor in them. If a given element combines with other substances in the plant much more of it will be taken up, than if no such combination is made.

There is therefore quite a range in the amounts of different elements found in the plant, and also in the

total amount of ash. Again, different plants growing on the same soil will take from it different amounts of the various elements.

(9) Variation in Fertilizing Constituents at Different Stages of Growth. Different plants not only use different amounts of plant food, but the same plant has a varying composition at different stages of growth. This matter has received careful attention at the Ducal Agricultural Experiment Station in Bernburg, Germany, and some of their results will be given here.

The amount of potash in the crop from one acre of wheat was 88 lbs. at a very early stage, 123 lbs. when just heading out, 122 lbs. when fully headed out but green, and decreased to 72 lbs. at the ripening stage, less than at a very early stage, showing that the plant had taken up large amounts of potash, used it in life processes, and then returned it to the soil, either by way of the roots or by excretion on the surface of the leaves and stems to be washed off by rain and dew. The same general relation holds for nitrogen in the case of the wheat plant, while phosphorus, on the other hand, reaches its maximum when the plant is fully headed out, and does not materially decrease at maturity. Analyses of another cereal, barley, at different stages in its growth showed the same general tendencies, although the absolute amounts are different.

Quite different results were obtained with the potato. The amount of potash in the tubers, leaves, and stems from one acre of potatoes was 47 lbs., when tubers were just beginning to set (June 17), 78 lbs. one month later (July 16), 112 lbs. two months later (Aug. 18),

and when the potatoes were fully ripe (Oct 5), 143 lbs. showing a continual increase in amount of potash absorbed. Similarly phosphorus increased from 8 lbs. at an early stage to 28 lbs. at ripening stage, and nitrogen from 45 to 111 lbs. This great difference between the cereals and the potato is probably due to the fact that the potato does not dry out on maturing as do the cereal crops.

It should be remembered that the experimental work here discussed was carried on under a particular set of conditions and with a particular soil. The results obtained might have been quite different under different conditions, for we have pointed out in the previous paragraph that the amount of an element taken up by a plant depends upon the relative amount in the soil in an available form. This general conclusion can be drawn, that the composition of a plant at maturity does not necessarily show the amount of plant food it may have absorbed during its growth.

(10) Average Amount of Salts Removed by Crops. While, as stated in previous paragraphs, the amount of various salts absorbed by plants from the soil varies greatly during different stages of growth still the amount of the three most important elements, Nitrogen (N), Phosphoric Acid (P_2O_5), and potash (K_2O), found in mature crops grown on ordinary clay loam soil is quite constant. Since these are the amounts removed from the soil by crops when harvested, they are very important to bear in mind.

The following table, taken from Bulletin 47 of the Minnesota Experiment Station, shows the amount of the

more important elements taken by different crops from clay loam soil.

Table showing the Plant Food material removed by the crops in pounds per acre.

Crop.	Gross Weight.	Nitro- gen.	Phos- phoric Acid.	Pot- ash.	Lime.
Wheat, 20 bu.....	1200	25	12.5	7	1
Straw	2000	10	7.5	28	7
Total		35	20	35	8
Barley, 40 bu.....	1920	28	15	8	1
Straw.....	3000	12	5	30	8
Total		40	20	38	9
Oats, 50 bu.....	1600	35	12	10	1.5
Straw	3000	15	6	35	9.5
Total		50	18	45	11
Corn, 65 bu	2200	40	18	15	1
Stalks.....	6000	45	14	80	20
Total		85	32	95	21
Peas, 30 bu	1800	.....	18	22	4
Straw	3500	.....	7	38	71
Total .....		.....	25	60	75
Flax, 15 bu.....	900	39	15	8	3
Straw	1800	15	3	19	13
Total		54	18	27	16
Meadow hay.....	2000	30	20	45	12
Red clover hay.....	4000	.....	28	66	75
Potatoes, 300 bu....	18000	80	40	150	50
Mangels, 10 tons....	20000	75	35	150	30

(11) Distribution of Elements in Plant. Study of the foregoing table will show that nitrogen and phosphoric acid go chiefly to the seed or grain of crops, while potash and lime are largely found in the stalks or straw. From this we are able to determine the probable losses when either the grain or straw or both are sold.

(12) Food Constituents of Plants. The chemist divides the chief food compounds produced in plants into three classes: carbohydrates, fats and proteids. The carbohydrates, such as starch, sugar and a large part of crude fibre and the fats and oils of the plant are made up of only three chemical elements: carbon, oxygen and hydrogen. These are derived from carbon-dioxide of the air and from water absorbed by the root. The proteids, however, which form the most valuable part of the food contain considerable nitrogen, small amounts of sulphur and in some cases phosphorus. These three elements are taken from the soil.

(13) Variation in Composition During Growth. Since young plants and growing parts of older plants have thin walled cells filled with protoplasm, they have a high per cent of protein and a low per cent of crude fiber or cellulose. Crops cut very green are therefore richer in protein than mature crops. Moreover, if crops are prevented from making full growth, the stunted crop is usually richer in protein than the crop making a larger growth. There is an exception to this when the failure to grow is due to lack of available nitrogen as mentioned in paragraph 15.

(14) Function of Elements. Although it is comparatively easy to determine which of the elements

found in the plant are essential and which are unessential to the growth of the plant it is very difficult to find out just what the use of the essential elements is to the plant. There are specific functions which each of the essential elements have to perform and there are more general functions which various elements can perform. While a certain minimum amount of each of the essential elements must be present for the specific functions, there must be larger amounts of some of the essential elements or of the non-essential elements to produce the best growth. A soil which is poor in all the essential elements will often be helped to a certain extent by an addition of any one while it is much more benefited by the addition of all those lacking.

One of the special functions of potash seems to be to aid in the process of starch formation. Corn growing on the marsh lands of our state has been greatly benefited by potash fertilizer and in all cases the increase of grain—containing a large amount of starch—has been greater than the gain in the stalks. The formation of starch takes place in the leaves, it being then carried to the seed and the potash is chiefly found in the leaves and stems of plants.

The phosphorus is necessary to the formation of some proteids, and since the proteids form a larger percent of the seed than of the stalk and leaves, the phosphorus is found in larger amounts in the seed or grain than in the stalk and leaves.

Calcium or lime seems necessary for the development of leaves, for plants grown in solutions free from calcium do not develop leaves readily.

Nitrogen is absolutely essential for the formation of proteids and the relative amount of protein found in the plant depends partly on the relative amount of nitrogen in the soil in an available form, as well as on the nature of the plant.

(15) Relation Between Composition of Plant and Amount of Food Material Available to it. The composition of the plant is to a certain extent dependent on the relative amount of the necessary elements available to it. When the amount of available nitrogen is small the plant cannot produce as much protein as it does ordinarily. The crop grown on soil very low in available nitrogen is therefore often low in proteid, the most valuable food material.

Experiments made by growing corn, oats and rape on three sand plots to which had been added different amounts of nitrates showed the following per cent of protein where plot one received no nitrates; plot two, a medium amount; and plot three, double this amount.

	Oats.	Corn.	Rape.
Plot 1.....	12.06 per cent.	8.44 per cent.	12.56 per cent.
Plot 2.....	15.81 per cent.	9.94 per cent.	14.00 per cent.
Plot 3.....	16.63 per cent.	11.25 per cent.	14.25 per cent.

These crops were cut green, as they would be used for soiling.

These experiments, with others, show that not only is the crop on fertile soil larger than that on poor soil; but it is richer in the most valuable food constituent.

The composition of plants is also influenced by their rate of growth and varies at different stages of growth. This is discussed in paragraph 20.

The influence which climate and soil have on the per cent of protein in wheat has been investigated by Deherain in France and by Soule in Tennessee.

During the period of most rapid growth of the cereals comparatively little starch is transmitted to the seed, most of it collecting in the upper part of the stem during this period and being carried to the seed during the ripening stage.

If therefore the weather becomes dry during the ripening stage less starch is carried to the seed and it has a relatively high protein content.

(16) Chemical Requirements of Different Crops.

Since different plants produce different relative amounts of carbohydrates, fats and proteids, we should expect that they would need somewhat different relative amounts of the various elements. Those plants which produce a relatively large amount of starch, such as corn and potatoes, require considerable available potassium while those which produce a relatively large amount of proteid should require considerable available nitrogen. This is found to be borne out by experience, but in addition to these facts which we can explain in this way, there are other cases where certain plants require relatively large amounts of certain elements for reasons we do not yet know. It will be helpful in studying the relation of the various crops to the soil and of their treatment with fertilizers to first study some of the most important cases of this varying requirement.

Cereals, such as wheat, oats and barley, need relatively large amounts of nitrates and phosphates, while not a very large amount of potassium is necessary. Corn in addition to available nitrogen and phosphate must have considerable available potassium, possibly on account of the large amount of starch which is produced. Potatoes also, both white and sweet, require considerable potassium. Timothy and most grasses require also large amounts of available nitrogen. Turnips do best when the amount of available phosphorus is large, while beets and carrots require more nitrogen. These are some of the facts which have been learned from experience, but our knowledge of this subject is still very incomplete.

(17) Uses of Water to the Plant and Amount Required. There are a number of ways in which water is of service in the growth of plants, among the most important of which are the following: (1) to keep the cell walls of the leaves moist so they can absorb carbon dioxide; (2) to evaporate from the surface and so prevent the plant from getting too hot, just as the evaporation of perspiration from the human body tends to keep it cool; (3) to furnish the small amount of water needed for building the various tissues in the plant; (4) to carry the salts from the soil into the plant and to the leaves where they are chiefly used in the chemical changes taking place there.

This current of water into the plant roots, up the stem and out of the leaves is called the *transpiration* current.

The rate of transpiration depends chiefly on the amount of moisture in the air, on the temperature, on

the strength of light and on the character of the plant. Moisture in the air lessens it; warmth increases and cold decreases it; strong light increases and darkness greatly retards it; and some plants transpire much less than others under the same conditions because they are protected in various ways or have fewer stomata.

A number of experiments have been made by different men to determine the number of pounds of water lost by the plant for each pound of dry matter formed by the plant. An average of these would be approximately as follows: Barley, 465; Oats, 500; Corn, 275; Clover, 575; Peas, 475; Potatoes, 385.

A single determination of soy bean shows that it used 527 pounds for each pound of dry matter. From these figures we would conclude that if no water ran off the surface or drained away a crop of 20 bushels of wheat would require only six inches of rain during the growing season; or a crop of 50 bushels of oats only eight inches; 60 bushels of corn, ten inches; 300 bushels of potatoes, six and one-fourth inches; two tons of clover hay, nine inches.

(18) Relation of Light to Plant Growth. In the development of the plant there are two processes going on; one is the process of forming starch, fats and proteids either for the plant itself or to be stored in some part of the plant, such as the seed or root. The other process is that of *growth* or the development of new tissue and parts. This latter process is carried on by the use of some of the material produced in the first process. From this we see that the plant differs from the animal in that the plant produces as well as uses food, while

the animal uses food only and must be supplied with it from outside.

Now the production of starch, fats and proteids requires light, while their use in growth and movement does not require light. We have all noticed the growth which potato vines will make from material stored in the tuber in the entire absence of light and not only is light not necessary but to a certain extent it retards growth. The tendency of plants to turn towards light is due to the fact that the side away from the light grows more rapidly than the other and pushes it over towards the light. The question as to the amount of light necessary for producing the greatest amount of food is not entirely understood, but it is known that the strength of light received on the earth's surface in our latitude during mid-day hours of the summer is as great as can be used by most plants. Moreover in all probability the intensity of light at five o'clock during clear days in the summer is as great as can be used by our crops.

It will therefore be seen that the intensity of light is not of so much importance as its duration. During the long summer days of Northern latitude much more rapid growth is possible than in the regions near the equator, because more food material is produced. The starches and sugars in particular require light to produce them and hence relatively larger amounts of these substances are produced in those regions where there are few clouds to interrupt the sunshine, than in those regions where there is much cloudiness. This is probably, in part, the reason why the sugar beet produces a relatively larger amount of sugar in Colorado where there

is much more sunshine than in the Mississippi Valley where there is more cloudiness.

(19) Relation of Temperature to Plant Growth.

The most favorable temperature for formation of food by the plant is usually the most favorable for growth also. When the amount of material produced by the plant is studied at different temperatures, it is found that it increases with increase in temperature up to a certain point and then decreases; that is, the production of food in the plant is lower at too high as well as too low temperatures. Probably the most favorable temperatures for our field crops are between seventy and seventy-five degrees Fahrenheit. Even corn, which is often supposed to need much heat, will make its very best growth without rising higher than seventy-five degrees. Since growth goes on during the night as well as day, the influence of warm nights is very great.

(20) Relation of Character of Plant to Rate of Growth.

It is frequently noticed that plants which are growing very rapidly lack in stiffness of stem. This is because the cell walls of the tissues are thin in rapidly growing plants, as was remarked in a former paragraph, and the growth is more rapid in either complete or partial absence of light than where it is intense. The result of this is that those plants or those parts of plants which grow in partial darkness are softer and less rigid than those which grow in strong light. The succulence of good vegetables is, therefore, largely caused by their rapid growth and so in the production of vegetables it is essential to hasten the growth in every way possible by supplying them with the best condition of moisture, light, temperature and food material.

(21) **Lodging.** The weakness of the stem of grain which causes it to lodge, is due to the rapid growth made when there are large amounts of water available and when the light is partly excluded either by cloudiness or by thickness of planting. It has been supposed that the degree of stiffness of the straw was determined by the amount of silica present, but this is probably not true. There is very little tendency in grain to lodge in dry regions even when large quantities of water are used in their irrigation, probably because of the continuous sunshine, although it may in part be due to the larger amounts of salts such as potash and phosphates in the soil.

CONDITIONS INFLUENCING FRUITION.

(22) **Translocation of Material in Plant.** The object of the plant in the production of seed is to secure the reproduction of itself. As a general rule plants tend to form seed when the conditions become unfavorable to continued rapid growth of vegetative parts. On the other hand if the conditions for vegetative growth remain very favorable, the formation of seed is retarded and the seed when formed is often not so well matured. The conditions most favorable to the formation of seeds are, therefore, different in some respects from those most favorable to vegetative growth, although, of course, a certain amount of growth is necessary to allow the plant to produce the seed in full maturity. It is very important for the farmer to realize the difference in the conditions necessary to the production of the largest amount of stalk and leaves on the one hand and of

seed on the other. In growing fodder and hay, a heavy growth of stalk and leaves is wanted, while in raising grain, a heavy yield of mature seed is the object.

The formation of material stored in the seed and fruit is largely the result of moving it from the stalk and leaves where it is produced to the seed or fruit where it is stored. In most of our farm plants growing under favorable conditions there is nearly enough of this material in the stalks and leaves at the time of flowering to reproduce the mature fruit and seed. Some water must, of course, be available to the plant during the ripening period, but little else is necessary. If now, there is an excess of water and especially of available nitrogen, there is a strong tendency to continue vegetative growth which retards and in some cases practically prevents the formation of seed. It is essential, therefore, to the best development of fruit and seed that the amount of these substances available to the plant be limited during the period of maturity. This principle is very important in planning a rotation of crops and will be referred to later when that subject is discussed.

(23) Relation of Growth to Soil. On account of the many ways in which the soil affects the plant's growth the importance of its study is very great. It supplies it with those chemical elements necessary, and with water. Then since a considerable part of the plant must grow under ground for these materials the temperature of the soil and its ventilation are important factors.

CHAPTER II.

THE ORIGIN OF SOIL MATERIAL.

In order to understand the distribution of the various kinds of soils and also the processes by which the elements in them become available to plants it is necessary to study their origin.

If we examine any soil carefully we find that it is made up of two different kinds of material. The first kind includes gravel, sand and clay and is derived entirely from rocks. The second, which forms the black or organic material and is called *humus*, is derived from the decomposition of animal and plant organisms which have grown in the soil.

(24) Soil-forming Rocks and Minerals. There are three chief classes of rocks in Wisconsin: granite and related rocks, limestone and sandstone. The granite occurs in the North Central part of the state. It is a *crystalline* rock composed of various minerals, the chief of which are *quartz*, *feldspar*, *mica* and *hornblende*. The quartz is white, the feldspar has flat surfaces and is pink or flesh colored. There are two kinds of mica, one white and the other black, but both are characterized by being in very thin layers which can be easily separated with the point of a knife blade. The hornblende is black, very hard, and usually occurs as more or less needle-like crystals.

The quartz contains only *silica*. The feldspar contains silica, alumina, potash, soda and smaller amounts of lime. The white mica contains besides silica and alumina, potash and the black mica, iron and magnesia. The hornblende contains silica, alumina, iron and magnesia chiefly. Very small amounts of a mineral called *apatite* which contains calcium and *phosphoric acid* are also found in granite. When the fresh granite rock is analyzed it is found to contain about 72% of silica, 16% of alumina, 6.5% of potash, 2.5% of soda, 1.51½% of lime, 0.5% of magnesia, 1.5% of iron oxide and very small amounts of phosphorus, chlorine and sulphur.

(25) Residual Soils. The action of frost, heat, water, especially when containing carbon, dioxide, plant roots, etc., tends to decompose the minerals of the granite. The rock is in this way decomposed and what can be dissolved is carried away in the water soaking through it. The quartz is not dissolved much but breaks up more or less and forms the sand of the soil. The feldspar, which forms a large part of the granite, gives rise to *kaolin*, the chief material in clay, while part of the silica and most of the potash, soda and lime it contains are dissolved and carried away. The iron and phosphoric acid are mostly left in the soil.

It will therefore be seen that the soil derived from granite differs very much in chemical composition from the rock. The chief differences are that the soil contains most of the silica, both as quartz sand and kaolin or clay, relatively more alumina, iron and phosphoric acid, but very much less potash, soda, lime and magnesia.

There is another class of crystalline rocks called *basalt*, which occurs north of the area of granite and in small areas within the granite region.

These rocks are similar to the granite but are black or gray in color and contain less silica, alumina and potash but much more iron and magnesia. The process of decomposition of the basalts is similar to that of the granite and the soil is similar though as the rock has little or no quartz there is very little sand in the soil.

The other two classes of rock, sandstone and limestone, are called *sedimentary* because they were formed from sediment deposited in the water of the shallow ocean which once covered a large part of the continent.

The sandstone was formed chiefly from sand derived from the quartz in the granite, with small amounts of undecomposed feldspar, mica and hornblende. This sand was deposited along the shore of the islands of granite rocks and as far out as the current of streams and waves could carry it.

The limestone was formed farther out from shore, partly as a deposit of what had been brought out in solution from the land and partly as the remains of the shells of mollusks, corals, etc. They therefore consist almost entirely of carbonates of lime and magnesia, but also contain small amounts of clay and fine silt which remained suspended in the water of streams running into the sea long enough to be carried out so far. This clay and silt, derived from the granite, contains the small amounts of potash, phosphoric acid and iron found in the limestone.

After these sedimentary rocks were raised above the

water the same agencies which act on the granite began to act on them. The sandstone on the surface was acted on by the frost and heat which tended to loosen the grains and leave them on the surface as sand.

The carbonate of lime and magnesia in the limestone is soluble in water containing carbon dioxide while the clay and silt is not soluble. The carbonate of lime and magnesia was therefore dissolved by the water and carried away while the small amount of clay and silt was left and collected as a layer of soil over the limestone. The amount of this clay and silt in the limestone is only two to eight per cent so that a layer a hundred feet thick of limestone would leave only two to eight feet of soil. Since this clay and silt soil left on top of the limestone originally came from the soil of the granite islands it is easy to understand why the soil from limestone and from granite are so much alike.

The soil on the granite, however, contains quartz grains, or sand which is coarser than any in the soil from the limestone, while the latter contains sharp, angular pieces of flint or chert.

These, then, are the kinds of residual soil we should find on the rocks of the state; clay on the granite and limestone, and sand on the sandstone.

(26) Alkali Soils. In regions where the rainfall is very light and is all evaporated, the salts formed by weathering are not washed out of the soil as they are in humid regions, but collect in the soil. These salts usually have an alkaline nature and the soils containing them are called *Alkali soils*.

(27) Glacial Soils. When we examine the soils of

most of the Northern part of the United States we find that they contain stones which are not like those found in quarries of the region, but are like those found in quarries at a distance north from one to five hundred miles. The soil also in many cases contains much more lime than residual soils. Geologists have shown that all this is due to a remarkable glacial ice sheet which collected in the region of Hudson's Bay and flowed south from the northern part of the United States and scraped off a great deal of soil from the rocks over which it passed and carried it to the country to the south. It brought blocks of granite and basalt away down to the southern part of the state and into Illinois. It ground off the limestone hills making a fine rock flour of it. The water formed when the ice melted sorted this material, carrying part of the finer portion far down the Mississippi river while gravel and sand were left as great terraces along the streams in the state.

Strangely enough, however, the ice flowed around a large area in the southwestern part of the state extending from a few miles west of Madison across the Mississippi river a little way into Iowa and Minnesota and from near Eau Claire south into northern Illinois. Within this unglaciated area the soils are derived from the limestone and sandstone underneath them and are therefore residual, while those over the area covered by the ice are glacial soils.

It will be seen that the character of the glacial soils depends very largely on the character of the soil and rocks over which the ice passed. In some regions in the northern part of the state where the rock was granite and the soil clay the ice removed the soil to a

considerable extent often leaving only a very thin layer over the granite rock.

In the southern and eastern part of the state most of the glacial soil contains ground limestone mixed with sand and clay. Throughout the area covered by the ice there are lakes, ponds and marshes resulting from its making undrained depressions in which the water accumulated.

It will be seen, therefore, that within the glacial area there is a very great diversity in the character of the soil. In the southeastern part of the state the glacial soil contains large amounts of lime carbonate while this has been almost completely dissolved away in the formation of the residual soils of the southwestern part.

(28) Wind Formed or Loess Soils. Over a large area in the Mississippi Valley is a kind of soil which is thought by geologists to have been brought to its present position by the wind. This soil, called *Loess*, is very fertile and covers large areas in Iowa, some in Illinois, Missouri and other states. In Wisconsin it occurs in the southeastern part of the state, extending in patches as far north as Chippewa Falls.

(29) Origin of Humus. The incomplete decomposition of vegetable matter, such as roots, leaves, etc., give rise to the black, waxy organic matter in soils, called *humus*. This part of the soil will be fully discussed in a later chapter.

(30) Soil and Subsoil. In many places in plowing or in digging, earth is turned up which is of a lighter color than that of the surface. The surface is made dark by humus, while its absence in the lower layer leaves it of a lighter color. Where this difference be-

tween the upper and lower layers is found, the surface is called the soil, and the lower layer the subsoil. Where, however, little or no humus is found in the surface it is still called the soil, but there is no distinction between the soil and subsoil. This occurs in most sandy regions and very generally in warm countries, even on clay soils, because the humus is largely oxidized.

CHAPTER III.

THE SUPPLY OF CHEMICAL ELEMENTS.

In Chapter I we have seen that all plants require certain chemical elements for their growth. With the exception of carbon dioxide, which is absorbed from the atmosphere by the leaves, and water, falling as rain, and, in the case of a leguminous plant, nitrogen which is absorbed from the air by certain bacteria in the soil, all of these elements are absorbed from the soil. We must now examine the soil carefully as a source of these essential elements.

(31) The Revolving Fund of Soil Fertility. The first thing to notice is that this material which is absorbed by the plants is used by them during their growing period, and that part of these materials which is not built up into the tissues of the plant is allowed to pass back out of the plant into the soil during the ripening stage as explained in paragraph 9. Moreover in the virgin condition the native vegetation falls to the ground and by decaying permits a large part of the material it contains to be reabsorbed by the fresh vegetation of the succeeding year. In this way it is seen that the soil is provided with a revolving fund of material which is used over and over again. When crops are removed from the land, however, this fund of revolving

material is gradually reduced and it is a well known fact that virgin soils under crop lose their fertility in a longer or shorter period unless this material is replaced in some form of fertilizer.

A small amount of the essential mineral elements becomes available from the weathering and decomposition of the rock particles in the soil each year and is absorbed by the growing plants and thereby added to the revolving fund. This, however, is in part counterbalanced by the leaching of small amounts of soluble material from the soil each year.

Under cultivated conditions a portion of the fertility of the soil is removed in products sold from the farm which may be either vegetable, as when grain or hay is sold directly, or animal, as in the bones and meat of fat stock or dairy products.

All of these relations are expressed in the accompanying illustration (Fig. 1).

A full understanding of the value of this rotating fund to soil fertility is of the utmost importance. While most soils contain a considerable supply of the essential elements, they can be thought of only as a store house from which but very small amounts may be withdrawn from year to year. The rapid growth of crops during the summer season must ordinarily be supplied almost entirely by the rotating fund. The vegetable matter left in the ground in the form of roots and stubble or returned in the form of manure is a very important portion of this rotating fund. It decomposes with sufficient rapidity to set free most of its content of the essential elements rapidly enough to supply good growth under favorable conditions, and not so rapidly

as to endanger serious loss by leaching before it can be absorbed by the crop. Moreover, this decomposition supplies the carbon dioxide which, absorbed in the moisture of the soil, acts as an acid on the inorganic or mineral portion of the soil causing this to decompose or weather. The action of the carbonic acid of the

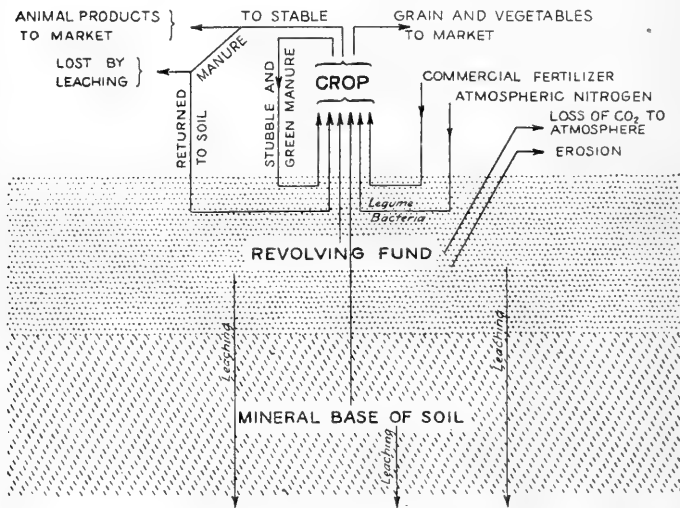


FIG. 1.—Indicating the factors which influence soil fertility.

soil is most rapid on limestones or lime carbonate in the soil, which is rapidly removed by leaching into the deeper waters, such as are drawn on by wells and into streams. This latter process is to a certain extent injurious, since soils from which the limestone has been in this way largely removed become acid and unsuitable for certain helpful bacteria, as will be seen in a

later chapter. Besides the vegetable portion of the revolving fund in the soil there is a considerable amount of various salts which are quite readily soluble in water, and yet are held physically by the fine soil grains, so that while they can be absorbed gradually by the fine root hairs of plants they are not readily leached out. Fertile soils subjected to percolation will continue to give up appreciable quantities of soluble matter until several times their volume of water has been allowed to percolate through them. This matter is probably held by the attraction of the soil grains, so that the moisture of the soil is in a more highly concentrated condition in the layer in contact with the soil grains than it is at some distance out from the surface of the soil grains.

(32) Limiting Factors in Soil Fertility. While all of the essential elements mentioned in Chapter I are absolutely necessary for the growth of crops, it is true that a few of them only are apt to be deficient in ordinary soils. Others are generally so abundant that we need give no particular care concerning them. Nitrogen, phosphorus, and less often potassium are in some soils so deficient that they must be given especial attention by the farmer, and they will therefore be discussed fully in succeeding chapters. The condition of acidity, referred to above, has a particular bearing on the fixation of nitrogen in the soil by bacteria and will therefore be discussed in a chapter on that subject.

Since all plants must be supplied with all of these essential conditions before satisfactory growth can occur, it is evident that failure in any one respect becomes critical. It is very commonly true that the maxi-

imum yield of any particular field is determined by some one factor which thereby becomes the *limiting factor* for that soil. This may be the supply of the element nitrogen or phosphorus or potassium, the amount of moisture available, or of oxygen in a highly saturated soil, or the temperature during a cold season or in a cold

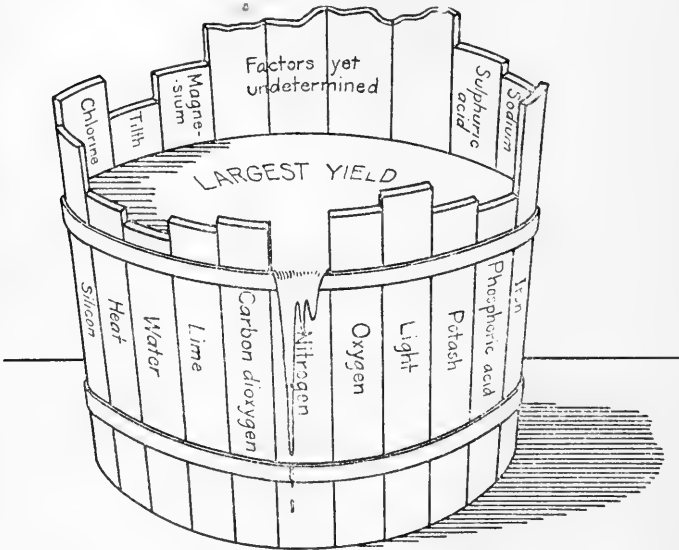


FIG. 2.—Illustrating the principle of *limiting factors* in soil fertility.

climate, or other factors. This relation is expressed in figure 2 devised by Dr. Dobenecks. The amount of water which the barrel can hold is determined by the height of the lowest stave. If the length of this stave is increased then the next shortest stave will determine the capacity of the barrel and so

on until all are of equal length. The same relation holds among the factors determining the fertility of the soil. Supplying a certain element which at one time is the limiting factor will increase the yield and if all the other conditions have been very favorable the increase in the yield from supplying the single factor may be very great. If, however, there are one or more other factors which are also low in value then they must in turn be improved before the highest yields can be reached.

CHAPTER IV.

HUMUS.

If you examine the soil grains closely you will find that they are usually coated with a black, waxy substance, largely organic in nature, which we call humus. In addition to this true humus, which has been formed by the partial decay of organic material returned to the soil, there is vegetable matter in practically all stages of decomposition, from that almost entirely undecomposed, to that which we call true humus.

(33) Composition of Humus. If humus is subjected to a chemical analysis, it will be found to contain the elements carbon, hydrogen, oxygen, and nitrogen, with small amounts of potash and phosphorus. If the composition of humus is compared with the composition of fresh organic matter, you will discover that the making of humus from fresh organic matter has meant an increase of carbon and nitrogen and a decrease of oxygen and hydrogen. There is reason to believe that not all of the fresh organic matter returned to the soil ever goes through this complex process of oxidation. Most organic matter oxidizes too rapidly to contribute anything to this store of inert, waxy material that we call humus. It has taken ages and generations for a very small residue of incompletely oxidized organic matter

to accumulate, and form true humus. The various kinds of partly decomposed vegetable matter in the soil grade into each other so gradually, however, that it will be best for us to consider it all under the general term humus.

(34) Rate of Decomposition of Vegetable Material. We may have vegetable matter decomposing so rapidly in the air, if ignited, that we call the process combustion, or rapid burning. In this manner thousands of tons of straw were destroyed during the early farming days in the middle West. The rate of decomposition in the soil leading to the making of humus varies greatly. The principal factors affecting the rate of humus-forming are (1) access of air, (2) temperature, (3) kind of vegetation, (4) reaction of the soil.

(35) Access of Air. The rate of decomposition of vegetation usually increases as the amount of water in the soil decreases. If the vegetation grows on very wet ground, as in a marsh, and on falling down, is largely covered by water which excludes the air, it will decompose very slowly. Indeed if it is kept entirely covered with water, it may remain almost entirely undecomposed and collect as peat. If the marsh becomes partly dried a part of the year, then the material will partly decompose and form muck. If the vegetation grows on land which is comparatively dry most of the year, then it may decompose more completely to form the true humus coating the mineral particles of the soil.

It is generally known that very sandy soils contain little humus, for the air can penetrate so rapidly and so completely that the humus is almost entirely decom-

posed. The low water-holding capacity of sands makes them drier, hence less vegetation accumulates, and correspondingly less material is available for humus forming.

(36) **Effect of Temperature.** High temperatures promote rapid oxidation of organic material, and low temperatures retard the process. This explains the difficulty that farmers in warm countries have in maintaining a supply of humus. This fact should also lend confidence to farmers in the cooler climates in their efforts to maintain a supply of humus. Oxidation of the vegetable material in soil is so rapid in many of our Southern states that it is absolutely essential to turn under green manuring crops practically every year.

(37) **Effect of Kind of Vegetation.** Sphagnum moss, and other mosses, such as grow in the marshes of Wisconsin decompose very slowly, while, on the other hand, the tissues of such succulent plants as peas, rape, etc., decompose very rapidly. Different portions of the same plant resist decomposition differently, thus leaves and fleshy stems decay quickly, while the fine woody roots decompose slowly. Hence it is that in forests, the fallen leaves decompose so rapidly, while the roots of the prairie grasses decompose slowly. Of course, in the forest the leaves, being on top of the soil are more exposed to the air than the roots of the prairie grasses growing in the rather poorly drained soil of a level country. The difference between prairie and forest is so pronounced that on prairies we find deep black soils, humus coating the soil grains often to the depth of several feet, while in the forests, especially in the up-

lands, we find light colored, shallow soils, the humus coating extending to the depth of only a few inches.

(38) Reaction of the Soil. Sour or acid soils possess such antiseptic properties that decay goes on very slowly. Thus many of our peat marshes are so highly acid that complete neutralization is impossible with moderate amounts of lime. On such soils, crops must be found that can adapt themselves to an acid condition of the soil.

(39) Function of Humus. Some one has said that "Humus is the life of the soil." Let us therefore inquire into the ways in which humus benefits the soil. Bulletin 135 of the Vermont Experiment Station summarizes these benefits in the following brief statement:

Humus serves

1. As a nitrogen supply,
2. As a mineral plant food supply,
3. As a store house for water,
4. As a source of warmth,
5. As an improver of texture,
6. As an aid to bacterial and other micro-organic growth in the soil.

(40) Nitrogen. We have previously pointed out that the process of humus making from fresh organic matter has meant an accumulation of nitrogen. The method by which this humus nitrogen becomes available to plants will be discussed in chapter VI.

(41) Mineral Plant Food in Humus. Practically all plant residues returned to the soil contain mineral plant food, originally obtained from the soil. The portion of the vegetable material, which is quickly oxidized, and does not go to form the inert, structureless humus,

yields up its ash content readily. It is this rapid availability of the ash content of plant residues that helps maintain the revolving fund discussed in a previous chapter. Some of the material thus quickly set free may be lost to the subsequent crops by leaching, or by other processes. When, however, the potash and phosphoric acid of the decaying vegetable matter, enter into the more or less "tight" waxy humus compound, it is probable, because of the difficulty in oxidizing this true humus that the ash content becomes very slowly available, if at all.

It is held by some investigators that the humus in the soil may act as an acid and combine with the mineral elements from the soil grains to form humates, which although not directly soluble in water, may decompose and become available to plants. The true chemical nature of humus is so little understood, however, that it is impossible to make definite statements concerning the action of the so-called humus acids.

Again, the oxidation of both true humus, and of unhumified vegetable matter, sets free carbon dioxide, which combines with the soil water to form carbonic acid, a very powerful solvent of soil minerals. Thus it is that addition of manure benefits the soil in two ways, in the plant food that it itself contains, and the plant food that, by its decay, is set free from the soil grains.

(42) Humus and Water-Holding Capacity. The black waxy coating of soil grains becomes somewhat gelatinous when wet, and like all such bodies, has the power of absorbing large quantities of water. It is hardly necessary to state that the high water-holding

capacity of our muck and loam soils is due to their high content of humus. Hilgard has pointed out that "Dry humus swells up visibly when wetted, the volume weight increasing to the extent of two to eight times; so that humus stand foremost in this respect among the soil constituents." This power of humus to retain moisture will be referred to again in connection with the general subject of water-holding capacity of soils.

(43) Effect of Humus on Temperature. Humus is able to affect the temperature of the soil in two quite distinct ways. In the first place, humus is a black material, so that an abundance of humus means that more heat will be absorbed from the sun, black colors being able to absorb more heat than lighter colors. In the second place, the various decay and oxidation processes, incident to the destruction of vegetable matter in the soil, give rise to considerable heat. We have all noticed this same process in the fermentation and heating of a manure heap, although, in such a case much more heat is evolved, and higher temperatures reached in a limited amount of material, than in the same amount of soil. The same amount of heat is evolved in the decay of the manure when spread over an acre of soil, but since it is spread out so thinly we are not able to detect the rise of temperature.

(44) Improver of Texture. The humus coating of the soil grains causes them to adhere to one another, so that, instead of a soil being made up of an infinite number of isolated soil grains, it is made up of groups of soil grains or *soil aggregates*, as they are sometimes called. The development of this crumb structure is particularly noticeable in soils containing large amounts

of true humus, such as our loamy soils. Further, we find this crumb structure disappearing from soils, as the humus is destroyed by poor methods of farming.

(45) Aid to Growth of Microscopic Soil Organisms. Our soils contain thousands of tiny organisms, such as bacteria and moulds. These bacteria and moulds depend upon the vegetable matter in the soil for their food supply. The soil organisms perform an immense amount of work in helping to bring about the decay of the plant residues returned, therefore they must obtain the necessary energy for this work from the oxidation of this vast organic food supply. Different organisms attack different kinds of vegetable matter or different elements in it, but there is such a complex array of material at hand, that each different organism finds a suitable food supply.

(46) Loss of Humus. We have mentioned various ways in which humus benefits the soil. Let us now inquire into how humus may be lost, so that we may learn to avoid such methods. Probably the single greatest cause of loss of humus is in the continuous growth of tilled crops. Determinations made at the Wisconsin Station, show that when a tilled crop, such as corn or tobacco has been grown for a period of 10 to 25 years continuously that there has been no increase in the total vegetable matter in the cropped soil as compared to the amount in a comparable virgin soil even though large amounts of manure have been annually returned to the soil. Several cases show an actual decrease in the amount of organic matter in the soil. When, therefore, there is an addition of manure, or some other vegetable matter, how great must be the total loss! In fact we

find many cases, where excessive tillage and cropping has reduced the supply of vegetable matter in the soil from 5 or 6 per cent to a few tenths of a per cent. It should be pointed out here that a mere avoidance of tilled crops will not maintain a humus supply, for a rotation of only cereal crops is also destructive.

The rate of loss of humus, is, of course, affected by the type of soil, sands losing their humus much more rapidly because of the easy entrance of air, than other soils.

Humus is also destroyed by great forest and prairie fires, but these sudden losses of humus are certainly not as alarming, as the slow, insidious oxidation in tilled soils.

(47) Maintenance of Humus. Since humus may be lost so readily, it is necessary to know what practices will aid us in maintaining and increasing our supply of humus. The current farm practices tending to keep up the humus supply are as follows: (1) Maintenance of permanent pastures and meadows, (2) green manuring, especially with the clovers and other legumes, (3) use of farm manures, and (4) crop rotation.

(48) Permanent Pastures and Meadows. The growing of such crops as the grasses, especially Kentucky blue grass, fills the soil full of tiny roots. Virgin prairie soils often contain 8 to 10% of total organic matter, which has accumulated because of the large amount of roots present. Similarly, soils that have been kept in pasture, or meadow, for a considerable number of years are not found to decrease to any great extent in their total organic matter, especially if such fields are supplemented with top dressings of the min-

eral, fertilizers. This supplementary top dressing is often practiced in England which is noted for the fertility of her permanent pastures. On meadows, where the hay crop is annually removed, the humus supply will decrease more rapidly than in the permanent pasture, but this may be avoided by occasionally turning under a green crop.

(49) Green Manuring. In Circular 120 of the Illinois Experiment Station, Dr. Cyril G. Hopkins states that the humus in Illinois soils must be maintained by plowing under manure, or clover and crop residues. In comparing green manuring with farm manure, he makes the following significant statement:

“As an average animal digests, and thus destroys, two-thirds of the dry matter in the food they eat, so that one ton of clover hay plowed under will add as much humus to the soil as the manure made from three tons of clover hauled off and fed, even if all the manure is returned to the land without loss by fermentation.” The above striking illustration emphasizes the fact that we are not returning every thing to the soil, no matter how carefully we handle our manure supply.

The crops used for green manuring should be the leguminous crops such as clover, alfalfa, and where adapted, such legumes as the vetches, lupines, serradella, cow peas, and soy beans. These crops are recommended for use because of their power of obtaining nitrogen from the air through the agency of the bacteria inhabiting the tubercles, or nodules on their roots. If clover does not thrive well, and other conditions are suitable, it is probable that the soil is acid, which condition should be corrected by the use of ground lime-

stone, marl, or slacked lime. Certain legumes seem to thrive in acid soils, and should be used as green manures on those soils, provided it is impossible, or unprofitable to correct the acidity of such soils.

(50) Farm Manures. Farm manure consists largely of vegetable matter, and as such, aids in restoring humus, but as has been pointed out this partially decayed material, is in an easily oxidizable condition, so that only a small portion accumulates as true humus. This seems to be especially true where excessive amounts of manure are used on tilled crops without rotation. The use of smaller amounts of manure, spread over larger areas is the economical way to apply manure.

(51) Crop Rotations. Crop rotations alone will neither maintain nor increase the supply of humus in the soil. A crop rotation which consists merely of a succession of corn and oats, or of a rotation of various cereals is not calculated to build up humus. On the contrary a rotation which embodies the practices heretofore mentioned, pasture, meadow, turning under of a green manuring crop, and an intelligent use of farm manures with the various crops raised, is calculated to maintain or even increase the supply of humus. The proper combination of these practices will have to be worked out by the individual farmer on his own soil, under the particular set of conditions operative on his farm.

CHAPTER V.

ACIDITY AND LIMING.

(52) **Prevalence of Acid Soils.** Sour or acid soils are to be found in widely separated parts of the earth. We have descriptions of the "sour land" of Alaska, the sour "veld" of South Africa, the "Säure Sandboden" of Germany, the acid sandy soils of France, the acid uplands of Rhode Island, and the acid marshes and uplands of Wisconsin, and they undoubtedly exist in many places not yet described. Neither is acidity confined to any particular type of soil. Tests in Wisconsin have shown the existence of acidity in both virgin and cultivated soils; in clay, sand, clay loam, and marsh soils.

(53) **Test for Acidity.** So important is the recognition of soil acidity as a factor in soil fertility that Hilgard says, "A test never to be omitted is that of the reaction of soil on litmus or other test paper to ascertain its acid, neutral, or alkaline reaction." The litmus paper test for acidity is performed as follows: Having procured a few pieces of sensitive blue litmus paper from a drug store, place the paper between portions of moist soil, allow the paper to remain in contact with the moist soil about five minutes, then remove the paper and examine for red spots. Any reddening

of the test paper indicates an acid soil. The test should be performed shortly after a rain before the soil becomes too dry. The use of well or cistern water to moisten the soil should be avoided, for such water may be either acid or alkaline, so that its use would lead to wrong conclusions. Avoid touching the litmus paper with the hands as much as possible for the natural moisture of the hands is ordinarily acid.

(54) Origin of Acidity. Results in Wisconsin point to two kinds of acidity, namely, that developing in the peat marshes, and that developing on the uplands and prairies of the state, especially in soils that have been cropped for a comparatively long time. Soils like the peat marshes contain large amounts of vegetable matter, which, in decaying sets free organic acids. This acidity prevents rapid decay of the vegetable matter, and the peat therefore accumulates.

The cause of acidity in upland soils is not so well understood. It is, of course, always associated with a lack of lime in the soil. It is probable that in the absence of sufficient lime, the oxidation of the vegetable matter in the soil gives rise to acids. A combination of causes may be at work, including the development of small amounts of mineral acids, and their acid salts. The use of ammonium sulphate, as a nitrogen fertilizer, unless supplemented with lime, has also been found to cause acidity. The primary fact to be remembered in connection with acidity is that it means a lack of lime in the soil.

(55) Harmful Effects of Acidity. 1. It hinders nitrogen fixation by the legumes, and is therefore espe-

cially harmful when such crops as clover and alfalfa are to be grown.

2. It makes the process of nitrification very slow (See Chapter VI), although nitrification may progress, if there are large amounts of organic nitrogen present, as in peat soils. On such soils applications of lime hasten nitrification.

3. It is commonly associated with, and is undoubtedly related to a deficiency in available phosphates (See ¶ 77).

4. It favors the growth of certain acid tolerating weeds, notably common sorrel, and the horsetail rush.

In considering the effect of acidity alone we must be careful not to ascribe to acidity certain harmful effects that may be due to lack of drainage, or absence of available phosphates.

(56) Effect upon Different Kinds of Plants. Not all plants are injuriously affected by an acid condition of the soil. One of our weeds, usually known as the common sorrel (*Rumex acetosella*) prefers acid soils, and its presence is practically a sure indication of an acid condition. The presence of the common horsetail rush (*Equisetum*) also indicates acidity. Cranberries and certain of the marsh grasses are also able to thrive under acid conditions. Of the cultivated crops, red clover, alfalfa, and sugar beets are peculiarly sensitive to acidity, while corn, oats, potatoes, and alsike clover are not so badly affected. Alsike clover has often made a good stand on fields too acid for the growth of red clover. Large yields of potatoes have been obtained on acid soils, where of course there were suitable amounts of potash and phosphate present.

(57) **Remedial Treatment for Acid Soils.** The treatment for acid soils universally recommended is the application of lime, provided, of course, that such treatment may be expected to yield a profit upon the investment. The forms of lime available to the farmer are ordinary quick lime, ground limestone, marl, and various by-products, such as lime refuse from sugar beet factories, marble dust, and shell refuse. The Rhode Island Experiment Station has shown that partial neutralization of the acid in the soil is often as effective as complete neutralization.

(58) **Lime.** Ordinary lime (the commercial product) should be applied in the water or air slaked form during the fall since it would be injurious to the seed if applied at the time of planting, or even shortly before. For the lighter soils, such as sands and sandy loams, apply at the rate of 10 to 15 bushels fresh lime (equivalent to nearly twice that of water or air slaked lime) per acre. For the heavier soils, such as the clays and clay loams, 25 to 30 bushels of fresh lime may be used. It is essential that the lime should be well slaked in order to avoid any caustic action upon the humus in the soil. For this reason, ground limestone, where the lime is in the carbonate form, is preferable to ordinary lime. If possible, the lime should be applied with some form of fertilizer drill, to insure an even distribution over the field. It should be applied after plowing and then be thoroughly mixed with the soil by harrowing. If it is not desirable to harrow the field, the lime may be left on the rough furrows.

(59) **Ground Limestone.** When available, ground limestone is to be preferred to lime, especially for the

lighter soils, or for soils very low in vegetable matter. Limestone ought to be the cheapest form in which to supply lime. Heavy applications, from 1,000 pounds to a ton per acre should be used. It is best applied in the fall before seeding to clover. This application should be repeated every fourth or fifth year, in order to maintain a good supply of lime carbonate in the soil. The limestone should be so finely ground that three-fourths of it will pass a 40-60 mesh sieve. If much coarser than this heavier applications can be used, but this is unprofitable where a long haul is necessary.

(60) **Marl—Lime Refuse.** Wherever deposits of marl occur these should be utilized, for marl usually contains a high percentage of lime carbonate. If the marl is thrown out, and partly dried, so that it crumbles readily, it can be applied at the same rate as ground limestone. Lime wastes from sugar beet factories are available, if properly dried, so that they can be spread evenly over the fields.

CHAPTER VI.

NITROGEN.

(61) Amount and Kinds of Nitrogen in the Soil.

Determinations at the Wisconsin Station of the amount of nitrogen in 21 samples of cropped clay loam soils showed an average of .106%, or 2,120 lbs. per acre 8 inches, while corresponding virgin soils contained .169% or 3,380 lbs. per acre 8 inches. Wisconsin peats usually have about 3% nitrogen, but since they are light soils, that amounts to only 1,100 lbs. per acre eight inches. Sandy soils vary in their nitrogen content depending upon the amount of organic matter present. Some sands run as low as .05% or about 100 lbs. per acre 8 inches up to as high good clay loam soils. Constant cropping may deplete the nitrogen in clay soils to the amount found in poor sands.

Most of the nitrogen in the soil is present as humus nitrogen, derived from the decay of vegetable matter. Under normal conditions all soils contain varying amounts of nitrate nitrogen, as well as a small quantity of ammonia compounds. Before humus nitrogen is formed, the fresh vegetable matter containing protein, the principal nitrogenous substances in all plants, must pass through various stages of oxidation and decay. These stages constitute the nitrogen cycle.

(62) **Nitrogen Cycle.** Nitrogen is one of the most important elements in plants, and although it constitutes four-fifths of the air, it is not available to most plants in that form. Most plants take their nitrogen from the soil in the form of nitrates.

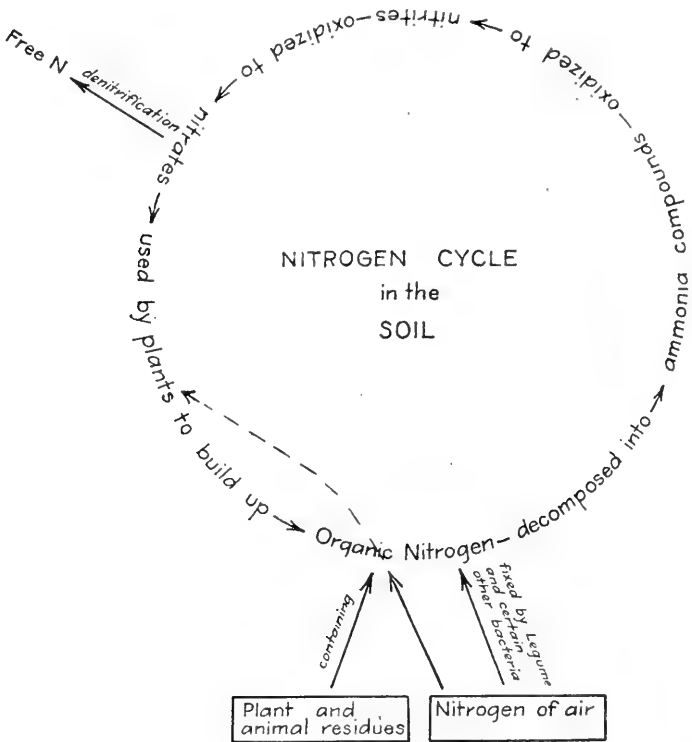


FIG. 3.—The Nitrogen Cycle in the soil.

When plants die their dead roots, stalks, leaves, and fruit are returned to the soil, where their decomposition is brought about through the agency of molds, bacteria, and other low forms of plant life. Of course plants may be used to feed animals, but even then we have a great residue of partially oxidized vegetable matter returned to the soil as manure. These various forms of nitrogen-containing vegetable matter cannot be used directly by the plant as food, but must undergo a process called nitrification. This nitrification or building of nitrates is carried on by bacteria in the soil. The process consists of three stages (see cycle in accompanying diagram), a different set of bacteria being at work in each stage. We first have the ammonifying bacteria converting the humus in the soil into ammonia. This ammonia then furnishes a food supply for the nitrite bacteria, with the resulting formation of nitrites, while a third class of bacteria use the nitrites as food, thereby producing nitrates. These nitrates are what the chemist calls a salt, that is a compound of a mineral element and an acid, the acid in this case being nitric acid. In fact, the nitrate bacteria do not actually build nitrates but build instead nitric acid, this then immediately unites with a mineral element, usually calcium, magnesium or potassium, to form nitrates. These nitrates are readily soluble in water and are therefore easily taken up by plants.

(63) Factors Influencing Rate of Nitrification.

The principal factors influencing the building of nitrates are as follows:

- (1) Aeration.
- (2) Temperature.

(3) Moisture.

(4) Reaction of the soil.

(5) Character of the humus.

(64) Aeration. The soil bacteria that form nitrates require an abundance of oxygen, and are therefore largely confined to the first four or five feet of soil. Nitrification is more rapid when the soil is loose enough to allow access of air than when too compact. Cultivation of the surface soil therefore promotes nitrification. In order to insure good aeration of the soil, we must have good drainage, for an excess of water excludes the air. Excess of moisture and absence of air in fact cause loss of nitrates, as will be shown in paragraph 74.

(65) Temperature. Nitrification is hastened by warm temperatures. The rate of nitrification is twice as great at 70° F. as at 50°, and twice as great at 90° as at 70°. The factors influencing soil temperatures will be treated under that head (See Chapter XI). Very low temperatures arrest nitrification, so that for example, but little nitrate is formed during the winter in a climate like that of Wisconsin. In warmer climates, as in our southern states, humus nitrogen is quickly changed to nitrates and may be leached out of the soil by heavy winter rains. In order to prevent this loss cover crops are sown to absorb the nitrates and thus hold them for the next summer's crop.

(66) Moisture. The most favorable amount of moisture for nitrification is that amount most favorable to the growth of crops. When all the space between the soil grains is full of water, as in saturated soil, no air can get to the nitrifying bacteria and they become in-

active. Excessive amounts of moisture, such as we have in undrained lands, favor the growth of certain bacteria, called denitrifiers, which have the power of setting free gaseous nitrogen from nitrates.

(67) Reaction. Nitrification is probably most active in a slightly alkaline soil. The nitric acid produced also requires some base such as lime, to neutralize it, in order that nitrates may be formed. Nitrification is not entirely prevented under acid conditions of the soil, for we have some acid peat soils that are well able to supply the necessary nitrate to their crops. A sufficient supply of potash and phosphate is as essential for the growth of these nitrate forming bacteria as it is for the higher plants. We must be certain that all other conditions are at their best before we can safely assert that any one factor is limiting nitrification.

(68) Character of the Humus. The development of nitrates also depends very much upon the character of the humus and vegetable matter in the soil. Some humus is readily acted upon, while the remainder is only slowly used. For this reason, when a piece of land is cropped several years without the addition of manure the humus most easily acted on is used first, and nitrates are formed rapidly; while after a few years, when this has been used up, the process of nitrification becomes much slower, and crops suffer for want of available nitrogen. Fresh succulent vegetable matter, like that turned under in clover, is easily transformed into nitrates so that a clover sod when plowed and cultivated usually becomes rich in nitrates.

(69) Close Use of Nitrates by Plants. The extent to which plants can reduce the nitrate supply in

the soil is appreciated when we compare the amount of nitrate in the soil under a rapidly growing crop, and the amount in an adjacent fallowed plot of soil. Bulletin 93 of the Wisconsin Experiment Station states that on July 9 the ground under oats contained 3.32 lbs. of nitrates per acre in the first foot of soil, while adjacent fallowed soil contained 57.8 lbs. per acre in the first foot. Plants quickly respond to a poor nitrate supply. Every farmer has noticed the yellowing of corn plants after a few days of cold, wet weather. The cold, wet weather causes a slow rate of nitrification, or even loss of nitrates, so that the corn is deprived of an essential part of its food supply and consequently turns yellow.

(70) Nitrogen Fixation. The diagram on page 48 indicates that certain plants, the legumes, can obtain nitrogen from the air. Nitrogen gathering bacteria inhabit the tubercles, or nodules, which develop on the roots of the clover, alfalfa and other plants of the legume family. The nitrogen of the air is transformed by these bacteria into organic nitrogen. Whether this organic nitrogen is directly absorbed by the plant, or whether it first passes through all the stages of oxidation, as does organic nitrogen from other sources, is not known. The diagram indicates this uncertainty by the use of two arrows proceeding from the words "Nitrogen of the Air," one indicating the ordinary route, the dotted arrow indicating the possibility of the direct absorption of the organic nitrogen by the plant.

Some nitrogen is fixed in the soil by bacteria not attached to the roots of plants, but the amounts of nitro-

gen fixed by these bacteria under actual soil conditions is not known. The distribution of these organisms, and their importance, is at present engaging the attention of many soil bacteriologists. The diagram used also includes this class of bacteria.

(71) Amounts of Nitrogen Fixed. Plots of land at the Rothamsted Experiment Station growing legumes, such as clover, vetches, and alfalfa for 21 years continuously had 757 pounds per acre more nitrogen than a similar plot in wheat for the same time. Ordinarily a crop of clover may be expected to add forty pounds of nitrogen per acre foot to the soil the first year, and 75 to 100 pounds more the second year, besides what is taken off in the hay crop. This, if changed without loss into nitrates, would be enough for a good crop of grain, corn or potatoes. It must not be forgotten, however, that clover and other legumes take other elements from the soil just as other crops do, so that fertilizers containing potash and phosphoric acid, especially the latter, must be used if clover or other legumes are to be grown continually. Many soils do not contain sufficient available phosphoric acid for a maximum crop of clover.

(72) Conditions Favoring Nitrogen Fixation by Legumes. In order to obtain the maximum amount of nitrogen from the air, when growing clover, or other legumes the soil should have

- (1) good drainage,
- (2) a neutral or slightly alkaline reaction which means an abundant supply of lime.
- (3) an abundant supply of all the essential elements, especially of phosphoric acid.

(4) and a suitable inoculation with the bacteria associated with the particular legume to be grown.

(73) Soil Inoculation. After the first three of the above conditions have been provided we must still be sure that our soil is well inoculated. In this part of the United States it is hardly necessary to inoculate the soil for the growth of common red clover. Many soils, however, are not adapted to alfalfa and other less common legumes because of this lack of inoculation. The upland acid soils of Wisconsin rarely contain the necessary alfalfa organisms. Various forms of artificial inoculation of the soil by so-called "liquid cultures," "Nitragin," and "dried cultures" have been tried, but none have been successful enough to be called practical although better results are constantly expected. The only practical method of inoculating the soil is the actual transference of some soil from a field that has previously grown the legume. In the case of alfalfa, inoculation with soil from patches of sweet clover is equally effectual. If a small portion of a field is well inoculated, soil will then be at hand for inoculating the remainder of the farm. After a new legume is once started, farm operations of cultivating, plowing, etc., soon spread the bacteria. Where it is impractical to inoculate with soil, alfalfa, for example, has often been finally successfully grown by constantly seeding small portions of alfalfa with the clover. Success in this case depends upon the fact that some of the alfalfa seeds have a few of the necessary bacteria clinging to them and thus some of the plants are inoculated. If this procedure is kept up, the inoculation will soon spread.

(74) **Losses of Nitrogen.** Nitrogen may be removed from the soil by

1. Leaching,
2. Cropping,
3. Denitrification.

Any treatment of the soil which promotes nitrification causes a loss of nitrates by leaching. Soils constantly cultivated are therefore more subject to this loss than soils kept in sod. Losses by leaching may be considerable and are probably relatively greater in a soil kept in a high state of fertility than in soils in a moderate state of fertility.

In a study of the nitrogen content of virgin and cropped soils, reported in the 23d Annual Report of the Wisconsin Station, the conclusion was reached that in clay loam soils of moderate fertility more than four-fifths of the nitrogen lost is removed by crops. Recent results obtained at the same station indicate that there is a considerable loss of nitrogen above that removed by crops, when soils have been fertilized with large amounts of barnyard manure, and have been cropped without rotation to some intensive crop, like tobacco or other truck crops.

Denitrification, as indicated in the diagram, consists chiefly in the loss of gaseous nitrogen from the nitrate-nitrogen in the soil. The bacteria causing denitrification do not require the oxygen of the air, but obtain their oxygen from the soil nitrates. These bacteria are inactive when the soil is well aerated. Poor drainage, and consequently little aeration, and insufficient cultivation, or cultivation when the soil is too wet, tend to promote denitrification. It is difficult to measure losses

by denitrification under actual field conditions, and such losses have probably been over-emphasized.

It is evident that the nitrogen content of soils is profoundly affected by the method of farming. The nitrogen containing substances in the soil are constantly undergoing changes, and at practically every stage are subject to losses unless used by the crops.

(75) Nitrogen Fertilizers. The two most important sources of soil nitrogen are that obtained from the air by legumes, and barnyard manure. When we recall that nitrogen in artificial manures is rated at 15 to 18 cents per pound, we can appreciate how invaluable are these two sources of nitrogen. Average barnyard manure contains about five-tenths per cent of nitrogen. Using the above valuation, a ten ton application of manure per acre, or the nitrogen remaining in the soil as the result of a good crop of clover is worth eighteen dollars.

The important commercial nitrogen fertilizers are sodium nitrate (Chile salt peter), ammonium sulphate, obtained as a by-product in the manufacture of coke and gas, dried blood, and other packing house products, and electrically fixed nitrogen, the latter not of commercial importance in the United States as yet. It should not be forgotten that all of these artificial fertilizers are expensive, and that nitrogen can be obtained from the air practically without cost.

Salts like sodium nitrate and ammonium sulphate are very soluble in water, and therefore tend to leach out of the soil, unless the crop is at hand to absorb them. Ammonium sulphate is retained by the soil more completely than sodium nitrate. These fertilizers are particularly

adapted to forcing the truck crops. Grass crops, which always tend to reduce the nitrate supply in the soil to a small amount, respond quickly to applications of such fertilizers. In order to avoid losses by leaching, these salts are applied at different times during the growing season. Seventy-five pounds per acre is the lowest quantity of these salts usually applied, while this quantity may be increased to 150 or 200 pounds per acre, depending upon the crop, and the condition of the soil.

Dried blood is ordinarily applied at the rate of 300 to 400 lbs. per acre. Dried blood becomes available to the plants more slowly and therefore there is not so much loss by leaching.

The great peat marshes of Wisconsin furnish an important nitrogen fertilizer. Peat may contain from two to three per cent of nitrogen in the dried condition, and is well adapted to use on sandy or clay soils. It should be partly dried so that it will spread easily, and then should be applied at the rate of at least 20 loads to the acre.

CHAPTER VII.

PHOSPHORUS AND POTASH.

PHOSPHORUS.

(76) Occurrence and Amount of Phosphorus.

The element phosphorus occurs chiefly in the mineral apatite in practically all rocks from which the soil grains are formed. It is customary to report the amount of phosphorus in the form of phosphoric pentoxide (P_2O_5), although it is not intended to imply thereby that the phosphorus is absorbed in this form by plants or exists in this form in the rock. It usually, as a matter of fact, exists as a chemical compound of calcium, iron or aluminum. The total amount of phosphoric acid (P_2O_5) in most soils varies between .05 and .25 of a per cent though not infrequently soils are met which contain less than .05 of a per cent and a few which contain more than .25. From this it will be seen that the total quantity of this element in many soils is so small that a comparatively small number of crops, if entirely removed from the land, would exhaust the original supply. Moreover this element occurs in those substances in the plant, chiefly in the grains of cereals, which are used directly for human food or indirectly through animals and later used as human food and thereby removed from the land. It is therefore abso-

lutely necessary to return this element to the land in some form as fertilizer.

(77) Soil Acidity and Availability of Phosphates. While the total supply of this element in most soils is sufficient for a considerable number of crops, it often becomes available too slowly to permit a good growth. This is particularly true in soils which have become acid. In fact it can be set down as a rule that acid soils are deficient in available phosphorus and a test for acidity (see paragraph 53) becomes a ready method for determining the needs of the soil in this respect. Just what the explanation of this fact is has not yet been determined. It is possibly because the calcium carbonate of the soil has been largely removed, so that it is not present to aid in the formation of calcium phosphates which are more readily soluble and available to plants than iron and aluminum phosphates which are not removed by the acid condition.

(78) Classes of Soil Deficient in Phosphorus. Lack of available phosphorus in the soil is found to exist first in very acid marsh soils and second in upland well drained soils which have become exhausted and have usually become acid after a considerable portion of the rotating fund of available material has been removed by a longer or shorter period of cropping.

In the case of the acid marsh soils, usually of a peaty nature, the acidity is frequently present to such an extent that it would be impracticable to neutralize it by any form of lime. In this case it is necessary to supply the phosphorus in an available form every year or in a form which will become available gradually and be taken up by succeeding crops. In the case of up-

land soils it is usually desirable to neutralize the acidity in order to secure better growth of legumes, as has been explained in paragraph 55, and the lime for this purpose will undoubtedly be helpful in retaining the phosphorus in the form of calcium phosphate. It is, however, necessary to supply this element as a fertilizer to maintain good growth on many of the upland clay loam soils, ordinarily of high fertility, after they have had from $1\frac{1}{3}$ to $1\frac{1}{2}$ of their total original supply of this element removed by a period of from forty to sixty years of grain farming.

(79) Influence of Method of Farming. Since the element phosphorus goes chiefly into the grains of cereals, a system of farming in which the grains are sold directly is most exhaustive in its effect on this element in the soil. On the other hand, where these grains and other parts of the plant are fed to stock on the farm a considerable portion is returned directly to the land in the manure. The amount sold from the farm in animal products varies considerably. Where only butter is sold the amount is reduced to the minimum. Where milk is sold a very important amount of phosphorus is removed from the milk and where fat stock, the bones of which contain a large amount of phosphorus, are sold the amount removed is very considerable. Moreover unless great precaution is taken a considerable amount of the phosphorus of the manure is lost by leaching before it is returned to the land. When carefully handled the loss need not be allowed to exceed 10 per cent of that in the manure, but where there is much leaching it may be 25 to 30 per cent or more. Where considerable quantities of feed are purchased for

consumption on the farm the loss in animal products by leaching of manure may be counterbalanced or even more than equaled so that a gain actually results. However, it is only on the very highest types of dairy farms that this takes place. The following tables are drawn up to show the income and outgo of phosphoric acid from a general grain farm and from a good average dairy farm, as they exist in the north central part of our country.

EXCHANGE OF PHOSPHORIC ACID ON A 100 ACRE DAIRY FARM.

I. Consumed on farm by 20 milch cows, 20 hogs, 10 neat cattle and 4 horses:

	Phosphoric acid, lbs.
1. Clover.....16 acres.....	450
2. Clover and timothy.....16 acres.....	350
3. Corn.....16 acres.....	400
4. Oats.....8 acres.....	160
5. Straw, 10 tons.....	40
6. Pasture and wood lot....35 acres.....	
Total	1,400

Loss, about 15 per cent, in food consumed..... 210

II. Sold from the farm each year:

1. Barley.....8 acres.....	120
2. 3 cows.....	60
3. 5 neat cattle.....	100
4. 20 hogs.....	50

Loss in Products sold..... 330

III. Feeds purchased:

10 tons wheat bran	600
--------------------------	-----

Loss, about 15 per cent, on feeds purchased..... 90

Total loss.....	630
Gain on feeds purchased.....	600
Net loss.....	30

EXCHANGE OF PHOSPHORIC ACID ON A 100 ACRE GRAIN FARM.

I. Consumed on farm by six milch cows, 5 horses,
10 hogs and 4 neat cattle:

	Phosphoric acid, lbs.
1. Corn.....10 acres	280
2. Oats.....25 "	450
3. Clover.....1 "	300
4. Clover and timothy }15 "	125
5. Straw.....35 tons	
6. Pasture and wood lot.....25 acres	
Total.....	1,155

Loss, about 15 per cent, on feeds consumed..... 170

II. Sold from farm each year:

1. Barley.....25 acres	375
2. 10 hogs.....	25
3. 3 neat cattle.....	45

Total loss on products sold..... 445

Total loss to the farm..... 615

From these tables it is evident that it will be necessary to purchase phosphate fertilizers in order to maintain the yield of crops on the great majority of farms. In all probability the outgo of phosphorus from the soil on 90 per cent of the farms of the country is greater than that returned in feed purchased.

(80) Phosphate Fertilizers. There are three principal sources of phosphate for use as fertilizers: (1) The bones of animals killed at the stock yards, (2) Mineral deposits of the tri-calcium phosphate, (3) basic slag from furnaces in which iron ores which contain considerable phosphorus are reduced. Besides these sources considerable phosphoric acid is found in fish scrap, dried blood, tankage, and other refuse products. Basic slag is not produced in this country, but is imported by the Atlantic coast states to a considerable extent from England where large amounts are produced

and from which it is largely shipped to other European countries.

Our two chief sources are therefore the stock yards and the phosphate mines. Bones are treated in three different ways to prepare them as fertilizers: (1) simply ground and sold as *raw bone meal*, (2) steamed to remove grease, etc., and sold as *steamed bone meal*, and (3) treated with acid to render the phosphorus more soluble and available to plants and sold as *acidulated bone meal*. The mineral phosphates are either simply ground to a flour-like condition and sold as *raw rock phosphate* or *floats* or it is treated with an equal weight of sulphuric acid to make it more soluble and available and sold as *acid phosphate*. Manufacturers give their products brand names, but they still belong to the above given classes. Mixed fertilizers are also prepared containing nitrogen and potash as well as phosphate in various proportions and given trade names, such as Tobacco Special, Potato Grower, etc., etc.

(81) Raw Bone Meal. This fertilizer contains 21 to 23 per cent of phosphoric acid and 3 to 4 per cent of nitrogen. It becomes available rather slowly and so a heavy application should be made at one time to become available during the next few years. It usually costs about \$22 a ton in Chicago and a good application is from 300 to 500 pounds per acre depending upon the crops to be grown, more being applied for truck crops than for general farm crops. This application is usually sufficient for three to four years.

(82) Steamed Bone Meal. This contains 28 to 30 per cent of P_2O_5 , costs about \$26 per ton in Chicago

and is used in the same way as the raw bone meal, but is more desirable.

(83) Acidulated Bone. Acidulated bone varies with different manufacturers in the amount of sulphuric acid used, and therefore in the amount rendered readily available and in the price and amount to be used.

(84) Raw Rock Phosphate or Floats. This contains from 20 to 32 per cent of P_2O_5 , is ground until 90 per cent will pass through a 60 or 80 mesh screen, and costs at the Tennessee mines \$3.50 to \$5.00 a ton in bulk in carload lots. It becomes available gradually when mixed with manure, applied on a clover or alfalfa sod, or to a soil highly charged with organic matter by the decomposition of which organic acids are set free to act on it.

Applied under these conditions at the rate of 600 to 1000 lbs. per acre for the first treatment of land exhausted of available phosphates and at the rate of 300 to 500 lbs. per acre every three to five years thereafter, it is probably the cheapest and best phosphate fertilizer for general farm use. It is an excellent absorbent for use in the stables and this is a good way to incorporate it with the manure.

(85) Acid Phosphate. This is made by mixing equal weights of raw rock phosphate and sulphuric acid and so contains only 12 to 16 per cent of P_2O_5 , but this is readily available without organic matter, and so can be used under conditions where the raw rock phosphate could not. It costs \$12 to \$15 per ton in Chicago. Three to five hundred pounds per acre every

two or three years is needed when no other fertilizer containing phosphorus is used.

POTASH.

(86) Amount of Potassium in Soils. The chemical symbol of potassium is K, but the amount of this element contained in any substance is usually stated in terms of the oxide, K_2O , and this is called *potash*. About six-sevenths of potash is potassium. Clay and loam soils contain from one to two per cent of potash; sandy soils, two-tenths to one per cent; and peat and muck, two-hundredths to five-tenths of a per cent. Assuming the weight of the surface soil over an acre to a depth of eight inches to be 2,000,000 pounds in the case of clay, two and one-half million in the case of sand, and one-half million in the case of peat and light muck, it will be seen that these soils contain on the average from twenty to forty thousand pounds per acre for the clay loams to a depth of eight inches, five to twenty-five thousand for sands, and one hundred to twenty-five hundred for peats and mucks. It will be seen from these figures that only peat and muck soils are deficient in their total supply of potassium and that in these soils it is absolutely necessary to add this element to secure good crops where it is below two-tenths or three-tenths of a per cent. In most soils the total supply of this element is sufficiently large for a long period of cropping if it were in an available form or would become available readily, but the potassium exists in the soil largely in the form of grains of feldspar and other minerals, which become soluble only with consider-

able slowness, so that occasionally sands and even clay soils are found deficient in available potassium. Nevertheless, it is true that with very few exceptions, clay, loam, and sandy soils become deficient in nitrogen or phosphate before they do in potassium, and it is very seldom that this element is the limiting factor.

(87) Loss of Potassium from the Farm. From a study of the composition of the different parts of the plant as given in the table in paragraph 10, it will be seen that most of this element goes to the stalk and straw of a crop and comparatively little to the grain. For this reason there is very much less loss of this element from the farm in the crops than is the case with phosphorus. Hay is about the only product of the staple crops commonly sold which removes a considerable amount of potassium.

(88) Potash Fertilizers. The all-important source of potash fertilizer is that of the Stassfurt mines in Germany. Besides this, wood ashes, which are available especially in the pineries, contain from four to six per cent of potash. The Stassfurt salts as mined in the crude form contain from 12 to 15 per cent of potash but are manufactured into sulphates and muriates or chlorides in which process the potash is concentrated, so that high grade muriate and sulphate of potash contain from 48 to 50 per cent of potash. These last mentioned salts will, therefore bear a larger expense for transportation than will a low grade salt of which Kainit is an example. Muriate of potash is somewhat cheaper than sulphate and is equally good for most crops, but for potatoes and tobacco and possibly some other truck crops the sulphate is preferable. These

salts are both readily soluble in water and therefore available to crops and may be applied on any land at the time of preparation for seeding, although there is very little lost if applied some time in advance since the potash is largely fixed in the soil. From 100 to 200 pounds of either the sulphate or muriate is a good application; the amount tends to vary with the crop, a larger amount being used for such crops as cabbage, sugar beets, or potatoes than would be necessary for grain, and, of course, the amount would vary with the character of the soil, a point which will be discussed in a later chapter.

CHAPTER VIII.

MECHANICAL COMPOSITION, TEXTURE AND TILTH OF SOIL.

When we examine any soil in the field we find that it is largely made up of lumps varying in size from the size of a pin head to several inches in diameter. If these lumps be dried and crushed they are found to be made up of particles of grains varying all the way from a size much too small to be seen with the naked eye up to coarse sand or gravel. The term *mechanical composition* refers to these ultimate particles and the term *texture*, to the way in which they are arranged and clustered into clumps. Both the mechanical composition and the texture of the soil vitally affect the growth of plants in many ways and their study is therefore of much importance to the farmer.

(89) Mechanical Composition. When samples of different kinds of soil are dried and the lumps crushed and then sifted through sieves of different sizes, it is found that while most samples contain grains of all sizes, from the finest up to sand, the relative amounts of the different sizes vary greatly. Clay soils contain a large amount of the finest grains with small amounts of the medium and coarser grains, while in sandy soils this relation is reversed. In alluvial or silty soils there is a large amount of the medium sized grains.

It is customary in a scientific study of soils to call the finest grains clay, the medium size grains silt, and the coarsest, sand. When the grains of clay are measured they are found to vary from sizes too small to measure, up to .005 of a millimeter in diameter. The fine silt varieties from .005 to .01 of a millimeter; the coarse silt, from .01 to .05; fine sand from .05 to 0.2; coarse sand from 0.2 to 1; fine gravel from 1 to 3 millimeters in diameter. In this classification the only difference between clay and sand is in the size of grain. Now, it is true that part of the extremely fine particles of clay are kaolin, resulting from the decomposition of feldspar in granite, as described in paragraph 25, nevertheless some of the finest particles of clay are pure quartz like those found in sand. Moreover, if pure quartz is ground fine enough, it has the plastic quality of natural clay. The chief differences in character of clay and sand are due to difference in size of grain. The following table gives the mechanical composition expressed in per cent of six different types of soil found in England as described by Professor A. D. Hall.

	Coarse Barren Sand.	Coarse Sandy Loam.	Fine Sandy Loam.	Heavy Clay Loam.	Heavy Clay.
Fine Gravel, 3 to 1 Mm	0.2	7.6	0.5	2.8	0.4
Coarse Sand, 1 to 0.2 Mm	22.6	44.9	15.0	14.1	0.8
Fine Sand, 0.2 to 0.05 Mm	60.8	23.1	49.0	31.2	6.4
Silt, 0.05 to 0.01 Mm	4.8	4.3	15.3	17.4	18.6
Fine Silt, 0.01 to 0.005 Mm	0.6	2.9	3.9	6.9	13.6
Clay, below 0.005 Mm	1.8	11.7	9.7	18.5	42.2

The remainder of the soil in each case is made up of humus, lime carbonate and moisture. It will be seen from the table that while all soils contain some grains of each size, there is a relatively large amount of sand both coarse and fine in the coarser soils and a relatively small amount in the clay soils, while clay soils contain a small amount of sand, but a relatively large amount of clay. Many alluvial soils, such as the loess of the Mississippi Valley, contain a much larger relative amount of silt size than any one of these six samples. It will be seen later that the mechanical composition of soils influences very profoundly their texture and capacity for holding water. It also influences the fertility to a certain extent, since the finer grained particles will dissolve in soil water more rapidly than the coarser grained, just as fine salt will dissolve more rapidly than coarse. This is because there is more surface on a given weight of the fine soil than of the coarse.

The surface of an inch cube is six square inches. If this cube be divided into cubes of a half inch on the edge, there will be eight of them and the total area will be twelve square inches. The area of the entire surface will double each time the diameter is divided in two. From this we see that the surface of all the grains of a cubic inch of soil would be very great and that the surface of the grains in a cubic inch of clay would be very much greater than in a cubic inch of sand. The following table gives the area in square feet of the grains in a pound of sand, silt and clay of given diameters.

Diameter of Grain.	Square Feet of Surface in a Pound.
Coarse Sand, 1 Mm.....	11.05
Fine Sand, 0.1 Mm.....	110.54
Silt, 0.01 Mm.....	1,105.38
Clay, 0.001 Mm.....	11,053.81
Fine Clay, 0.0001 Mm.....	1,100,538.16

(90) **Texture and Tilth.** Everyone who has cultivated soil realizes the influence of its texture on the growth of the crop. On this texture depends the readiness with which roots can penetrate it, the readiness with which oxygen can enter it to be used by the roots, and by the bacteria in developing nitrates and to oxidize the humus producing carbon dioxide. It also determines to a certain extent the water holding capacity of the soil.

Now the texture of a soil or the arrangement of its grains is affected by the following conditions:

1. Mechanical composition,
2. The amount of water it contains,
3. The character of the soil water,
4. Humus.
5. The roots of crops,
6. Freezing and thawing,
7. Cultivation.

When the texture is favorable to growth of the crop, the soil is said to have a good tilth; when unfavorable, to have a poor tilth.

(90a) **Mechanical Composition and Texture.** The smaller the size of the grains, that is, the finer the me-

chemical composition, the greater is its tendency to cling together so that when cultivated it tends to break up into lumps. The way in which these aggregates are formed as the moisture dries out of the soil is illustrated in fig. 4. It will be seen that as the films of water

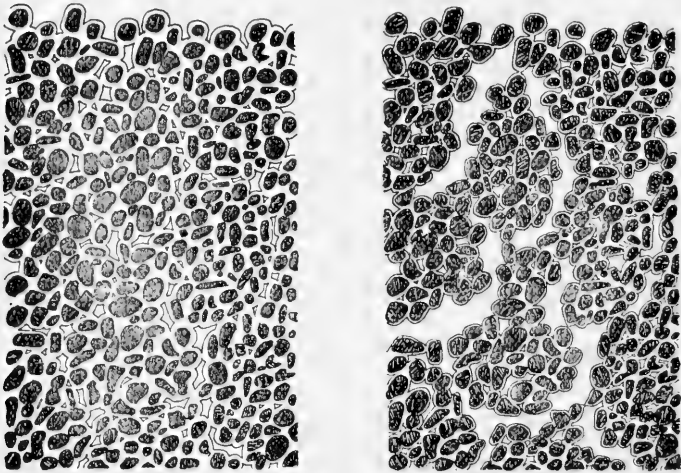


FIG. 4.—Illustrating the formation of soil granules.

become thinner and the soil grains are drawn closer together large cracks are formed leaving the soil in a granular condition. Sands composed of coarser grains show very little of this tendency, but fall apart readily. The mechanical composition of the soil will, therefore, aid us to a certain extent, to predict its texture under field conditions.

(91) **Amount of Water.** When soils are extremely wet, that is, when saturated, the particles tend to fall apart or *run*. This effect is increased when the soil is

stirred while wet. As the soil dries, the particles tend to adhere more and more firmly and when extremely dry, the clays which have run while wet become very hard and if cultivated in that condition break up into lumps. The sands, not having sufficient adhesive power, fall apart when entirely dry, while they are held in a fine, crumb like texture while partly wet.

(92) Texture and Soil Solution. Many salts when dissolved in water tend to make the soil grains gather into clusters or *flocculate*. If for instance a little clay be shaken with pure rain water it will remain in suspension for a long time, making the water turbid. If, however, a very little alum be dissolved in the water it will cause the clay to flocculate and settle, leaving the water perfectly clear. Salts occurring in the soil have the same effect. Lime put on the soil often benefits the soil by causing the grains to cluster, thus giving it a better texture, especially where it would otherwise have a tendency to run. On the other hand some salts and other substances tend to break down the clusters of soil and make them run or puddle. Ammonia or ammonium salts have this effect.

(93) Humus and Texture. As the vegetable material in the soil decomposes, humus is produced. This humus spreads over the surface of soil grains, often covering them like a coat of black paint. In the case of sand this has the effect of making the sand grains cling together, thus giving it a firmer and closer texture which prevents it from drying out so rapidly as well as greatly increasing its water-holding capacity. In the case of clay, on the other hand, the humus tends to weaken the adhesiveness and so prevent the formation of large, hard

clods on drying, to a certain extent. Humus, therefore, greatly improves the texture or tilth of both sandy soils and clay soils.

The development of the root system of plants causes the movement of soil particles in contact with them thus modifying their texture. The most important effect of the roots, however, is the result of their decay, leaving holes in the soil and subsoil. The amount of this effect depends largely on the character of the roots. Such roots as those of alfalfa, which are often more than a third of an inch in diameter and extend several feet into the soil, often have a very decided effect in loosening a compact subsoil. The same result is produced by earthworms.

(94) Freezing and Thawing. The effect of the freezing and of the expansion of the water contained in the soil, is to separate the soil clusters, breaking down the larger chunks. One of the chief benefits of deep fall plowing is due to the fact that the exposure to the surface where there is frequent freezing and thawing breaks up the mass, giving it a better texture.

(95) Cultivation. One of the most important objects of cultivation is to improve the texture of the soil. This will be discussed in the chapter on Principles of Tillage.

CHAPTER IX.

WATER-HOLDING CAPACITY OF SOILS.

(96) **Three Forms of Water in Soil.** If sand is placed in a stoppered funnel and water poured over it until it is entirely soaked and then the stopper removed part of the water will drain away while part remains in the soil. The water which drains off is called drain or *gravitational* water. If the soil is examined after drainage it will be found that the water still in the soil is in the form of films around the grains and in the smaller angles between the grains. Since this water is held by the grains of soil in the same way that water is held in a capillary tube it is called *capillary* water. Again, if soil is allowed to dry in the air as completely as it will, it will be found that if it is put in an oven and heated it will give up some water. If after drying completely in this way it be allowed to stand in the air it will again absorb some moisture. This water is called *hygroscopic* moisture and of course is usually small in amount.

(97) **Use of Water in these Different Forms.** It would seem that the plant could use the water in all forms equally well; but when it is remembered that the soil must contain air for the growth of roots and for the process of nitrification it will be seen that conditions will be better when part of the water is drained

off. If the root hairs come in contact with the soil grains to get moisture they will act more strongly to dissolve the grains.

(98) The Amount of Capillary Water Held by Soils. Since the water is held as films around the soil grains, the amount so held depends in part on the area of the surface of the grains. Now, the area of the soil grains depends on their size; the finer the soil the greater the area of a given amount. The area of soil grains is very large. In one cubic foot of the finest clay soil there are 175,000 square feet of surface, or more than four acres. In a cubic foot of sandy loam the area is 35,000 square feet, or over three-fourths of an acre, while in coarse sand it is only 6,000 to 8,000 square feet.

The importance of even small amounts of clay in soils is shown by the above data. In truck soils the clay constitutes about 10 per cent; in wheat soils 20 per cent, and in the best grass soils 30 per cent.

Humus also has a very great power to hold water, and the water-holding capacity of our loam soils is due to a considerable extent to the humus. To show the effect of clay and humus on the water-holding capacity of soils a pint each of humus soil, of clay loam and of sand soil was placed in percolating jars, water poured on till it began to drip, then allowed to drain twelve hours and the water still held determined. It was found to be for the humus soil 315 c. e., for the clay loam 230 c. e., and for the sand soil 153 c. e.

In the field after heavy rains have given the soil all it can hold and it has rained few days, approximately the following amounts will be held:

	Sandy loam.	Clay loam.	Humus soil.
First foot.....	3 in.	3½ in.	5 in.
Second foot.....	2 in.	3 in.	3¾ in.

Sand in clay soils has the effect of allowing a rain to wet down farther than the pure clay would, because of its much less capacity to hold water. Hence a small rain will reach to the roots of plants in a sandy soil or even in a clay soil containing sand, when it might not reach them in a clay soil containing little sand.

(99) Availability of Soil Moisture to Plants. It is, of course, impossible for the plant to extract all the water from the soil and when plants wilt a sandy soil will contain the least water, the clay loam more and the humus most. Still, when the amount contained when plants wilt is subtracted from what the soil can hold, it will be found that the plants have taken least from sand, more from clay loam and most from humus soil. The amount of water in the first four feet of soil which is available to crops is approximately as follows: very sandy soils four inches, clay loam five inches and very humus soils seven inches.

(100) Cultivation and Culture to Increase Water Capacity of Soils. In a region like ours where the rain is apt to be deficient it is desirable to improve the water-holding capacity of soils. Fall plowing has an advantage over spring plowing in that the loose condition of the soil tends to hold the winter rain and snow so that it soaks into the ground instead of running

off. The direction of plowing with reference to the slope also makes a difference in this respect. If the furrow slice be turned up-hill it tends to hold water better than when turned down. Subsoiling is another method of increasing the amount of water the soil can hold. This method of plowing is followed to quite an extent in Europe, but so far as tried in the west does not seem to increase the crop enough to justify the extra labor. The looseness of soil produced by some crops is quite important. But in all probability the most effective method of increasing the water capacity is by developing humus. This can be done by growing and plowing under catch crops when the soil will not be dried too much by this, i. e., during a wet season, and by pasturing. A piece of very sandy land was found in the summer to have 16,000 pounds more water per acre where manure had been applied than where not.

CHAPTER X.

MOVEMENTS OF SOIL WATER.

Since the entire pore space of soils must not be filled by water or there will be a lack of air for the plant roots and for the bacteria which carry on the process of nitrification it is necessary that artificial means be used to draw off the excess. This is the object of drainage. Since the amount of water within the reach of plant roots is often too small for their needs it is necessary to take advantage of and increase the upward movement of water through the soil penetrated by roots and to prevent as much as possible its loss by evaporation from the soil surface.

(101) Causes of Movements of Soil Water.

There are three causes of movements of water in soils. The first is the force of gravitation; second, surface tension causing capillary movement; and third, heat. The force of gravitation while acting in a line toward the center of the earth will cause movements of water on even very gentle inclines under the surface of the soil as well as on it. Capillary movement may take place in any direction. It tends to move the water from places of greater towards places of less moisture and to so distribute it that the films surrounding the grains are of equal thickness and so the fine soils will hold more than the coarse ones. The thermal or heat move-

ments are due to the fact that when the soil is warmer at one point than at another the water will evaporate where the soil is warmer and pass as vapor through the soil to the cooler parts and there condense. Heat may therefore cause movements of water in any direction in the soil. When these forces act in the same direction the water will move most rapidly.

(102) Ground Water. Of the water which falls on the ground, part runs off while part sinks in. Of that which sinks in, part is used by plants while the remainder passes on down and accumulates as the ground water entirely filling the pore space between soil grains. The surface of the saturated part is called the *ground water* level. This surface however is not level but rises and falls with the surface of the ground though being less uneven than the surface.

(103) Percolation and Seepage. The downward and lateral movements of this ground water, produced by gravitation either alone or together with capillary attraction are called percolation and seepage, respectively. The rate of these movements of water depends on a number of factors, the most important of which are: first, the size and arrangements of the soil grains; second, the height of water pressure; third, the distance the water must flow before finding an outlet; and fourth, the temperature of the water.

The flow of water through sand or soil under similar conditions is approximately proportional to the square of the diameter of grain, that is water will flow four times as fast through a soil having a given diameter of grain than through one having half that diameter, etc. It may flow 1000 times as fast through a coarse

sand as through a clay. The rate of flow is dependent directly on the pressure head, that is if the ground water surface falls one foot per rod the flow will be twice what it would be if the fall were but 6 inches in that distance. The warmer the temperature the more rapid will the water move because the viscosity of the water is less when warm than when cold.

The checks and cracks formed during the drying of clay soils, and the holes left by the roots on decaying are the chief channels in the movement of water through heavy clay soil.

(104) The Advantages of Drainage. Some of the more important advantages of drainage are the following: First, it increases the water available to plants; second, allows humus to decompose more rapidly; third, warms the soil by lessening the evaporation and by allowing the warm rain to soak in; fourth, it gives better ventilation; and fifth, gives a larger mass of soil on which the plants can draw for food material.

Soils continue to improve in texture for several years after drains are put in because the drains allow the water to escape from the checks and cracks formed during dry periods in place of remaining and causing the soil to run into the cracks and fill them up again.

(105) Capillary Rise of Water. The *rate* at which water will rise in soils is greater the coarser the grain. It is also more rapid in moist than in dry soils. The *height* to which the water will rise is greater the finer the soil, or what amounts to the same thing, the greater its compactness.

There are two ways in which we must be able to con-

tion of the movements of soil water. The first is that of bringing it from lower layers to the seed during a dry spring and second to prevent its loss from the surface. It will be seen from the above mentioned facts that the most effective means of raising is compacting by the use of a heavy roller. The prevention of loss by evaporation can be accomplished by making the surface soil thoroughly dry and loose, that is by developing a soil mulch.

The characteristics of a good mulch are that it should be thoroughly dry, loose and not too fine. The efficiency of the mulch is about as great when its thickness is three inches as when greater. There is, therefore, nothing gained by deeper cultivation, in this respect. Of course the crust developed by even a light rain destroys the mulch and necessitates a new cultivation. The effect of light rains in this way is often to cause loss of more water than they brought to the soil.

CHAPTER XI.

TEMPERATURE OF SOILS.

The influence of temperature on germination and growth was discussed in the first chapter and its influence on the chemical and biological changes, including nitrification, were mentioned in the sixth chapter. As an illustration of the influence of temperature on the growth of roots the following table from Hall giving the growth of roots of corn at different temperatures, is quoted.

Temperature.	Millimeters.
63 degrees Fahrenheit.....	1.3
79 degrees Fahrenheit.....	24.5
92 degrees Fahrenheit.....	39.
93 degrees Fahrenheit.....	55.
101 degrees Fahrenheit.....	25.2
108.5 degrees Fahrenheit.....	5.9

It will be seen that there is an optimum temperature at about 93 degrees. We have now to consider the conditions which modify the temperature of the soil. They are first, character of the soil, including color and specific heat; second, roughness of surface; third,

amount of water; fourth, slope and situation; fifth, decomposition of organic material.

(106) Character of the Soil. The color of the soil influences to a certain extent the amount of heat absorbed from the sun. The black soils absorb more heat than the red and the red more than those of lighter color. This is one of the ways in which the black humus is helpful in the soil. The specific heat, or the relative amount of heat necessary to give the same weight of different soils the same increase in temperature, also has its influence. The amount of heat necessary to raise the temperature of a pound of sand one degree is only two-thirds of that necessary to raise a pound of clay and only one-half of that needed to raise a pound of humus one degree. However, the sandy soils are much heavier, volume for volume, than the humus soils, so that these two factors tend to offset each other to a certain extent and yet it will be seen that a small amount of humus in the sandy soil will give it a black surface to absorb the heat effectively, while the sand is easily heated so that soils of this type warm up very much more rapidly in the sunshine than do clear sands, clay or soils largely composed of humus.

(107) Amount of Water. Water in the soil must, of course, be warmed when the soil is warmed, and owing to its high specific heat greatly retards the rate at which the soil is warmed, but the most detrimental effect of water on the temperature of the soil is due to the fact that its evaporation from the surface uses up so much of the heat. The amount of heat necessary to evaporate one-tenth of an inch of water over the surface of a field would be enough to raise the tempera-

ture of the wet soil to a depth of six inches over thirty degrees if none were radiated to the air. The percentage of water in the soil is the most important factor in soil temperature. Those soils which are relatively dry are usually early, while those that are wet are late not simply because the dry soils can be cultivated before the wet ones but because they are warmer and seeds will germinate in them sooner than in the late ones.

Undrained soils are often 10° to 12° colder than similar drained soils. This coldness of undrained soils has much to do with the formation of frost on marshy ground.

(108) Roughness of Surface. It follows from the above that any condition which will prevent the rise of water to the surface or its evaporation will allow the soil to warm up so much the more rapidly. If the texture is loose and open so that capillarity is interrupted this will lessen the amount of water evaporated from the surface and so tend to increase its temperature. There is, however, another factor which must be considered, namely the heat conductivity of the soil. If the soil does not conduct the heat from the surface downward, the surface itself may be very warm, while the lower layers remain cold. Now looseness of texture greatly lessens the rate at which heat is transmitted from the surface downward, while compacting the soil as by rolling, will aid this process of conduction. It is found that soils that have been rolled may be three or four degrees warmer at a depth of three inches than unrolled soils, in spite of the fact that more water is brought to the surface as a result of rolling.

The best condition is produced by rolling the ground when necessary and then harrowing the surface to develop a thin dry mulch to prevent evaporation.

If the surface be somewhat rough, the evaporation is lessened because the wind does not have as free play over the surface as when the ground is smooth. Any other shelter such as that of a hedge or woods which lessens the effect of the wind also allows the soil to become warmer. The difference due to this may be as much as two or three degrees, which is quite an important amount in the germination of seed and growth of roots.

(109) Slope and Situation. The south slope of hills tends to become warmer than a flat surface and this in turn warmer than the north side of the hill. This is because the surface is more nearly perpendicular to the sun's rays and hence a greater amount of heat is received per square foot. The difference between the south and north slope may be as much as two degrees. The influence of situation whether on low lying ground or on higher slopes or hilltops is also of importance. The soils of the lower ground are usually considerably colder than those of the hillsides and hilltops for several reasons. There is usually more water in the lower regions which tend to keep them cold as seen above. There is also a tendency for the cold air to collect in the low places which cools the soil. This is the most important factor to be considered in the selection of ground for crops such as fruit, vegetables, etc., which are in serious danger of being affected by frost. It is also of importance in selecting ground for corn raising in the northern part of the state. Frost is often

experienced on marsh ground while the temperature on high land, within a few miles, is as much as ten degrees above freezing.

(110) Decomposition of Organic Material. The decomposition of vegetable material is the result of chemical and biological changes which produce heat. When the amount of organic material is very large and it is decomposed rapidly, the temperature may be raised several degrees.

In the soil the organic material usually forms a small part and its decomposition is so slow that the heat developed is not large. A very heavy dressing of manure may have the effect of raising the temperature two or three degrees for a short time.

CHAPTER XII.

VENTILATION OF SOILS.

(111) **Necessity of Ventilation.** We have seen that ventilation of soil is necessary, first, to supply oxygen used by bacteria in the process of nitrification and by roots in growth; and second, to remove the carbon dioxide which is produced by the decomposition of the humus, so that it may not accumulate in quantities large enough to injure the roots and so that it may become available to the plant by absorption by the leaves. One of the greatest objections to a large amount of water in the soil is that this water logged condition does not allow access of air to the soil.

(112) **Agencies Causing Ventilation.** The change of air in the soil is affected by first, expansion and contraction due to changes in temperature; second, by change in barometric pressure, third, by wind; and fourth, by rain.

The expansion and contraction of air contained in the soil as it is warmed during the day and cooled during the night tends to force some air out in the day and draw some fresh air in at night, producing a crude sort of breathing.

The constant change of barometric pressure also produces this result. The unequal pressure of the wind, blowing strong at times and ceasing again, also tends

to change the air in the soil particularly on hillsides which are exposed to this action. A rainfall brings fresh air into the soil in two ways: first, in solution in the water, and second, by drawing it in after the water percolates down into the soil.

Tillage affects the ventilation to the depth to which the soil is cultivated.

(113) Excessive Ventilation. While a certain amount of ventilation is necessary to supply oxygen and to remove carbon dioxide, it is quite possible for it to be so large as to oxidize the humus more rapidly than it can be accumulated with the result that it disappears almost entirely from the soil. This is the effect very generally in extremely sandy soils which allow the air a too ready access. Difficulty is also experienced in the southern states in retaining humus in the soil where the temperature being higher hastens its oxidation. Anything which will lessen the ventilation will also lessen the oxidation of the humus.

CHAPTER XIII.

TILLAGE.

The work of cultivation or tillage involves the greater part of the labor which the farmer has to do in the production of crops. It is very important, therefore, that he study carefully the objects to be gained and the methods of attaining them.

The most important objects of cultivation are: First, to improve texture; second, to kill weeds; third, to conserve moisture, and fourth, to cover vegetation so as to add humus to the soil. It very often happens that two or more of these objects are attained at the same time, but it is desirable that they be thought of distinctly and that the effectiveness of the tillage be considered from the standpoint of each object to be gained.

(114) Cultivation and Texture. The process of plowing has for its chief object the improvement of the texture or tilth of the soil. The effect of bending the furrow slice by means of the mold board is to break it up into larger or smaller lumps making it more open and porous. The form of the mold board determines the amount of this bending or crumpling. The long, slightly curved mold board of the breaking plow may allow the furrow slice to slide from it with comparatively little bending while a plow with a steeper or

more highly curved mold board will bend the furrow slice so as to break it up very thoroughly. This is the desired result and the best plowing in this respect is one which leaves the ground rough and uneven.

The condition of the ground at the time of plowing with reference to its moisture content has a very great influence on the texture developed. If the ground is too wet the working of the soil by plowing tends to puddle it so that on drying the soil is left in a very bad condition. This applies particularly to clay soils. Sandy and humus soils are not so badly affected and can therefore be plowed when relatively much wetter than clay soil. If the soil be too dry, on the other hand, it will be hard so that not only is the draft of the plow much greater but the furrow slice does not break up so completely and large unbroken clods are left.

It is extremely important to plow at just the proper condition of moisture to produce a good tilth and the farmer should study each field carefully and note the results of plowing under different conditions till he recognizes the proper conditions to secure the best results.

The depth of plowing depends on the kind of soil to some extent and also on the time of plowing. In general, clay soils should be plowed more deeply than is necessary or desirable for sandy soils. It is also desirable that clay soils be plowed in the fall in order to give time for the clay to acquire a good texture.

This is particularly important when the plowing is deeper than usual, since if new clay soil be turned up in the spring it will have a poor texture and tend to develop a crust on the surface easily after rain, thus giv-

ing a poor tilth of the soil. After plowing in the spring it is often very helpful in developing a good texture to go over the ground with plunker or a float at the close of each day's plowing while the lumps are still moist enough so as to be readily broken. The repeated plowing of the soil to the same depth tends to develop a hard-pan. This can be avoided by plowing at different depths different seasons. The disc plow has some advantages over the ordinary mold board plow in this respect; it does not leave the plowed land lying upon a perfectly smooth surface without good contact with it as the ordinary plow often does. The disc plow does not clean well in clay soils unless they have some sand in them. In using the cultivator for improving tilth, it is necessary to pay attention to the amount of moisture in the soil as in the work of plowing. The chief use of the cultivator so far as tilth is concerned is to destroy the crust which develops after even a slight rainfall.

(115) Cultivation to Kill Weeds. The time at which weeds are most easily killed is just as the seed is germinating. By stirring the surface of the soil so as to expose the germinating seed to the sun and air to dry, it can readily be destroyed. Since not all seeds germinate at the same time a repetition of this cultivation may be necessary. For light sandy soils a close toothed weeder is the most effective, but for heavier soils a light spiked toothed harrow will give better results.

(116) Cultivation to Conserve Moisture. A large part of the United States is subject to drought. It is, therefore, important at such times to prevent the

loss of water as much as possible. Much can be done by proper cultivation to lessen the water lost by evaporation from the surface. It was seen in Chapter X that water cannot rise readily through dry soil nor through one which is very open.

The loss of water can, therefore, to some extent be prevented by stirring the surface of the soil so as to dry it completely and leave it loose or in the form of a mulch. It is not desirable that the mulch be broken up so fine as to form dust, for the moisture will rise through this more rapidly than if it is somewhat coarser, but it is extremely important that it be thoroughly dry. The depth to which the soil can be cultivated for this purpose will depend somewhat on the crop though three inches is usually as effective as a greater depth. It is very important that the crust produced by rain be broken as soon as possible, since this crust allows the moisture to escape rapidly.

The wetness of a smooth surface of ground in the spring is due usually not so much to rain or snow at that time as it is to the moisture brought up from below by capillarity. This does not evaporate so rapidly in the spring while the soil is cold and hence leaves the ground wet. By plowing so as to leave the surface rough and uneven less water will be drawn up from below and the ground will dry off more rapidly and therefore get warm enough for planting at an earlier date.

(117) Cultivation to Cover Vegetation. One of the greatest benefits of plowing is that it turns under the vegetable matter so as to keep it moist and allow it to decay. Fall plowing has the advantage over

spring plowing in that it allows decomposition of vegetation to go on to a certain extent during the winter. Of course where green manuring is used it is often desirable to allow it to grow for a while in the spring. Care should be taken, however, that the green manuring crop be not allowed to dry the soil beyond a good growing condition for the crop which is to follow.

(118) Labor in Cultivation. A large part of the expense involved in producing most crops is for the labor of preparing and cultivating the land. The influence of the texture of the soil on this labor is therefore extremely important. When two soils are equally fertile but one requires 25 per cent more labor than the other the expense of the extra labor reduces the net profit.

CHAPTER XIV.

BARNYARD MANURE.

The all important fertilizer available on every farm is barnyard manure. Progress in farming methods has been marked just so far as a careful economical use of farm manures has been practiced.

(119) Factors Affecting Value of Manure. The principal conditions affecting the value of manure are as follows:

1. Food of the animal,
2. Age of the animal,
3. Kind of animal,
4. Product from the animal,
5. Kind and amount of litter used.
6. Care of the manure.

(120) Food. Animals fed on food substances low in fertilizing constituents will produce a manure of correspondingly low value. For example, animals fed on straw and timothy hay, which are low in nitrogen and phosphorus, will produce a manure much lower in value than if fed bran and clover hay, substances relatively high in nitrogen and phosphorus.

(121) Age. Young animals are constantly removing from their food nitrogen to build up muscle, etc., and lime and phosphorus to build up bones, while ma-

tured animals just maintaining themselves remove comparatively little of these fertilizing constituents. Therefore manure from mature animals is more valuable than that from young growing animals.

(122) **Kind.** The following table adapted from Wolff shows the percentage composition of fresh manure from various animals and its value per ton, figuring nitrogen at 15 cents per pound, and phosphoric acid and potash at 5 cents per pound.

Average Composition of Fresh Manure (Wolff).

	Nitrogen. %	Phosphoric acid. %	Potash. %	Value per ton.
Cow .....	.44	0.16	0.40	\$1.89
Horse.....	.58	0.28	0.53	2.55
Pig.....	.45	0.19	0.60	2.14
Sheep.....	.83	0.23	0.67	3.39

The following table from Bulletin No. 56 of the Cornell Station is even more instructive for it shows the amount and value of manure per 1,000 lbs. of live weight of animals.

	Amount per day, pounds.	Value per day, cents.	Value per year, dollars.
Sheep.....	34.1	7.2	26.09
Calves.....	67.8	6.7	24.45
Hogs.....	56.2	10.4	37.96
Cows.....	74.1	8.0	29.27
Horse.....	48.8	7.6	27.74

(123) Liquid and Solid Manure. The liquid portion of the manure is of different composition than the solid portion. Urine contains a high per cent of nitrogen, but only a trace of phosphoric acid. Most of the phosphoric acid is found in the solid excrement, while the potash is largely confined to the urine. Nitrogen is the most expensive fertilizer, yet it is in a form most readily lost. The utmost care should be taken to preserve the liquid manure by the use of absorbents, and by thoroughly mixing it with the solid excrement.

The following table adapted from the work of Anodynaud and others, reported in Experiment Station Record, Vol. 5, p. 142, shows the comparative composition of liquid and solid excrement.

	Nitrogen. %	Phosphoric acid. %	Potash. %
Horse urine	1.52	trace	.9
Horse—solid excrement..	.55	.35	.1
Cow urine.....	1.05	trace	1.36
Cow—solid excrement....	.43	.12	.04

(124) Product. Manure from milch cows is relatively lower in nitrogen and phosphorus than manure from beef animals, or from animals being fed a maintenance ration. Vivian estimates that a cow giving an annual yield of 5,000 lbs. of milk removes in the milk fertilizing materials amounting in value to \$4.98.

(125) Litter. Straw is the common absorbent used. The effect of the litter upon the texture of the

manure is as an important consideration as its effect upon the chemical composition. Coarse wheat or rye straw will make a loose strawy manure, while oat straw will tend to produce a more compact fertilizer. Finely cut corn stover is therefore of more value as bedding than the coarser stalks.

Well dried mossy peat is a good absorbent and is also a source of nitrogen. Wood shavings are commonly used as litter in cities, where straw is expensive or unobtainable. They retard the decay of manure and tend to cause drying out of soils on which they are applied. Manure containing wood shavings should not be applied to light sandy soils, but can be safely applied as light dressings on clay or clay loam soils.

(126) Care of Manure. Results at the Ohio Experiment Station (see Ohio Bulletin No. 183) demonstrate that the exposure of manure to the weather of winter and early spring deprives it of about one-third of its value. When applied to crops in the field a ton of yard manure produced an increase of value of \$2.15 as a ten-year average, while a ton of fresh manure produced an increase of \$2.96 as a ten-year average, showing a loss of 81 cents a ton, or 27 per cent due to exposure.

(127) Handling Manure. Because of losses due to exposure in the yard, where leaching and fermentation may take place, it is more economical to use other methods in handling this material. Where the fields are not too rough so as to cause side hill wash, it is most economical to haul the fresh manure directly to the field as fast as it is produced. This means hauling out a large

amount of the manure in the winter and consequently hand spreading. Because of the desirability of using a manure spreader, it is a good plan to store the manure in sheds where it must be kept compact and moist. Where large quantities of well rotted manure are desired by gardeners, the material can be composted. Composting of manure, or even storing in deep stalls or sheds, will aid in the killing of any weed seeds that there might be in the manure. The deep stall method, although unsanitary where dairy cows are kept, may well be used in case of young cattle.

(128) Application of Manure. In the ordinary farm rotations, it is usually found best to apply manure to corn ground. It is often found advantageous to apply top dressings to grass land. Top dressings of manure on heavy clay soils will materially aid in making such soils of lighter texture. The coarser manures, such as rotted straw or horse manure, are well adapted to marsh soils, while the well rotted manures should be used on sand soils. Coarse manure applied to sand will cause loss of water. In all cases, and on all soils, light and frequent applications of manure are more economical than very heavy applications at greater intervals.

(129) Re-inforcement of Manure. Average barnyard manure contains .5% of potash, .5% of nitrogen, and .3 to .35% of phosphoric acid. It will be noticed that the percentage of phosphoric acid is relatively low. Because of this fact and because soils generally are becoming depleted in their phosphoric acid content, it has become quite profitable to use ground rock phosphate

(floats) as an absorbent in the stables. The ground rock phosphate not only acts as an absorbent to retain the liquid portion of the manure, but is itself a source of fertility. Although experimental evidence is somewhat conflicting concerning the effect of rotting manures upon rock phosphate, field experience seems to show a marked increase in the availability of the phosphate where used with the manure.

(130) Long-time Effect of Manure. The effect of an application of barnyard manure is felt much longer than a single application of artificial fertilizer containing the same amount of plant food. Every farmer has noticed this effect of manure on a plot of soil, three or even five years after its application. An experiment at Rothamsted Station with barley showed beneficial effects even after manuring had been discontinued for 20 years. Every effort should be put forth to conserve this store of plant food, and to return it to the soil.

CHAPTER XV.

CLASSIFICATION OF SOILS.

Soils may be classified with reference to the following different bases:

1. Adaptability to different crops,
2. Chemical composition,
3. Physical composition,
4. Mode of origin.

With reference to the crops to which they are adapted, they are frequently classified into truck, grass, and intermediate soils.

(131) Truck Soils. Soils to be adapted to truck crops are such as quickly become dry enough to work after heavy rains. This is necessary because such crops require transplanting and considerable work on the land so that if the ground is not suitable much valuable time is lost. Truck crops also require a soil that warms readily. Soils of open texture permit the development of the coarse rooted truck crops. Sandy soils have these characteristics and are therefore best adapted to this use. While they are not as fertile as other soils this can be made good by the use of fertilizers which are relatively less expensive than the labor involved in growing such crops. Moreover manure, available usually in large quantities in the cities which form the market for

the crop decomposes rapidly in these warm soils and becomes available to the crop. Many vegetables grow more rapidly on these warm, highly fertilized soils than they would on colder soils and are therefore of better quality.

(132) Grass and Grain Soils. Grasses that are used for pasture or for hay, grow throughout the season, and therefore draw especially heavily on the supply of water in the soil. Moreover the roots of grasses are extremely fine enabling them to penetrate compact clay soils and thereby take advantage of the large water-holding capacity which these soils have. Heavy clay soils are, therefore, often spoken of as grass and pasture soils. This leaves the intermediate soils, such as loams, which are adapted to other intermediate crops, such as corn, and also some truck crops, and grain, but less well to grasses.

(133) Chemical Composition. Chemical composition of soils influences the growth of crops in two ways:

1. By the presence of the necessary plant food.
2. By the presence, in certain cases, of injurious substances, e. g., the accumulation of soluble salts in alkali soils.

Several classes of soils have therefore been characterized chiefly by peculiarities in composition. Among these may be mentioned peat and muck soils, largely composed of vegetable matter; recent glacial clays in a limestone region, characterized by excess of lime carbonate in the subsoil; black prairie soils, characterized by considerable amounts of organic matter, though having good drainage; and alkali soils, characterized by large amounts of soluble salts which collect as a result

of weathering in a climate where the rainfall is too small to cause their removal.

(134) Physical Composition. Recognizing the importance of physical composition and its influence on the operations of tillage, water-holding capacity, temperature, and other factors influencing the growth of crops, soils may be classified on the basis of their mechanical composition into as many subdivisions as desirable. The following subdivisions are the ones most commonly made:

1. Gravelly sand,
2. Fine sand,
3. Sandy loam,
4. Fine sandy loam,
6. Silt loam,
7. Clay loam,
8. Clay.

To these must be added from a purely physical point, classes to include those having large amounts of organic matter, such as peat, consisting largely of sphagnum moss; and muck, in part sphagnum moss and in part vegetable matter from grasses, all in process of decomposition.

(135) Mode of Origin. Soils are in all cases the results of the action of certain physical forces on rocks. They may be classified on the basis of the agent chiefly concerned in the formation of the soil from this rock material. On this basis soils are classified into:

1. Wind blown or loess soils (see paragraph 28).
2. Residual, those formed in place by direct weathering of the rock (see paragraph 25).

3. Glacial (see paragraph 27).

4. Alluvial, transported soils deposited by water.

5. Colluvial, those formed by wash on side hills together with sliding which takes place in such locations.

While it is important to study the various factors which influence the character of the soils, as indicated in the above classification, it must still be recognized that any practical classification to be used by the farmer must be based primarily on the relation of the crop to the soil and the kind of farming to which adapted and so must include all of the factors above mentioned. Such a classification would recognize types of soil each characterized by a combination of physical and chemical characters which give them a distinct uniformity and a distinct relation to agricultural practice. No complete classification of soils looked at from this standpoint has been made, but some of the more important types will be mentioned in a succeeding chapter together with their crop adaptations and special treatment necessary to maintain them in a good state of fertility. Before classifying soils on this basis, we must examine the relation of the various important crops to the soil and climate. This will be the subject of the next chapter.

CHAPTER XVI.

CONDITIONS OF CLIMATE AND SOILS NEEDED
BY VARIOUS CROPS.

There is nothing more essential to the success of the farmer than a full knowledge of the conditions necessary for the best growth of the various crops. Some of these conditions he cannot modify but must adapt himself to, while others can be influenced by proper methods of cultivation.

The chief conditions over which the farmer has little influence are those of the climate and of the fundamental character of the soil. It is very important, however, to know the relation between the climate and soil and various farm crops in order to be able to select those crops which are adapted to the climate and soil of his locality.

(136) Relation of Character of Plant to Character of Soil. There is a great variation in soils in their texture and fertility and there is also a great variation in plants in the character of their root systems, in the length and time of their growing period, and in the elements which they require from the soil. It is not strange, therefore, that some plants are adapted to one condition and some to another.

The character of the root system determines to a considerable extent the texture of soil to which the plant

is adapted. Coarse rooted plants and those producing tubers require a somewhat open texture to permit of their best development. Others less coarse, such as alfalfa and corn can grow in soils of medium texture, while soils of very close texture can be penetrated with ease only by fine roots such as those of the cereals and grasses.

Some plants make a very large part of their growth in a short period of time. Corn, for instance, in Wisconsin, often makes nearly one-half its growth in a month. In this case it is essential that there be a large amount of available plant material ready during that time.

Some plants on account of the great length of their roots are able to draw water from depths of soil beyond the reach of other plants. Such is the case with alfalfa and brome grass.

Leguminous plants are able to supply themselves with nitrogen when tubercle forming bacteria are present, but these bacteria do not develop rapidly in soils which are acid. These plants also seem to require larger amounts of lime than most crops (see table in paragraph 10) and hence thrive unusually well on the loess soils of the Missouri and Mississippi valleys and on the glacial till of the northern states where this contains very large amounts of ground limestone. They also do well on limestone soils where the thickness of residual soil from which all lime has been removed is not too great to permit the roots to get to the partially undecomposed limestone.

The winter killing of plants is often dependent on

the character and condition of the soil. Clover is much more apt to be killed in poorly drained soils and in those of close texture than in well drained and open textured soils on account of the heaving produced by the freezing of the water in the soil.

(136a) Relation of Crop to Climate. The distribution and amount of rainfall in a given region also exercises a very great influence on the kind of crops to which it is adapted. Corn is especially adapted to the Mississippi Valley not only on account of the fertility of the soil, but on account of the fact that the rainfall of this region is greatest during the months of June and July when corn is making its most rapid growth.

The grasses do best in a region having an even and copious rainfall, such as that of the Atlantic Coast states.

These and many other factors must be considered in determining the conditions necessary for the best development of the various crops. Their systematic study can best be made in connection with the study of the individual crops.

For convenience we may classify farm crops into three classes; first, tilled crops; second, cereals; and third, grasses and clovers.

TILLED CROPS.

All those crops which are planted in rows so as to admit of tillage, such as corn, potatoes, tobacco, rape and the root crops generally, have certain features in

common. The chief one is that of coarseness of root system and size of stalk. The first causes them to be adapted to somewhat open textured soils through which the coarser roots may ramify, while the second makes them adapted to intertillage because the plants finally grow so large as to completely cover the ground with foliage. The foliage is so extensive that it utilizes all the light reaching the soil during the later growth of crops, while still leaving space for tillage during the earlier growth. Tilled crops all have the same season of principal growth, which starts later than in the case of the cereals and grasses, thus allowing nitrification to produce the necessary supply of nitrates before the time of greatest need.

(137) Corn. Corn has already become the greatest crop produced in America and will undoubtedly grow in importance for some time to come. It produces a larger amount of grain and of fodder per acre and of a kind which can be more easily handled than any other crop.

(138) Roots of the Corn Plant. The corn plant develops two classes of roots. The primary roots, from six to twenty in number, spread laterally in all directions and grow down in a direction which varies greatly with the character of the soil. The secondary roots, starting from the first and second nodes above ground, branch out as braces to the soil and develop horizontally comparatively near the surface. In a deep loam soil the roots at six weeks from planting, when the plant is about a foot and a half high, often meet between two rows which are forty-two inches apart and extend to a

depth of eighteen inches. When the corn has reached the height of three feet, the roots usually extend to a depth of twenty-four inches and reach horizontally entirely across the space between the rows. When the corn comes into tassel, the roots are usually three feet deep, and when ripe, four feet and over. After the first month or five weeks, the soil is filled with roots to within two and one-half to four inches of the surface depending on the amount of moisture in it.

(139) Corn on Clover Sod. The soil to which corn is best adapted is a deep, fertile, somewhat open textured loam having a large water-holding capacity, but a surface such that it becomes warm early. Corn is the most vigorously growing plant which we commonly raise and the one which takes the greatest amount of material from the soil, particularly nitrogen and potash. This, together with the lateness of starting, permits the use of stable manure, green manure or other organic forms such as dried blood which will be transformed into available material for the growth of the crop, as will also the roots of a clover sod. It must not be forgotten, however, that the clover, while adding large quantities of nitrogen to the soil takes away large amounts of potash and phosphoric acid, which deficiency must be made good either by stable manure or by artificial fertilizers to secure the best growth of the corn on ground not containing large amounts of available potash and phosphate.

Where the available potash and phosphoric acid in the soil is sufficient for both clover and corn, the benefit of the clover sod to the corn is very great. The Canadian Experiment Station report a yield of eight and a

half tons of green fodder per acre more on a clover sod than on ground which had grown grain the previous year. This is a gain of forty per cent.

(140) Effect of Stable Manure on Corn. The effect of stable manure is chiefly noticeable in the earliest growth of the plant. Nine average hills of the corn on the manured portion of a field which had previously grown several crops without fertilizer weighed 52.4 pounds, while that on the unmanured portion weighed 29 pounds July 29. Later during the season the difference was not so great although of course the manured portion produced a heavier crop than the unmanured, the yield being 8,440 pounds of dry matter per acre on the manured and 5,965 pounds on the unmanured. Professor Latta of the Indiana Experiment Station found that a single application of fifty tons of fresh horse manure increased the yield an average of ten and four-tenths bushels per acre per year for eleven years. He also found that an application of artificial fertilizers containing more nitrogen, phosphoric acid and potash than the crop took from the soil gave a yield of only four-fifths that of cow manure. Humus and sandy soils very frequently require potash for the growth of corn, while clay soils are frequently benefited by phosphoric acid.

(141) Potash for Corn on Marsh Soils. The marsh soils of southern Wisconsin, of Indiana and Illinois practically always contain enough nitrogen and phosphoric acid for the heaviest crops of corn, but are lacking in available potash. It is often more economical, therefore, to use an artificial potash fertilizer rather

than stable manure on these soils, provided there is other land on which the farmer can use the manure. The potash can be applied either in the form of Kainite at the rate of four to five hundred pounds per acre spread broadcast before the last harrowing in preparing the seed bed or in the form of chloride or sulphate at the rate of 75 to 100 pounds per acre applied with a drill. Care must be taken that the salt is far enough from the grain not to retard or prevent its germination. It should be three or four inches from the seed and if the soil is quite dry it may be necessary to reduce the amount used to 50 pounds per acre. The Kainite applied broadcast is perhaps as economical where the ground is to be planted to corn two years in succession, while the chloride or sulphate is preferable for a single crop of corn since it is more readily available when applied in the manner above described.

(142) Preparation of Soils for Corn. Deep plowing is especially important in the preparation of clay soils for corn and should as far as possible be done in the fall. A thorough working with the disc harrow in the spring followed by a plunker or float where necessary to break clods will then leave the ground in good condition for planting. The discing is particularly effective in compacting the soil and produces a close contact between the furrow slice and subsoil. The practice of listing so generally followed in the Southwestern states with marked success has no advantage over the usual method followed in this section.

When the corn is planted early on account of favorable weather the planting should be deeper than when

done later in the season. The planting should also be deeper on light than on heavy soils.

The root system regulates itself to the depth of planting. The distance apart of rows and of hills in the row depends on both climate and soil. In the south where the long warm season permits a very large growth much wider planting is desirable than in the North.

(142) Cultivation of Corn. Frequent cultivation is necessary but no rule as to the number of times of cultivation can be made. A light harrowing to kill weeds and fine the surface after the corn is up two inches is usually necessary. Cultivation should follow every rain to destroy the crust which it produces; care being taken to so time it as to develop the best tilth, all possible work being done when the soil is in proper condition. This cultivation should, as far as possible, be shallow so as to avoid cutting the roots which come close to the surface. A mulch of three inches is as effective as one of greater depth, while the loss to the corn by cutting of the roots which are growing in the soil near the surface where nitrification is most rapid may be serious. The results of a large number of experiments show that deep cultivation reduces the yield from three to five bushels per acre besides requiring more labor than shallow cultivation. In a wet season deeper cultivation may be necessary to cover weeds.

(143) Potatoes. The most desirable conditions for potatoes are very similar to those for corn. It is especially important that the soil be loose and not liable to bake. The cracks in the soil permit access of the sun's rays, thereby causing sunburn. On a piece of

moderately heavy clay soil, the amount of sunburn, in one case, as a result of the baking of the ground was found to be over 10 per cent. Clay loam soils containing sufficient humus to render them open textured for the development of tubers, and to prevent baking, will ordinarily give larger yields of potatoes than the more sandy soils to which they are supposed to be best adapted.

Thorough preparation of the ground is very important. Deep fall plowing followed by shallow spring plowing or discing, together with deep planting and careful cultivation to keep a proper mulch and to prevent loss of water, are the essentials for success. Flat culture is preferable to the ridging system in general, although in the event of a very wet season the ridged ground may shed the water better. Potatoes are very similar to corn in their demands on the fertility of the soil and are especially benefited by potash fertilizers. Sulphate of potassium is said to produce a better quality than chloride.

(144) Tobacco. The texture of the tobacco leaf depends on the rate of growth, on the amount of shading and on the amount of moisture in the atmosphere. It is very important, therefore, that the soil should be so rich as to cause very rapid growth of the crop and to permit close planting which shades a large part of the leaves. A heavy crop of tobacco uses large amounts of water so that the soil should have a large water-holding capacity and yet be dry enough on the surface to allow it to warm up readily in the spring.

This crop is a very heavy feeder on nitrogen and especially on potash. It therefore does exceptionally well on a good clover sod. It would be better to practice a short rotation with clover than to grow tobacco continually on the same ground. Manure is often better applied as a top dressing and disked in than plowed under.

It is bad policy to use all the manure produced on the farm on the tobacco land and allow the remainder to be exhausted. It would be better to use some potash and phosphate fertilizers on clover sod for tobacco and use part of the manure at least for other crops.

(145) Effect of Heavy Manuring on Tobacco Soils. The common practice of using excessively large applications of manure on tobacco land results in an enormous loss of phosphoric acid from fields so treated. Recent results obtained at the Wisconsin Station (see Research Bulletin No. 2, Wis. Exp. Sta.) from a study of 16 tobacco fields, whose average cropping period was 46 years, *30 years of that time to tobacco*, show an average loss of over 3,000 pounds of phosphoric acid per acre surface eight inches, above that taken by the tobacco and other crops. On the average five times as much phosphoric acid had been added in the manure as was removed by the crops. This enormous wastage of one of the fertilizing constituents which we are forced to buy when it becomes deficient should be avoided by spreading the manure over larger areas, and by rotating the tobacco with clover and other crops. How great the loss of nitrogen and potash is under the present system is now being studied at the Wisconsin Station.

(146) Tobacco Soils. The soils which give the finest quality of leaf have a certain combination of characteristics. They are usually very fine sandy loams occurring in valleys in such a situation that the water moves to the lower layer from the slopes while the surface dries off so as to be warm. The protection of the hills also doubtless increases the humidity of the atmosphere. In some cases these soils are derived from a shale which produces a soil of good texture and contains relatively large amounts of potash. Many soils which have the proper texture and situation are lacking in sufficient potash for the best tobacco production and should be fertilized with potash fertilizers; sulphate being preferable to chloride. Thorough cultivation is important, but should not be so late as to stimulate a late growth of the plant which prevents it from ripening properly.

(147) Sugar Beets. The sugar beet is best adapted to the latitude of Wisconsin, probably because of the greater amount of light during its growing period and of cool nights during its ripening period than farther south. The amount of sugar probably averages three or four per cent higher in beets grown on the fortieth parallel than in those grown on the thirty-eighth. The greater amount of sunshine of arid regions increases still more the per cent of sugar.

Sugar beets do best on rather distinct clay loam soils, although with proper fertilizers they may do well on more distinctly humus or sandy soils. Contrary to a somewhat general opinion, there is no injury to the quality of beet produced by the use of stable manure

as has been proven by the New York Experiment Station. At that place manure was found to give better results in point of yield and quality of beet than any combination of commercial fertilizers. The roots of the sugar beet do not come so near the surface as those of potatoes according to Ten Eyck and hence permit of deeper cultivation where this is desirable, although a depth of three inches is ordinarily sufficient.

The sugar beet requires very fertile soil and does well on good clover sod manured. They also do well following tobacco which has been heavily manured.

(148) Rape. Rape is an exceptionally strong feeder requiring large amounts of nitrates and hence does best in a soil very rich in humus. It should grow rapidly so as to be tender and rich in proteids. When used for a soiling crop it is therefore very desirable to prepare the ground thoroughly and manure it heavily so as to get a heavy, thick growth of tender leaves. Its cultivation should be similar to that for potatoes and when the leaves are cut off for fodder, should be cultivated at once to stimulate a new growth. On sufficiently fertile soil or one manured, it is an excellent catch crop, growing rapidly during the latter part of July and August when the moisture is sufficient. It also endures dry weather after being well rooted.

CEREALS AND FLAX.

All grain crops, in the main, are alike in their essential requirements from the soil and in their effect on it, although they differ among themselves in many minor respects. They are adapted to finer soils in general

•

than those on which the tilled crops do best, chiefly on account of their fine root system. They start growing early in the spring and hence require a store of available material at that time for the most rapid growth. This is particularly true in reference to nitrates and cereals, therefore, do best on soil which has been cultivated the previous year and has therefore accumulated nitrates. As a rule they require a relatively large amount of available phosphate.

(149) Oats. Oats are particularly well suited to the northern part of the country as is shown by the fact that a bushel of northern grown oats frequently weighs as high as forty pounds, while a bushel of southern grown oats frequently weighs only twenty pounds. The oat is a strong feeder and adapted to a very large variety of soils. The danger of lodging, however, makes it less desirable for use on heavily manured ground which has raised corn the preceding year, than rye, the strong stalk of which prevents lodging. This danger of lodging makes it desirable to use less seed on rich soil; two bushels per acre often being better than a larger amount.

(150) Rye. Rye, on account of the fact that it is sown in the fall, and therefore starts early in the spring is available for use on very light sandy soils which are liable to be too dry for other crops later in the season, although for its best development a more fertile soil is required.

(151) Wheat. Wheat makes its best growth on deep clay loam soils containing considerable humus. The large yields secured formerly in this and adjoining states were probably due to the large amounts of humus

in the virgin soils which has since been reduced by cropping. While large yields are produced in the northern regions of our own country and in Canada, experiment has shown that wheat grown farther south, in Kentucky and Tennessee, is richer in protein than that grown farther north.

(152) Buckwheat. Buckwheat probably takes less of the mineral elements from the soil than any other cereal. It does well on very light, poor soil, provided the moisture is sufficient. It is also well adapted to wild marsh lands because of the lateness with which it may be planted, thus allowing these lands to dry.

(153) Flax. Flax is particularly adapted to the open prairie loam soils, rich in humus and under proper conditions is a very profitable crop. While its requirement in the way of fertility is not as great as that of other grain, it cannot be grown on the same ground in successive years, unless treated to prevent a fungus disease. This fungus usually disappears in the course of five to eight years, when another crop may be grown. That flax does not reduce the fertility of soils as much as other grains is shown by the fact that crops do better following flax than following most of the other grains.

GRASSES.

(154) Soils for the Grasses. There is probably a wider range in the adaptation of grasses to different soils and climates than of any other group of cultivated plants. Some are adapted to very moist ground and are not injured by water standing on them for some time, but often require these conditions to make their best

growth; others again are especially adapted by their structure and habit for growing on extremely dry soil and are quickly killed by an excess of moisture. A few do well on either dry or wet soils. It is, therefore, especially necessary to select varieties of grass carefully with reference to the conditions under which they are to be grown. In general the grasses are suited to a much finer clay soil than other crops, although some of them grow better on deep humus soils than on clay.

(155) Preparation of the Soil for Grasses. In raising the grass crops nothing is more important than the securing of a strong vigorous growth at the very start. To do this it is essential that the seed bed be clean and very thoroughly prepared; much more care being necessary than in preparing ground for most other crops. While it is desirable that the soil be deep, it is particularly important that it be in the best tilth and thoroughly fined. To promote rapid growth from the start it is necessary that there be sufficient available fertility and moisture. The best condition as regards fertility can usually be produced by applying a moderately heavy dressing of well rotted manure to ground from which an early crop of cereals such as rye or barley has been taken; plowing it shallow and thoroughly discing it, then harrowing it during the following four weeks at such times as will produce the best effect on texture and then sowing grass in the early autumn. This plan, however, would frequently fail on account of lack of sufficient moisture in the fall in which case it would be necessary to wait until the early spring of the following year before sowing the grass.

When sown in the fall it may be sown with rye and in the spring with a light seeding of barley or of oats; the barley being preferable. The nurse crop should be cut rather high so as to leave the stubble for the protection of the grass.

Timothy makes its best growth on clay loam but also does well on very moist soil if not covered by water until too late in the spring. Brome grass does well in regions subject to drought on account of its very strong deep root system. It also seems to be adapted to marsh lands where it produces a finer hay than timothy.

CLOVERS.

(156) Soil Treatment for Clover. The clovers are especially valuable both for use as hay and for adding nitrogen to the soil. They are especially adapted to loam and clay loam soils containing an abundance of lime and hence grow exceedingly well on the loess soils of the Missouri and Mississippi rivers and on the glacial soils of the northern part of the country. Where the soil is not well supplied with lime this should be added at the rate of twenty to thirty bushels per acre the fall preceding the sowing of the clover (see paragraphs 58-60).

While clover has the power of using nitrogen from the air it requires larger amounts of the other elements than most crops and will make a better start on fertile soils containing considerable nitrates as well as the other elements. Better success will therefore be attained in sowing it on ground which has been manured for the crop preceding. When sown with a nurse

crop, as is desirable on soils which are at all weedy, the nurse crop should be light and one which is cut off early; hence the advantage of barley over oats or wheat. When oats are used it is usually desirable to sow not more than a bushel and a half to two bushels of grain or else to cut it early for hay, thus leaving more moisture for the clover.

CHAPTER XVII.

ROTATION OF CROPS.

(157) **Advantages of Rotation.** Among the advantages gained by raising several crops rather than a single one are, first, it distributes labor through the season or year; second, it lessens the danger of a complete failure due to unfavorable conditions for the single crop, and third, it allows of a rotation of crops. A rotation of crops is desirable because, first, it tends to improve the texture of most soils; second, allows manure to be applied to that crop which can make the best use of it at the time of application, while others are benefited by the fertility following its complete decomposition in the soil; third, it distributes the draft on the fertility of the soil and fourth, it tends to destroy diseases to which individual plants are subject. In spite of the fact, therefore, that there are some disadvantages in rotation such as that it sometimes requires the growth of a crop on a field to which it is not best adapted and sometimes does not give the most convenient placing of crops for the work of raising them; yet it is on the whole very desirable in general farming.

(158) **Some effects of Rotation.** In the raising of grain it is found that continuous cropping of a soil develops a very poor texture, probably the result of the

thorough drying which these crops produce. This unfavorable condition of texture is very largely remedied by raising a tilled crop such as corn or potatoes on the soil. A very striking illustration of the increase in the yield of grain due to interrupting continuous crops with corn, is reported from the experiment station of North Dakota. On a very uniform piece of ground wheat was grown for five years preceding 1899. That year wheat was grown on one plot, corn on a second, potatoes on a third and the fourth was summer-fallowed, being cultivated and kept free from the weeds. The following year wheat was sown on all of these plots with result that the yield on the ground which had grown wheat continually was 7.1 bushels per acre; on the plot which grew corn the year previous the yield was 25.1 bushels; on the one which grew potatoes, 24.3 bushels; and on the summer-fallowed plot, 29 bushels per acre. While this influence is doubtless greater in that state than it would be here under different conditions of soil and moisture, there is no question about its importance throughout this region.

The application of stable manure is very desirable in raising corn and potatoes, while when used on grain ground directly there is danger of rank growth, causing lodging and incomplete filling of grain. The grain however, is very much benefited by the application of manure to the tilled crop the previous year.

A considerable part of our prairie region is not well adapted to permanent pasture grasses and better pastures are secured for a year or two following a crop of hay or clover and timothy; these grasses being sown

with one of the grains as a nurse crop. Many crops are subject to diseases and insect enemies which become worse with successive crops on the same ground. Among these may be mentioned the corn root worm in corn, the Hessian fly in wheat and the fungus disease of flax. A rotation of crops is very helpful in destroying these.

(159) Systems of Rotation. The basis of many systems of rotation is a three-fold division of, first, tilled crops, second, grain or cereal, and third, grass crops. The number of crops of each of these three kinds introduced into the rotation depends chiefly on the relative amount of each kind which the farmer wishes to raise. If it is desired to plant one-third of cultivated land to corn, one-third to grain and one-third to hay then a three year system would be developed. The use of the hay ground for pasture the following year would make it a four year rotation. If, however, twice as much ground is to be planted to one of these three classes, than to another, then this class must occupy the ground two years in succession. So in some of the northern states a five year system is developed consisting of first, corn; second, barley or wheat; third, a second grain crop such as oats or rye with which clover or timothy are sown; fourth, hay; and fifth, hay and pasture. An excellent short system adapted to farming without stock raising consists of first, clover, second, potatoes, and third, winter wheat. This is often profitable in the vicinity of towns where manure can be procured and where the clover can be readily sold at a good price after having added nitrogen to the soil.

CHAPTER XVIII.

TYPES OF SANDY SOILS AND THEIR MANAGEMENT.

(160) Types of Sandy Soils. The term "sandy soils" may be used to cover a considerable range of variation in physical texture, including every thing from coarse, wind blown sands to comparatively fine sandy loams. It also includes considerable variation in the amount of organic matter. They may be roughly subdivided into three classes:

1. Coarse sandy soils,
2. Sandy loam soils,
3. Black sandy loams.

COARSE SANDY SOILS.

(161) Management of Coarse Sandy Soils. Coarse sand soils are seriously deficient in many of the important factors which go to produce fertility. The water-holding capacity is frequently the limiting one, but they are also deficient in nitrogen on account of the readiness with which any vegetable matter which they may contain is oxidized and lost. They are also extremely low in potash and even in phosphoric acid. Indeed it is practically necessary for one operating on such soils to make the soil. They are also difficult to

manage on account of the readiness with which the sand is blown by the wind.

Such soils, however, have some advantage in the readiness with which they warm up in the spring and after rains. The treatments especially called for on such soils are:

1. Protection from wind,
2. Increase of humus and nitrogen,
3. Addition of essential mineral elements,
4. Cultivation to conserve moisture.

(162) Protection from Wind. It frequently happens that wind storms, especially of spring and early summer, blow these sands with such force as to cut crops entirely to the ground. Corn after reaching a height of two or three feet frequently has its leaves stripped from the stalk, and tomatoes that have been transplanted three or four weeks may be so entirely destroyed that one would scarcely think that the field had ever been planted. This destruction by the wind can be lessened by leaving strips of Jack pine and other native vegetation between comparatively narrow strips of cultivated lands. Such wind breaks should be two or three rods wide and should be left along roads and fences, and at frequent intervals across the larger fields. This protection, while helpful, is not complete and should be supplemented by so arranging the cultivated crops that those which are sown in the fall and soon cover the ground in the spring, as rye, alternate with corn and other crops planted later in the season. By arranging lands in narrow strips of not more than six or eight rods wide in this way, great protection can be given.

(163) **Increase of Humus and Nitrogen.** On account of the great water-holding capacity of humus it is extremely important to increase this material in sandy soils as much as possible. Where such soils are comparatively flat and not too high above ground water their humus can probably be increased somewhat by careful management. The turning under of green manuring crops, or letting the land lie in clover and grasses for two and three years without cutting, will doubtless increase the humus to some extent. It must be recognized, however, that the conditions are entirely-unfavorable to the development of humus, and that only by the greatest care can this be accomplished. The supply of nitrogen for cultivated crops should as far as possible be gained by fixation through legumes, but it must be recognized that the nitrogen fixed in one crop of legumes is exhausted quickly in the succeeding year when under cultivation. The nitrogen left by the legumes is largely consumed by the first crop, so that short rotations are necessary. Except under unusual conditions of origin, such as an arid climate, or where affected by glacial action, or by the presence of limestone rock, sandy soils are as a rule acid and for the growth of medium red clover, alfalfa, and some other legumes, treatment with ground limestone or marl or other lime carbonate is necessary to secure good results. (See paragraphs 59 and 60.) Some other legumes, such as serradella, yellow lupine, and alsike clover are less affected by acidity and may be used to advantage where the lime treatment is omitted (See paragraph 56).

(164) Addition of Essential Mineral Elements.

The addition of potash and phosphoric acid may be in the form of barnyard manure or commercial fertilizers. Manure used on such lands should ordinarily be well rotted in order to avoid the drying effect of material used in bedding, but, of course, special care is necessary in this composting to prevent loss of the soluble material as indicated in paragraph 126. The commercial fertilizers muriate and sulphate of potash, or wood ashes where available, should be used as indicated in paragraph 88. Phosphoric acid may be applied in the form of floats if thoroughly incorporated with manure or applied on a good green manuring crop or clover sod, but under other conditions acid phosphate should be used.

(165) Cultivation to Conserve Moisture. No other soils require as much care in their cultivation to conserve moisture as do the sands. Constant cultivation during a dry season to prevent the firming of such soils will thereby greatly lessen evaporation and materially increase the crop.

(166) Crops for Sandy Soils. On account of the low water-holding capacity of these soils they are adapted especially to those crops which have relatively low water requirements, such as the grains, especially rye, which being seeded in the fall is in condition to begin growth immediately in the spring. Beans and buckwheat are well adapted to sandy soils. On account of the readiness with which they can be worked such crops as potatoes, strawberries and other truck crops can be profitably grown on these soils when sufficient care is taken to have these crops go onto the land after a good

green manuring crop or on a good clover sod, the organic matter of which will retain a good supply of moisture for at least one year.

SANDY LOAMS.

(167) Management of Sandy Loams. Sandy loam soils vary all the way from distinct sandy soils to silt loams and clay loams. The lighter phases have the same general characteristics of those of the distinctly sandy soils though to a less marked extent and their management is therefore very much easier. These soils on account of considerably larger water-holding capacity, although still low enough to permit them to become warm readily are exceptionally well adapted to a considerable range of crops, especially truck and small fruit. Many soils of this general class have a very high value on account of their natural adaptation to these crops. Their management is similar to that of the sandy soils.

BLACK SANDY LOAMS.

(168) Management of Black Sandy Loams. There are considerable areas of black sandy loam soils which have been formed by the gradual drying up of marshes having a sandy subsoil. This leaves a sandy soil with a large amount of black humus. Such soils are better than the distinctly sandy soils not having much humus, in that they possess a good water-holding capacity. However, their fertility is often not much greater than sandy soils since this black humus may be of an acid character and contains relatively little mineral matter

and moreover oxidizes slowly when present in considerable amounts. Its oxidation after cultivation will usually yield a fair supply of nitrogen to growing crops, but such soils are apt to be deficient in both potash and phosphate, and require either barnyard manure or commercial fertilizers to supply this deficiency. They are apt also to be quite highly acid and for the growth of clover or alfalfa would require lime treatment. This class of soils, while better adapted than the coarse sandy soils to such crops as corn and potatoes and other crops requiring large amounts of water, are not so well adapted for growing vegetables as are the fine sandy loams above mentioned.

CHAPTER XIX.

TYPES AND MANAGEMENT OF CLAY SOILS OF
HUMID REGIONS.

(169) **General Character of Clay Soils.** Clay soils vary in texture from fine sandy loams to heavy clays. As a class they are more subject to erosion than are sandy soils and the influence of topography is therefore much greater. Their water-holding capacity is so great that drainage is an important factor. On account of their good water-holding capacity it is less difficult to maintain humus and therefore nitrogen than in the case of the sandy soils. Clays have a much larger amount of available potash, but the supply of phosphoric acid is frequently too small to balance the other conditions so that these soils need phosphate treatment. Three types of clay soils will be mentioned, each of which has some distinct characteristics.

HEAVY CLAY SOILS.

(170) **Occurrence.** There are considerable areas of very heavy clay soils in the northern part of the country, most of which were formed either in lakes which existed during the glacial period or in former extensions of present lakes. The heavy red clays of the Lake Superior and Green Bay area and the heavy

clays of the Red River Valley may be cited as illustrations.

(171) **Drainage.** From their mode of origin such clay lands are frequently so level as to have poor surface drainage and, on account of their extreme fineness, also lack underdrainage. Drainage is, therefore, the all important treatment required for their improvement. This may be either surface or underdrainage. By the laying out of fields on such soil in narrow plow lands, the dead furrows of which are deepened and either retained permanently or at least two years out of three in the same place, and these dead furrows connected with end ditches, great improvement in surface drainage may be effected.

Underdrainage by tile constitutes a permanent improvement of such soils of the greatest possible value. It greatly lessens the care which is necessary to effect surface drainage, and on many flat clay soils, is much more effective than surface drainage can be. It is often supposed that such tenacious clays cannot be tile drained, because it is thought that the water cannot move horizontally through them. As a matter of fact most of these fine clay soils usually check and crack to a considerable extent on drying out during a dry season and if underdrained by tile, water falling will pass out quite readily through the checks and cracks so that these are retained and the physical condition improves from year to year. It has been demonstrated repeatedly by practical experience that the heaviest of these clays can be successfully tile drained.

(172) **Tilth of Heavy Clay Lands.** Heavy clay lands when plowed in the fall and allowed to lie in the rough furrow will be found to greatly improve in texture, provided sufficient care is taken not to cultivate them when so wet that puddling would result. Such treatment will improve tenacious clays, so that, while at the beginning of their cultivation their working costs at least double the labor for ordinary clay loam soils, they can be so improved that the labor involved is comparatively little greater than that on much lighter soils. The thick roots of such plants as clover and alfalfa by their rapid decomposition greatly aid in the development of good tilth on such soils. The use of coarse manure is also beneficial in this respect. It has been the practice in older countries to apply lime to such soils for the purpose of improving their tilth. This effect it undoubtedly has, but it may also cause the burning out of the organic matter, which frequently exists in very small quantities in such soils, so that its use for this purpose is questionable. At least two tons of quick lime per acre are necessary to effect a noticeable improvement in the tilth.

(173) **Fertilizer Requirements.** As above stated, these soils are apt to be deficient in nitrogen and phosphate. Nitrogen should be supplied by the growth of clover or other legume and the phosphate can be most cheaply supplied in the form of floats, though where little organic matter is present and no manure available acid phosphate should be used instead. (See Paragraph 84.) Peat, which is frequently available in the vicinity of both clay and sandy soils, contains in a partially dry condition two or three times the amount

of nitrogen contained in barnyard manures, and while it becomes available slowly its application at the rate of 20 to 30 loads to the acre is very effective in adding nitrogen to such soils.

(174) Crops for Clay Soils. The large water-holding capacity of such soils renders them particularly adapted to grasses, but they are also well adapted to grains such as wheat and barley. Heavy clay soils are apt to be comparatively cold and are consequently less well adapted to corn. When kept in good tilth fair yields of root crops can be obtained, though this soil is not especially adapted to such crops.

EXHAUSTED CLAY LOAM SOILS.

(175) Management of Exhausted Clay Loams. Large areas of the central and eastern states consist of clay loam soils which have been under crop from two to five generations, largely in grain, with comparatively little regard to maintaining their fertility. Soils which have this history are characterized by low organic matter, much acidity, and lack of available phosphates, and require treatment accordingly. The acidity must be corrected by the use of lime or lime carbonate, as indicated in paragraphs 58 to 60, in order to permit the growth of good nitrogen fixing legumes which will add the necessary nitrogen for other crops. Since these lands are as a rule adapted to dairying or the raising of other classes of live stock, manure should be available, which, when supplemented with floats or rock phosphate, as indicated in paragraph 84, will add the necessary phosphate. The use of green manuring crops

and of pasture in rotation will increase the humus supply. This treatment is important not only for its influence on fertility, but also for its tendency to retard erosion to which these soils are particularly subject.

ROUGH CLAY LANDS AND EROSION.

(176) **Management to Lessen Erosion.** Large tracts of clay soils along our rivers and their tributaries are so steep that they constitute a distinct type of agricultural lands. The cropping of such lands by cultivated crops greatly increases the tendency to erosion, which is the greatest difficulty met with in the management of these soils. Such lands are therefore best fitted for grazing purposes. It is especially important in the selection of farms in such regions that care be taken to have the farm include some sufficiently level land to permit of considerable cultivation, as well as considerable rough land which must be used as pasture. It is frequently possible to take off one crop of corn every fourth or fifth year without serious injury since the newly broken sod is very much less liable to wash than the soil after the sod is rotted.

The withdrawal of water from side hills through dead furrows or shallow ditches leading to the main ravines, which can be kept well grassed greatly retards the erosion by lessening the amount of water going over the surface. Dead furrows used for this purpose should have a low gradient. This system of contour plowing will greatly lessen erosion of lands having less steep slopes, although kept in cultivated crops a large portion of the time.

CHAPTER XX.

MARSH SOILS.

(177) **Characteristics of Marsh Soils.** Marsh soils have been formed by the drying up and filling in of lakes and marshes to such an extent as to permit their drainage and cultivation. They are characterized by an excess of organic matter and a deficiency of the mineral elements. These soils may have either a clay or sand subsoil and vary greatly in depth. An important distinction may be made between marsh soils which are acid and those which are neutral.

ACID MARSH SOILS.

The excess of organic matter in marshes develops acidity and causes, when not neutralized by lime, a distinctly acid soil. Such soils exist in regions of granitic and other crystalline rocks and of sandstone. They include practically all of the marshes of central and northern Wisconsin and large areas of Minnesota and Michigan and other states. These soils are usually largely formed of sphagnum moss producing a peat and varying in depth from a few inches to 12 or even 15 feet. They are extremely light in weight, a cubic foot of dry peat weighing but 15 pounds as compared with 70 pounds for a cubic foot of an ordinary clay loam soil.

(178) · **Nitrogen and Acidity of Peat Soils.** The excess of nitrogen in peat soils usually makes it unnecessary to grow legumes for the purpose of increasing nitrogen. It is therefore unnecessary to neutralize their acidity as in the case of sandy or clay soils. Indeed the acidity is frequently so concentrated that the amount of lime which would be necessary to neutralize it would make the expense prohibitive. It occasionally happens, however, that such soils are so cold that nitrification does not take place readily and under such conditions a nitrogen fertilizer may be used. This is true of considerable areas of peat lands in Europe, but has met with by the writers to a very slight extent in this country.

(179) **Phosphate and Potash.** Acid marsh soils, in common with acid soils generally, are deficient in available phosphates. Indeed this deficiency is more striking in the case of peat lands than of most other soils. In many cases without the addition of a phosphate fertilizer in some form, the yields are unprofitably small. On account of the abundance of organic matter and the acidity in such soils raw rock phosphate can be used to advantage to supply this element. Half a ton to the acre for the first treatment and 300 to 400 pounds every third or fourth year thereafter will be sufficient to supply the phosphorus for the growth of good crops. These soils are usually very deficient in potash, and this may be supplied in the form of wood ashes, of which 30 to 40 bushels per acre is a good treatment, or of muriate or sulphate of potash, of which 100 to 150 pounds to the acre every year is sufficient.

(180) Crops for Acid Marsh Soils. These lands in the colder sections of the country are more subject to frosts than upland and for this reason they are not well adapted to corn and potatoes, for which they would otherwise be well suited. The leading crop on such lands should be the hay grasses, of which timothy and alsike clover are perhaps the best. When given the above mentioned treatment with phosphate and potash fertilizers, such soils should yield from two to two and one-half tons of excellent hay annually. Rape, millet, and buckwheat are other crops well adapted to such lands.

NEUTRAL MARSH SOILS.

(181) Characteristics of Neutral Marsh Soils. Within the region covered by glaciers during the glacial period and where underlaid by limestone rocks, the surface soils have usually been thoroughly mixed with ground limestone from the rock below. This lime carbonate is being dissolved out gradually by percolating waters and carried to the marshes, so that the acidity, produced by the decomposition of vegetable matter is neutralized. As a rule, therefore, the marshes of such regions as the southeastern portion of Wisconsin are not acid. They differ in this respect from the central and northern, part of the state. The subsoil is most commonly clay. These soils, therefore, ordinarily nitrify more rapidly than the acid marsh soils, and seldom show need of phosphate fertilizers. They are, however, often deficient in potash.

(182) Neutral Marsh Soils and Potash. The only difficulty met with in regard to the fertility of the

neutral marsh soils is their deficiency in potash. On drained marsh soils of this type, patches varying from a few square rods to many acres develop, on which corn or other crops turn yellow at a very early stage in their growth and therefore fail to mature. This, where the drainage is good, is practically always an indication of lack of potash, and the addition of a potash fertilizer alone will enable this soil to produce heavy yields. From 100 to 150 pounds of sulphate or muriate of potash on such soils will frequently be found to be as effective as a fair application of barnyard manure. Where the muck or peat is not too deep, say from 12 to 16 inches, its cultivation during a period of years will cause it to settle, so that deep plowing and the roots of crops will reach the clayey subsoil. This subsoil contains an abundance of potash, so that the deficiency in this element which exists at first often disappears, and special potash treatment becomes unnecessary. Of course continued cultivation will require a general fertilizer such as barnyard manure.

(183) Crops for Neutral Marsh Soils. These soils are adapted to the same crops as acid marsh soils, but when so situated that frost is not troublesome are especially adapted to corn. If well fertilized with potash, cabbages can be successfully grown on the neutral marsh soils.

APPENDIX.

EXPERIMENT STATION BULLETINS RELATING TO SOILS
AND SOIL TREATMENT.

The following list, although very incomplete, includes some of the more important experiment station literature available in bulletin form, bearing directly upon the subject of Soils. Earlier bulletins, and material published in the various Annual Reports can be consulted at the Agricultural Library. Wisconsin students will find that bulletins issued by the Illinois, Iowa, Ohio, Minnesota, and Wisconsin Stations bear more directly upon Wisconsin conditions than those from other stations.

NORTH CENTRAL.

ILLINOIS.

- Bulletin No. 99—Soil Treatment for the Lower Illinois Glaciation. (Hopkins.)
Bulletin No. 115—Soil Improvement for the Worn Hill Lands of Illinois. (Hopkins.)
Bulletin No. 123—The Fertility in Illinois Soils. (Hopkins.)
Bulletin No. 125—Thirty Years of Crop Rotations on the Common Prairie Soil of Illinois. (Hopkins.)
Circular No. 82—Physical Improvement of Soils. (J. G. Mosier.)

- Circular No. 110—Ground Limestone for Acid Soils. (Hopkins.)
- Circular No. 116—Phosphorus and Humus in Relation to Illinois Soils. (Hopkins.)
- Circular No. 127—Rock Phosphate or Acid Phosphate. (Hopkins.)

IOWA.

- Bulletin No. 1—Extension Division—Farm Manures. (A. H. Snyder.)
- Bulletin No. 82—The Principal Soil Areas of Iowa. (Stevenson et al.)
- Bulletin No. 95—The Maintenance of Fertility with Special Reference to the Missouri Loess. (Stevenson, et al.)
- Bulletin No. 78—Drainage Conditions in Iowa. (Stevenson and Christie.)
- Bulletin No. 98—Clover Growing on the Loess and Till Soils of Southern Iowa. (Stevenson and Watson.)

WISCONSIN.

- Research Bul. No. 2—Factors Influencing the Phosphate Content of Soils. (Whitson and Stoddart.)
- Bulletin No. 138—Land Drainage. (Whitson and Jones.)
- Bulletin No. 85—Development and Distribution of Nitrates and Other Soluble Salts in Cultivated Soils. (King and Whitson.)
- Bulletin No. 93—Development and Distribution of Nitrates in Cultivated Soils. (King and Whitson.)
- Bulletin No. 139—Principles and Maintenance of Soil Fertility. (Whitson and Stoddart.)
- Bulletin No. 146—Drainage Conditions of Wisconsin. (Whitson and Jones.)
- Bulletin No. 147—Report on Northern Sub-Station Work. (E. J. Delwiche.)
- Bulletin No. 174—The Conservation of Phosphates on Wisconsin Farms. (Whitson and Stoddart.)
- Circular No. 6—Synopsis of Wisconsin Drainage Laws. (E. R. Jones.)
- 23d and 24th Annual Reports—Articles on Nitrogen Content of Soils as Affected by Methods of Farming. (Whitson, Stoddart, McLeod.)

OHIO.

- Bulletin No. 150—Ohio Soil Studies I, (Chemical and Mechanical Analysis of the Soils Under Experiment). (Selby and Ames.)
- Bulletin No. 159—The Maintenance of Fertility (Liming the Soil). (Thorne.)
- Bulletin No. 182—The Maintenance of Fertility (Field Experiments with Fertilizers on Cereal Crops and Potatoes. Results for Thirteen Years). (Thorne.)
- Bulletin No. 183—The Maintenance of Fertility, Production, Reinforcement, and Value of Manure. (Thorne.)
- Bulletin No. 184—The Maintenance of Fertility (Thorne) (Statistical Data (1894–1906 inclusive).
- Bulletin No. 206—Field Experiments with Fertilizers and Manures on Tobacco, Corn, Wheat, and Clover in the Miami Valley. (Thorne.)
- Circular No. 79—How to Determine the Fertilizer Requirements of Ohio Soils. (Thorne.)

MINNESOTA.

- Bulletin No. 70—Influence of Wheat Farming Upon Soil Fertility. (Harry Snyder.)
- Bulletin No. 89—Soil Investigations:
1. The Influence of Crop Rotations and Use of Farm Manures upon the Humus Content and Fertility of Soils.
 2. The Water-Soluble Plant Food of Soils.
 3. The Production of Humus in Soils. (Harry Snyder.)
- Bulletin No. 94—Soil Investigations. (Snyder.)
Part 2. Loss of Nitrogen from Soils.
- Bulletin No. 109—The Rotation of Crops. (Hays, Boss, & Wilson.)

EASTERN.

RHODE ISLAND.

- Bulletin No. 90—Top Dressing Grass Lands. (Wheeler and Adams.)
- Bulletin No. 96—Influence of Lime upon Plant Growth. (Wheeler.)

- Bulletin No. 114—A Comparison of Nine Different Phosphates upon limed and unlimed Land with Several Varieties of Plants. (Wheeler and Adams.)

VERMONT.

The following Vermont Bulletins are the "special feature" articles contained in the Annual fertilizer bulletins of the Vermont Station.

- Bulletin No. 130—Soil Biology in its Relation to Fertilization. (J. L. Hills, et al.)
 Bulletin No. 135—Soil Deterioration and Soil Humus. (J. L. Hills, et al.)
 Bulletin No. 143—Soil Physiography. (J. L. Hills, et al.)

PENNSYLVANIA.

- Bulletin No. 90—Soil Fertility. (Thomas F. Hunt.)

MARYLAND.

- Bulletin No. 66—Lime—Sources, and Relation to Agriculture. (H. J. Patterson.)
 Bulletin No. 70—Chemical Composition of Maryland Soils. (Veitch.)
 Bulletin No. 110—Investigations on Liming of Soils. (H. J. Patterson.)

NEW YORK (Cornell Sta.).

- Bulletin No. 254—Drainage in New York. (E. O. Fippin.)
 Bulletin No. 264—Experiments in the Growth of Clover on Farms where it once grew, but now fails. (G. F. Warren.)

WESTERN.

CALIFORNIA.

- Bulletin No. 128—Nature, Value, and Utilization of Alkali Lands. (Hilgard.)

COLORADO.

- Bulletins Nos. 46, 58, 65, 72—A Soil Study (in four parts). (W. P. Headden.)
 Bulletin No. 99—How can we maintain the Fertility of our Colorado Soils? (W. P. Headden.)

WASHINGTON.

Bulletin No. 85—Washington Soils. (R. W. Thatcher.)

UTAH.

Bulletin No. 100—Arid Farming Investigations. (W. M. Jardine.)

Bulletin No. 104—The Storage of Winter Precipitation in Soils. (J. A. Widtsoe.)

NEW MEXICO.

Bulletin No. 61—Dry Farming in New Mexico. (J. J. Vernon.)

OREGON.

Bulletin No. 90—Acid Soils. (A. L. Knisely.)

WYOMING.

Bulletin No. 80—Dry Farming in Wyoming. (J. D. Towar.)

MONTANA.

Bulletin No. 74—Dry Farming Investigations in Montana. (Atkinson and Nelson.)

SOUTH DAKOTA.

Bulletin No. 54—Subsoiling. (N. E. Hansen.)

SOUTHERN.

TEXAS.

Bulletin No. 99—Composition and Properties of Some Texas Soils. (G. S. Fraps.)

FLORIDA.

Bulletin No. 93—Acid Soils. (A. W. Blair and E. J. Macy.)

MISSISSIPPI.

Bulletin No. 108—On Prevention of Erosion, etc. (C. T. Ames.)

KENTUCKY.

Bulletin No. 126—Soils. (Peter and Averitt.)

INDEX.

- Absorption of water by seed, 1.
Acidulated bone, 64.
Acid Phosphate, 64.
Acid soils, marsh, 136; prevalence of, 42; treatment for, 45.
Acidity 42, and availability of phosphate, 59; effects on different plants, 44; harmful effects of, 43; origin of, 43; test for, 42.
Aeration, 50; effect on formation of humus, 33.
Agencies in soil formation, 20.
Alkali soils, 22.
Availability of phosphates, 59.
Availability of potash, 65.
- Beets, sugar, 115; manure on, 115; soil for, 115.
Bone, Acidulated, 64.
Bone meal, raw, 63; steamed, 63.
Buckwheat, 118.
- Capacity of soil for water, 75.
Capillary rise of water, 81.
Capillary water, amount, 76.
Cereals, soils for, 116.
Chemical requirements of crops, 12.
Classification of soils, 101.
Clay, definition of, 69; flocculation of, 73.
Clays, heavy, 131; crops for, 134; drainage, 132; fertilizers for, 133; erosion of, 135; improvement of tilth, 133; occurrence, 131.
Clay loams, management, 134.
Clays, rough, erosion, 135.
Climate, relation to crop, 107.
Clover, soil treatment for, 120.
Corn, 108; cultivation of, 112; on clover sod, 109; manure on, 110; on marshes, 110; roots of, 108.
Crops, 107; for acid marsh soils, 138; chemical requirements of, 12; for green manuring, 40; for heavy clay soils, 134; for neutral marsh soils, 139; rotation of, 122.

Cultivation, objects of, 90.

Cycle of nitrogen, 48.

Denitrification, 74.

Distribution of elements in plants, 9.

Drainage, advantages of, 81; of heavy clay soils, 132.

Dried blood, 56.

Early soils, 128.

Erosion of clays, 135.

Fallowing, effect on nitrification, 52.

Fertilizers, nitrogen, 56; phosphate, 62, 63, 64; potash, 66.

Fertility, factors influencing, 27, 28, 29; limiting factors, 29-31; revolving fund of, 26.

Flax, 118.

Floats, 64.

Flocculation of clay, 73.

Fruition, conditions influencing, 17.

Germination, conditions necessary, 1.

Glacial soils, 22.

Grass and grain soils, 102.

Grass soils, 118; preparation of, 119.

Green manuring, 40.

Ground limestone, 45.

Ground water, 80.

Growth, 1; conditions for, 4; rate of, 16; relation to light, 14; relation to soil, 18.

Heavy clays (See clays, heavy)

Humus, 32; composition, 32; effect on temperature, 37; effect on texture, 37, 73; effect on soil organisms, 38; function, 35; loss of, 38; maintenance of, 39-41; origin, 24; plant food in, 35; water-holding capacity of, 36.

Hydroscopic moisture, 75.

Inoculation of soil, 54.

Kaolin, 20.

Leaching of lime, 28.

Leaching of nitrogen, 55.

Legumes, nitrogen fixation by, 52, 53.

Legumes on sandy soils, 127.

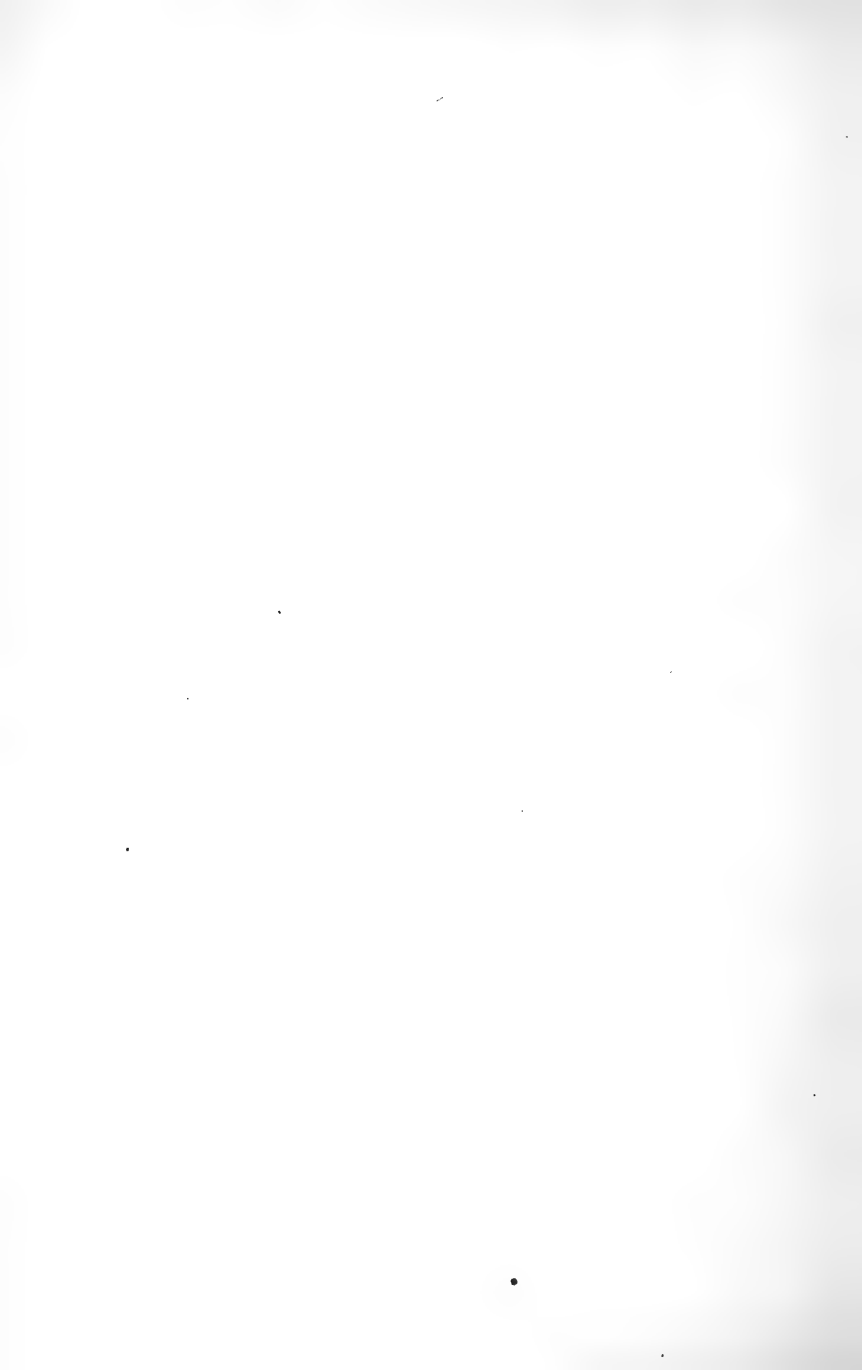
Light, relation to plant growth, 14.

Lime, application of, 45.

- Limestone, ground, 45.
Lime refuse, 46.
Limiting factors in fertility, 29.
Loams, clay, 134.
Loams, sandy, 129.
Lodging, 17.
Loess, 24.
- Management of soils, 125; of heavy clay soils, 131; of rough clay lands, 135; of acid marsh soils, 137; of neutral marsh soils, 138; of coarse sandy soils, 125; of sandy loams, 129; of black sandy loams, 129.
- Manure, 95; amount produced by live stock, 96; application, 99; care of, 98; composition of fresh, 96; composition of liquid and solid, 97; litter, 98; lasting effect of, 100; manure on corn; 110; re-inforcement of, 99; value of, factors influencing, 95.
- Marl, 46.
- Marsh soils, 136; acid, 136; character, 136; need of phosphate and potash, 137; neutral, 138; nitrogen in, 137.
- Mechanical composition, 68; and texture, 71.
- Mineral plant food in humus, 35.
- Moisture of soil, availability to plants, 77.
- Movements of soil water, 79.
- Nitrates, close use by plants, 51.
- Nitrification, influenced by, 49; aeration, 50; character of humus, 51; moisture, 50; reaction of soil, 51; temperature, 50.
- Nitrogen, 47; amount in soil, 47; cycle of, 48; fertilizers, 56; removal from soil, 55; in humus, 35; kinds of in soil, 47.
- Nitrogen, fixation, 52; amount of, 53; conditions favoring, 53.
- Neutral marsh soils, 138.
- Oats, 117.
- Organic matter, decomposition, 34, 87.
- Origin of soil material, 19.
- Oxidation of vegetable matter, 33.
- Oxygen, relation to germination, 3; to nitrification, 50; to denitrification, 55.
- Percolation and seepage, 80.
- Phosphorus, function in plants, 10.
- Phosphorus in soils, 58; amount, 58; availability of, 59; maintenance of, 62; occurrence of, 58; relation to method of farming, 60; soils deficient in, 59.

- Phosphate fertilizers, 62.
Plant, character of in relation to character of soil, 105.
Plant food in humus, 35.
Plant food removed by crops (Table) 8
Potash, function in plants, 10.
Potash in soils, 65; amount, 65; availability, 65; loss of, 66.
Potash fertilizers, 66; for corn on marsh soils, 110.
Potatoes, 112.
- Rape, 116.
Raw bone meal, 63.
Residual soils, 20.
Rock phosphate, 64.
Rocks forming soils, 19.
Roots of corn, 108.
Roots and texture, 74.
Rotation of crops, 122; advantages of, 122; effects of, 122; systems of, 124.
Rye, 117.
- Sand, definition, 69; effect on mechanical composition, 70, 72.
Salts, influence of on germination, 3; amount taken up by plants, 5, 7.
Sandy loams, management, 129.
Sandy soils, 125; acidity of, 127; conservation of moisture in, 128; crops for, 128; legumes on, 127; management of 125; maintenance of humus and nitrogen in, 127; types of, 125.
Seepage, 80.
Slope of land, effect on temperature, 86
Soil grains, area of surface per pound, 71.
Soil, origin, 19; classification of, 101.
Steamed bone meal, 63.
Subsoil, 24.
Sugar beets, 115.
- Temperature for germination, 2.
Temperature, relation to growth, 16.
Temperature of soils, 83; influenced by amount of water, 84; character of soil, 84; organic matter, 87; roughness of surface, 85.
Texture, 71; effect of cultivation on, 74, 90; of humus on, 73; of freezing and thawing on, 74; of water, 72; relation to roots, 74; relation to soil solutions, 73; relation to tilth, 71.
Tillage, objects of, 90.

- Tobacco, 113.
Tobacco soils, 115; effect of heavy manuring on, 114.
Translocation of material in plant, 17.
Transpiration current, 13.
Transpiration, rate of, 13.
Truck soils, 101.
- Ventilation of soils, 88; necessity for, 88; agencies causing, 88; excessive, 89.
Variation, 6; in fertilizing constituents at different stages of growth, 6; in composition during growth, 9.
- Water, absorption by seed, 1.
Water in soil, 76; availability to plants, 77; capillary, 76; cultivation to increase, 77; kinds of, 75; movements of, 79; removal of, 81.
Water used by plants, 13, 14.
Wheat, 117.
Wind breaks, 126.





LIBRARY OF CONGRESS



00014584924