Soils and Soil Fertility

FARM SCIENCE SERIES

Soils and Soil Fertility
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SOILS
AND
SOIL FERTILITY

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PREFACE

The aim of this book has been to give an outline of the principles of soil fertility in a form adapted for use in agricultural courses as given in High and other Secondary schools.

While it is assumed that students using the book will have had, or will take at the same time, a course in botany, a brief statement of the essential requirements for plant growth is made in Chapter I, to serve as a starting point in the study of the soil.

An effort has been made to make the book practical and give much information which can be immediately applied in farming, but a greater effort has been made to explain clearly the principles underlying farm practice so far as it applies to the management of the soil. It is distinctly recognized that knowledge of these principles is far from complete and that there are differences of opinion on some phases of the subject, but we have tried to give only those conclusions which are well supported by fact and accepted by the majority of authorities on the subject.

It is hoped that the laboratory exercises can be given as outlined and that field excursions and practical illustrations may be used to establish the principles discussed in the class room.

While great care has been taken to avoid error in the figures used, we can scarcely hope that no mistakes have been made in this first edition and we shall be greatly indebted to those of our readers who shall report any mistakes they may find.

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The University of Wisconsin,
October 28, 1912.

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INTRODUCTION

The business of the farmer is to produce the various food materials and those from which clothing is made. These materials are of both animal and vegetable origin; but since all agricultural animals must depend on vegetation for their food, the growth of farm crops forms the basis of all agriculture.

Two classes of factors must be considered with reference to any agricultural plant: First, those having to do with its growth, such as the fertility of the soil, the influence of climate, etc.; and second, those which have to do with its reproduction, including its relation to other plants. It is important to distinguish between production and reproduction. The purpose of this book is to discuss those factors only which determine the general growth, or production, of the plant. The second class of factors would be studied in a course in plant breeding or plant propagation.

All of the factors of soil fertility and of climate are so closely interrelated in their influence on the growing plant, that it is undesirable to discuss one class of these factors separately from the other. We shall therefore consider both the climatic and the soil influences on the growth of plants. Unfortunately, we have in our language no term covering the compound relation of these influences on the plant, and so are under the necessity of using the simple term "soil fertility" to cover both classes of factors.

CHAPTER I

CONDITIONS ESSENTIAL FOR PLANT GROWTH

1. The Three Periods in the Life of the Plant. 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 effects 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 only to one or two periods of its development.

CONDITIONS NECESSARY FOR GERMINATION

2. Essentials for Germination. The three essentials for the germination of seeds are water, a suitable temperature, and oxygen. The seed must have moisture and air to change the plant food which is stored in it to a form which can be used for the growth of the young plant. Temperature limits the influence of these factors and affects the chemical changes which take place. No other factor is important except as it influences one or all of these three primary factors of water, air, and temperature.

3. The Absorption of Water. The first act in the germination of a seed is the absorption of water. The factors which influence this process are temperature, the amount of moisture in the soil, the closeness of contact between soil and seed, and the amount of soluble salts in the soil.

4. *Influence of 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. The other influences of temperature on germination are discussed elsewhere. (See Sec. 8.)

5. *The Amount of Moisture.* A certain definite amount of moisture must be present in soils before any absorption of water can take place. The water absorbed by the seed is largely film (capillary) water; for in taking this form of water it can still get air. A seed could, of course, get all the water it needs for germination in a saturated soil, but it would not germinate on account of the exclusion of air. Seeds will not germinate in air-dry soils even though such soils may contain 10 per cent of water, for the reason that the water is held too strongly by the soil particles and will not pass to the seed.

6. *Contact of Seed and Soil.* In order that the seed may obtain this film water, the soil and the seed must be in close contact. The ease with which the seed absorbs water from the soil depends on the temperature and on the number of points of contact between soil and seed. This contact is governed by the fineness of the soil and the firmness with which it is pressed about the seed. It is for this reason that care in preparing the seed bed and in firming the soil by rolling or harrowing after the seed is planted is so essential for good germination. The fineness depends very largely on the condition of the soil while it is being prepared for seeding. The degree of fineness necessary for good germination varies with the kind and the size of the seed. The smaller seeds, such as those of the grasses and clovers, require a finer seed bed than is essential for corn or peas.

7. *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. It is in this way that salts in the soils of arid regions often prevent germination. Some salts are actually poisonous to plants, even in small quantities; while others simply prevent the water from entering the seed, and are not injurious except when present in considerable amounts.

8. **The Effect of Temperature.** 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. The averages of a few of their determinations are as follows: Wheat and barley germinated best at 75° F., red clover at 70°, and corn and rape at 90°. Corn failed to germinate at all at temperatures below 48°, while 40° was the lowest temperature at which the other seeds germinated.

There is usually little to be gained by sowing seeds in the spring so early that the ground is too cold for the best germination of those seeds, although the moisture conditions may be better early in the season for some crops, as red clover, for instance.

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

9. **The Influence of Oxygen.** The work of constructing new tissues and of forcing the newly formed root

through the soil implies a source of energy. This comes from the oxidation of food stored in the seed, just as the energy which a man uses in doing work comes from the food he consumes when it is oxidized in the muscle tissues. Therefore, the germinating seed requires a supply of available oxygen, and the soil in which it lies must allow the air to reach it, or the seed will rot. The access of air to the seed is frequently prevented by too much water and by the puddling of the soil, as will be described later.

10. The Germinating Seed Requires No Outside Food Supply. During the process of germination, the plant depends upon the food supply that is stored within the seed. In fact, the process of germination consists merely of dissolving the soluble food constituents in the seed and translocating them and building them up into new cells in another place. It is often noticed that seed will germinate and grow for a short time better in poor, sandy soil and still better in sawdust or other loose material, than in a very fertile soil. This shows that no other conditions than a suitable supply of moisture and oxygen and a proper temperature are needed for the germination of seeds.

The extent of growth made by seedlings developing in sawdust or in 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 are able to make but little growth; while larger seeds with an abundant food supply, such as the pea and bean, may develop seedlings of considerable size. In some cases, the plants reach one-fourth the size usually attained in ordinary soil, and even produce flowers.

CONDITIONS ESSENTIAL FOR VEGETATIVE GROWTH

11. The Necessary Conditions for Growth. We have noted that seeds will germinate if they have suitable conditions of moisture, temperature, and oxygen. Neither light nor outside plant food is necessary for this process, but without these growth can continue only until the supply of food in the seed is exhausted. A seedling produced in the dark and from the food supply of the seed, will be found to have practically the same dry weight as the dry seed from which it sprang. In order to gain in dry weight, the plant must obtain raw food material from outside sources, build this food material up into foods within itself, and use these foods for its continued growth. The plant requires light in order to effect some of these changes. In addition, since we commonly grow crops in soil, that soil must be easily permeable to the growing roots. The six essentials for the growth of crops are, therefore, moisture, air, light, plant food, suitable temperature, and a permeable soil. The features which distinguish growth from germination are the use of elements or food material from the soil and the utilization of light.

THE USE OF FOOD MATERIAL

12. Elements Taken from the Soil. When plants are analyzed, the following elements taken from the soil are found: Sodium, potassium, calcium, magnesium, iron, silicon, chlorin, sulfur, phosphorus, and nitrogen. With the exception of the nitrogen, these are largely left in the ash on burning. Besides these elements, there are a number of others which are often found. Some of the elements named are not absolutely necessary to growth, as has been shown by growing plants to maturity in a solution which did not contain them. Those which do not seem to be essential are sodium, silicon, and chlorin. All of the others must be present or growth will cease before maturity.

13. Foods Built Up in the Plant. The raw materials that the plant uses are the mineral elements from the soil, the carbon dioxid from the air, and the water taken in by the roots. In the green leaf of the plant, and by means of the radiant energy of the sun, the carbon dioxid and water are united into simple substances which condense into more complex compounds called carbohydrates. Starches, sugars, and crude fiber, the last being the material from which cell walls are made, are built up in this way. The process of building carbohydrates is called *photosynthesis*, which means putting things together by the action of light. Some of the very simple carbohydrate-like materials formed unite with the nitrogen from absorbed nitrates to make a new class of compounds, the proteins. Carbohydrates contain only carbon, oxygen, and hydrogen. The proteins, however, always combine nitrogen with these three elements and, in addition, small amounts of sulfur and in some cases phosphorus. Still a third class of compounds, the fats and oils, are found in plants. These are compounds closely related to the carbohydrates, and are probably built up in much the same manner. They consist of carbon, oxygen, and hydrogen.

14. Factors Controlling the Use of the Elements Taken from the Soil. The amount of any one of the various elements taken up from the soil by plants depends on three factors: First, the concentration of the salts of that element in the soil; second, the compounds that it enters into in the plant; third, the individual characteristics of the plant.

15. *Effect of Concentration.* When plants are growing in a soil containing large amounts of a given element in soluble form, more of that element is usually taken up than is actually required by the plant for its growth. It frequently happens that much larger amounts of nitrates, for instance, will be absorbed by corn than can be utilized in the growth of the plant. Instances are on record where nitrates have collected in corn stalks in this way to such an extent as to be injurious to animals eating them.

16. *Selective Power of Plants.* As a given element is used within the plant in the construction of organic compounds which are not readily soluble, the supply of that element in the sap solution is decreased. The osmotic pressure of that particular element is thus reduced within the plant, allowing additional salts containing this element to be absorbed from the soil. In this way, the element phosphorus, which is taken into the plant in inorganic salts, is built up into proteins, so that more and more of this element continues to be absorbed by the roots. On the other hand, such an element as sodium, which can be absorbed readily from the soil, is not utilized within the plant, and after the sodium in the sap solution has reached a certain concentration, diffusion outward is equal to diffusion inward, a condition of balance is established, and no more is absorbed. In this way the plant exerts what is called "selective power." It selects the elements phosphorus, potassium, nitrogen, and sulfur which it requires, and leaves those which come into the plant but which are not used in building up its compounds.

17. Variation in Content of Essential Elements at Different Stages of Growth. Not only do different kinds of plants use different amounts of each plant food, but any single 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; some of the results obtained at this station are presented here.

The quantity of potassium in the crop from an acre of wheat was computed to be 73 pounds when at a very early stage, 102 pounds when just heading out, 101 pounds when fully headed out but still green, and only 60 pounds at the ripening stage, which is less than at a very early stage. The plant had taken up large quantities of potassium, 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. Phosphorus, on the other hand, reaches its maximum amount when the plant is fully headed out, and does not materially decrease at maturity. Analyses of barley at different stages in its growth showed the same general tendencies, although the absolute quantities were different.

Quite different results were obtained with the potato. The quantity of potassium in the tubers, leaves, and stems from 1 acre of potatoes was 39 pounds when tubers were just beginning to set (June 17); 55 pounds one month later (July 16); 93 pounds two months later (August 18); and 119 pounds when the potatoes were fully ripe (October 5), showing a continual increase in the potassium absorbed. Similarly, phosphorus increased from 3.5 pounds at an early stage, to 12.2 pounds at the ripening stage; and nitrogen from 45 pounds to 111 pounds. 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 conducted under a particular set of conditions and with a particular soil. The results obtained might have been somewhat different under other conditions; for, as has been pointed out in a previous paragraph, the quantity of an element taken up by a plant depends upon the relative amount in the soil in an available form. The 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.

18. Average Amounts of Salts Removed by Crops. While, as stated in previous paragraphs, the amounts of the various salts absorbed from the soil by plants vary greatly during different stages of growth, still the quantities of the three most important elements, nitrogen, phosphorus, and potassium, found in mature crops grown on ordinary agricultural soils are quite constant for any particular plant. Since these are the quantities removed from the soil by harvested crops, they are very important to bear in mind. The following table shows the quantities of the more important elements taken by different crops from clay loam soil.

Table I. The number of pounds to the acre of nitrogen, phosphorus, potassium and calcium removed from a clay loam soil of average fertility, by given yields of various crops.

Crop	Weight of crop	Nitrogen	Phosphorus	Potassium	Calcium
	Pounds	*Pounds*	*Pounds*	*Pounds*	*Pounds*
Wheat—					
Grain, 30 bu.	1800	33	6.2	7.7	.70
Straw	3158	15	3.0	16.2	5.85
Total	4958	48	9.2	23.9	6.55
Barley—					
Grain, 40 bu.	1920	35	7.0	8.1	.85
Straw	2447	13	2.0	21.5	5.70
Total	4367	48	9.0	29.6	6.55
Oats—					
Grain, 50 bu.	1600	35	5.2	8.3	1.1
Straw	3000	15	2.6	29.1	6.8
Total	4600	50	7.8	37.4	7.9
Corn—					
Grain, 65 bu.	3640	40	7.9	12.5	.7
Stalks	6000	45	6.1	66.4	14.3
Total	9640	85	14.0	78.9	15.0
Flax—					
Grain, 15 bu.	900	39	6.5	6.6	2.1
Straw	1800	15	1.3	15.8	9.3
Total	2700	54	7.8	22.4	11.4
Peas—					
Grain, 30 bu.	1800	64.5	7.9	18.3	2.8
Straw	3500	36.4	3.0	31.5	50.7
Total	5300	100.9	10.9	49.8	53.5
Potatoes—					
224 bu.	13,440	47	9.4	63.5	2.4
Potato vines	4,274	20	1.2	0.9	16.2
Total	17,714	67	10.6	64.4	18.6

Table 1.—Continued.

Crop	Weight of crop	Nitrogen	Phosphorus	Potassium	Calcium
	Pounds	*Pounds*	*Pounds*	*Pounds*	*Pounds*
Sugar beets— (Roots only) 15 tons	30,000	48.0	10.5	82.2	8.8
Red clover— Hay, 2.42 tons	4840	(102)	10.9	69.2	64.2
Alfalfa— Hay, 4 tons	8000	(200)	17.9	95.5	135.7
Timothy hay	3000	16.2	3.5	17.6	3.6
Kentucky blue grass	4374	77.5	10.2	88.2	6.5
Tobacco leaves	1600	70.0	3.5	75.5	50.7
Cabbage, 28 tons	56,000	168	25.3	45.7	70.4

19. Distribution of Elements in the Plant. Study of the foregoing table will show that nitrogen and phosphorus go chiefly to the seed or grain of plants, while potassium and calcium 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. Fig. 1 shows the distribution of the elements between the straw and the grain of the oat plant.

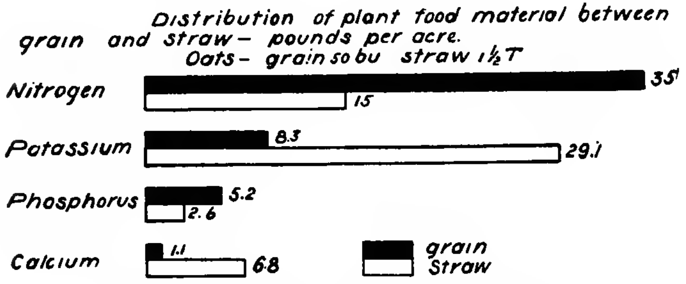

Fig. 1. Distribution of elements in the plant.

20. 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 percentage of protein and a low percentage of crude fiber, or cellulose. As the plant gets older, the cell walls become thickened; and as these walls are composed of carbohydrates, the proportion of carbohydrates then increases. Moreover, the older cells usually lose their protoplasm, which is rich in protein. Crops cut green are therefore richer in protein than mature crops. Moreover, if crops are prevented from making their full growth, the stunted crop is usually richer in protein than the crop making a larger growth. The germ is rich in protein, while the remainder of the seed consists largely of starch or some other form of carbohydrate. The starch is formed in the leaves and is translocated to the seed during the ripening stages. If conditions are not favorable to this translocation, the grain formed will be shrivelled, but will be relatively richer in protein than the fully-developed kernel would be.

21. Specific Influence of Elements on the Production of Food Constituents. Although it is comparatively easy to determine which of the elements found in the plant are essential and which are unessential to its growth, it is very difficult to find out in just what way these essential elements are used.

22. *Potassium.* One of the specific functions of potassium seems to be to aid in the process of starch formation. Corn growing on the marsh lands of Wisconsin has been greatly benefited by potassium fertilizers; and in all cases the increase of the grain, which contains a large proportion of starch, has been proportionately greater than the gain in the stalks. The formation of starch takes place in the leaves, from which it is carried to the seed. The potassium, therefore, is chiefly found in the leaves and stems of plants. The relation of potassium to carbohydrate production is well illustrated by the following figures from Hall's "Fertilisers and Manures:"

Table II. The effect of potassium on the production of mangels at Rothamsted, 1900.

Plot	Manure	Leaf per acre	Roots per acre	Sugar per acre
5A	Ammonium salts and Superphosphate.....	2.95 tons	12.00 tons	0.797 tons
4A	Ammonium salts, Superphosphate, and Potassium..........	3.25 tons	28.95 tons	2.223 tons

The quantity of sugar produced was more than doubled when potassium was added to the plot. Director Hall aptly describes the condition on plot 5A as follows: "The photosynthetical process had been limited by want of potassium; all the machinery was there and power was in excess, but the machinery was running idle for the lack of one necessary link—in this case, the potassium."

23. *Phosphorus.* Phosphorus is necessary to the formation of some proteins; and since the proteins form a larger proportion of the seed than of the stalk and leaves, the phosphorus is found in larger quantities in the seed or grain than in the stalk and leaves. Those proteins which are active in the cellular division at the growing points of the roots and tips of plants are rich in phosphrous, so that it may be said that phosphorus has a very important influence on the rate of growth of both roots and shoots of plants; and the development of roots can be directly affected by changing the phosphorus supply in the soil in which they are growing. If one root of a plant is in a soil or in a water solution rich in this element, it will grow rapidly, while another root of the same plant in a poor soil or solution will grow very slowly.

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

25. *Nitrogen.* Nitrogen is absolutely essential for the formation of proteins. The amount of protein found in the plant depends on the relative amount of nitrogen in the soil in an available form, as well as on the nature of the plant.

26. Influence of the Supply of Food Material on the Composition of the Plant. The composition of the plant is to a certain extent dependent on the relative amounts 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. Crops grown on soil very low in available nitrogen are therefore often low in protein, the most valuable food material.

Experiments made by growing corn, oats, and rape on three sand plots to which had been added different quantities of nitrates showed the following percentages of protein, where plot 1 received no nitrates; plot 2, a medium quantity; and plot 3, double this quantity. These crops

Table III. Effect of different quantities of nitrogen on the protein content of oats, corn and rape.

	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

were cut green, as they would be if used for soiling. All the plants grew normally. While there was some difference in color, those growing on richer soil having a darker green color than those on poorer soil, the plants of each kind were all of practically the same size. These experiments, with others, show that the addition of a specific fertilizer may affect the quality of the crop by promoting the formation of one valuable constituent, even though the total weight of the crop is not increased.

27. Specific Requirements of Different Crops. Since different plants produce different proportions of carbohydrates, fats, and proteins, we should expect that they would need somewhat different relative amounts of the various elements. Those plants which produce a relatively large quantity of starch, such as corn and potatoes, require considerable available potassium, while those which produce a relatively large quantity of protein require considerable nitrogen. In addition to facts such as these which we can explain, there are other cases where plants require relatively large quantities 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 their treatment with fertilizers to study some of the most important cases of these varying requirements.

Cereals, such as wheat, oats, and barley, need relatively large amounts of nitrogen and phosphorus, while not much potassium is necessary. Corn, in addition to available nitrogen and phosphorus, must have considerable available potassium, possibly on account of its large starch production. Potatoes, both white and sweet, also require considerable potassium. Timothy and most grasses require large amounts of available nitrogen. Turnips do best when plenty of phosphorus is available, 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.

RELATION OF AIR TO PLANT GROWTH

28. Plants Use Carbon Dioxid and Oxygen. Food production is a process involving the use of the sun's energy to effect the combination of carbon dioxid and water in the formation of starches and other foods (Sec. 13). Air is necessary to supply carbon dioxid; plants give off oxygen during this process. Growth, involving the production of new cells, the lifting of the shoot in the air, and the thrusting of roots into the soil, requires energy. This energy is obtained from the oxidation of food particles in the plant cells, which process unlocks the energy used in the production of those food compounds. Carbon dioxid is released in this process. Respiration, or the absorption of oxygen and the release of carbon dioxid, is continually going on in all parts of the plant. The roots need oxygen quite as much as do the leaves and other parts above ground. Plants increase in weight during growth because the assimilation of carbon dioxid and water takes place at a more rapid rate than respiration.

This use of oxygen and carbon dioxid can well be shown by a simple exercise. Sprout some barley or wheat seeds in a pint bottle, adding just enough water to keep the seeds moist. Keep the bottle in the light until the leaves are about 3 inches long. Now stopper the bottle tightly and put away in a dark place for two days. In the absence of light only absorption of oxygen can take place. At the end of the two days, test the air in the bottle with a lighted splinter. The gas in the bottle is carbon dioxid, which does not support combustion. Now again stopper the bottle and place it in the light for two days. If the lighted splinter is then thrust into the bottle, it will continue to burn, showing that oxygen is present. The oxygen must have been released by the plant in the process of carbohydrate building.

INFLUENCE OF WATER ON PLANT GROWTH

29. Uses of Water to the Plant. 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 dioxid; (2) to evaporate from the surface and prevent the plant from getting hot, just as the evaporation of perspiration from the human body tends to keep it cool; (3) to keep the cells of the plant turgid, thereby enabling it to maintain an erect position; (4) to furnish the small quantity of water needed for building the various tissues in the plant; and (5) to carry the salts from the soil into the plant and to the leaves, where they are used chiefly in the chemical changes taking place there.

30. Transpiration. The flow 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 moisture in the air, the temperature, the strength of light, and the character of the plant. Transpiration is lessened by the moisture in the air; it is increased by warmth and decreased by cold; it is increased by strong light and retarded by darkness. Some plants transpire much less than others under the same conditions because they have fewer stomata or are protected in various other ways, as by hairs and by reduction of leaf surface.

31. Amount of Water Transpired. A number of experiments have been made to determine the number of pounds of water lost by transpiration of the plant and by unavoidable evaporation from the soil for each pound of dry matter formed. Some averages of these results are approximately as follows: Barley, 465; oats, 500; corn, 275; clover, 575; peas, 475; potatoes, 385.

Fig. 2. Irrigating potatoes in experimental work at the Wisconsin Experiment Station.

From these figures it can be calculated that if no water ran off the surface or drained away, a crop of 20 bushels of wheat to the acre would require only 6 inches of rain during the growing season; a crop of 50 bushels of oats, only 8 inches; 60 bushels of corn, 10 inches; 300 bushels of potatoes, 6¼ inches; 2 tons of clover-hay, 9 inches. These figures apply to countries having a semi-humid climate, such as that of the United States east of the Missouri River. When growing in a very dry climate, plants require more moisture. Crops growing in such states as Colorado, Utah, and Wyoming, with a rainfall of from 10 to 20 inches, require from 50 to 100 per cent more water than the figures just given.

RELATION OF LIGHT TO PLANT GROWTH

32. Manufacture and Use of Food. In the development of the plant there are two processes going on. One is the process of forming starch, fats, and proteins, either for immediate use or to be stored in some part of the plant, such as the seed or root; the other is that of growth, or the development of new tissue and parts. This growth requires the use of some of the material produced in the first process. From this it can be seen that the plant differs from the animal in that the plant is able to manufacture its own food, while the animal must have its food supplied from outside sources.

The production of starch and fats in the plant requires light, while the translocation of these foods and their use in growth do 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; not only is light not necessary, but to a certain extent it retards growth.

33. *Intensity of Light.* The question as to the brightness of light necessary for producing the greatest amount of food is not entirely understood, but it is known that the strength of light received in our latitude during the mid-day hours of a clear summer day is greater than can be used by most plants. In all probability, the intensity of light at 5 P. M. during clear days in the summer is as great as crops can use to best advantage.

34. *Duration of Light.* It will be seen, therefore, that the intensity of light is not of so much importance as its duration. During the long summer days in northern latitudes much more 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; hence relatively larger quantities of these substances are produced in those regions where there are few clouds to interrupt the sunshine than where there is much cloudiness. This is probably, in part, the reason that the sugar beet produces relatively more sugar in Colorado than in the Mississippi Valley.

RELATION OF TEMPERATURE TO PLANT GROWTH

35. Temperature Affects Food Production. The most favorable temperature for the formation of food by the plant is usually the most favorable for growth. When the quantity of material produced by the plant at different temperatures is studied, 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 lowered by too high as well as by too low temperatures. Probably the most favorable temperatures for our field crops are between 70° and 75° F. Even corn, which is often supposed to need much heat, will make as good growth where the daily temperature does not rise above 75° as it does when the days are hot. Since, however, growth goes on during the night as well as by day, the influence of warm nights is very great.

INFLUENCE OF SOIL PERMEABILITY

36. Desirability of a Permeable Soil. Since it requires some energy on the part of the plant to force its roots through the soil, the permeability of the soil to the roots influences the growth of the plant. When the soil is loose and open so that the growing tips of the roots can penetrate it readily, the growth is much more rapid, providing, of course, other favorable growing conditions are present. Many crops are unable to make good growth on heavy clay soils or those having hardpan close to the surface, because their roots cannot readily spread through such soils. Proper cultivation to make the soil more permeable is therefore often a matter of great importance.

EFFECT OF RATE OF GROWTH ON THE PLANT

37. Rapid Growth Causes Succulence. 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, and the growth is more rapid in either complete or partial absence of light than when it is intense. The result is that those plants or those parts of plants which grow in the shade or 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. In the production of tender vegetables it is essential to hasten the growth in every way possible by supplying them with the best conditions of moisture, light, temperature, and food elements. Light, as already stated, is necessary for the production of the foods used in growth.

38. Lodging. The weakness of the stems of grain, which causes it to lodge, is due to the rapid growth made when there are large quantities of water available, and when the light is partly excluded either by cloudiness or by the plants shading one another. 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. An excessive nitrogen supply tends to produce too rapid vegetative growth, a condition that can probably be remedied by the addition of more available phosphorus and potassium. There is very little tendency for grain to lodge in dry regions, even when large quantities of water are used in irrigation, probably because of the continuous sunshine, although it may be due in part to the large amounts of salts, such as those of potassium and phosphorus, which are present.

CONDITIONS INFLUENCING FRUITION

39. Translocation of Material in the Plant. The object of the plant in the production of seed is to reproduce itself. As a general rule, plants tend to form seed when the conditions become unfavorable to continued rapid growth of the 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 a certain amount of growth is necessary to allow the plant to produce the seed in full maturity. It is very important that the farmer realize the difference in the conditions necessary to the production of the largest quantity 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.

40. The Production of Fruit. The formation of the fruit of plants is the result of the movement of material from the leaves, where it is produced, to the seed or other fruit, where it is stored. In most of our crop plants growing under favorable conditions there is nearly enough of this material in the stalks and leaves at the time of flowering to produce the mature fruit. Some water must of course be available to the plant during the ripening period, but little else is necessary. If 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 seed and other fruit that the quantities of water and nitrogen available to the plant be limited during the period of maturity.

41. Effect of Climate on Composition. A good illustration of the effect of this principle is seen in the relation between the composition of wheat and the climate in which it was produced. When wheat is grown for a number of years in a moist climate, such as that of the New England states, it develops a relatively large proportion of soft starch, and becomes a soft variety of wheat. If this seed is then taken to a region characterized by drier weather during the ripening period, and is grown there for a few years it will gradually change this character, becoming harder and more dense. In the same way corn changes its character; when grown in Illinois, Iowa, or states farther south, it produces a comparatively soft kernel with a large proportion of soft starch; while if taken to the northern part of Wisconsin and adapted to that climate, it will gradually develop a larger proportion of flinty or horny starch.

CHAPTER II

ORIGIN AND CLASSIFICATION OF SOILS

42. Soil Defined. In order to understand clearly the various chemical and physical processes which determine the fertility of soils, and to know the variations in the character of soils in different localities, it is necessary to study the source and mode of origin of each type. Soil is a blanket of loose matter formed over the land surface of the earth by the interaction of surface agencies on the underlying rocks.

43. Physical Make-up of the Soil. If we examine some soil closely, we find that it is made up of grains of various sizes, which were derived from rocks; and of a black or dark grown substance coating the grains, which came from the partial decomposition of vegetable matter. There is also more or less vegetable matter in the form of fine roots and stems of plants.

The finest grains which remain in suspension in still water for many hours are called *clay*. Grains a little larger, which will sink to the bottom of a jar of water in an hour, are called *silt;* while the coarser particles, which will all sink in a few minutes, are called *sand*. Clay soils consist largely of clay, with small proportions of silt and sand. Loam soils are largely made up of an even mixture of the finer sand and coarser silt particles. They contain little clay or coarse sand. Silt loam soils are largely composed of silt with some clay and fine sand. Clay loams contain a little more clay than the silt loams, while sandy loams contain more sand.

ROCK-FORMING MINERALS

44. Composition of Rocks. If we examine almost any common rock, such as granite, we find it is made up of grains of different sizes and of different colors and degrees of hardness. These are particles of various minerals. A *mineral* is a substance of practically pure chemical composition occurring in nature, which usually crystallizes in a definite form. While several hundred minerals are known to exist, only a few of these are at all common in rocks.

The most common and important rock-forming minerals are quartz, feldspar, mica, hornblende, pyroxene, olivine, calcite, apatite, and pyrite. All except quartz and the three last named are known to the chemist as *silicates;* that is, they are salts of silicic acid, and contain silicon dioxid combined with various metallic and nonmetallic elements, chief among which are sodium, potassium, magnesium, iron, and aluminum. Calcite is a carbonate of calcium, while apatite is a phosphate of calcium, containing also a small proportion of chlorin and fluorin.

45. Description of Important Minerals. *Quartz* is composed entirely of silicon dioxid, or silica. It is usually nearly pure white, though frequently translucent. When it crystallizes under suitable conditions it develops a hexagonal, prism-like form. When it breaks, the surfaces are rough and show no tendency to crack along definite lines.

46. The Feldspars. There are several different kinds of feldspar, of which *orthoclase* is one of the most common.

It is a silicate of potassium and aluminum, which is usually pink or flesh-colored, though sometimes quite white. It breaks with two well-defined, smooth surfaces or *cleavage planes,* at right angles to each other. This mineral forms a large part of true granite.

The *plagioclase feldspars* include several varieties which form a series varying from the pure sodium aluminum silicate, *albite,* through mixtures of varying proportions of this with calcium aluminum silicate, to the pure calcium aluminum silicate, called *anorthite.* The name albite comes from its white color, but the other plagioclase feldspars are often pink in color and resemble orthoclase; in fact, it is usually difficult to distinguish between the plagioclase and orthoclase feldspars by appearance alone.

47. Mica. There are two principal kinds of mica, the white mica, or *muscovite,* and black mica, or *biotite.* Micas are readily distinguished from other minerals by the ease with which they can be split into thin plates or flakes. They are quite soft as compared with quartz or feldspar. Muscovite is a potassium aluminum silicate, while biotite is a silicate of iron and magnesium.

48. Other Silicates. *Hornblende* is a black, shiny mineral as hard as feldspar and usually forms somewhat elongated crystals, often so much elongated as to be needle-like, though sometimes it occurs in flat tabular crystals. It is a silicate of iron and magnesium, differing but little chemically from biotite.

Pyroxene is a black mineral forming small chunk-like masses in rocks in which it occurs. It is a silicate of iron, magnesium, and calcium, but contains somewhat less silica than hornblende or biotite.

Olivine is a silicate of magnesium or of magnesium and iron.

49. **Calcite** is a carbonate of calcium occurring chiefly in marble and limestone. When it is pure and crystallizes from water in a way that develops crystal surfaces, it produces a wide variety of forms. Iceland spar and dog-tooth spar are different crystal forms of calcite formed by crystallization from water in cavities of rocks.

50. **Apatite** is a phosphate of calcium which contains small proportions of fluorin and chlorin. It is usually found as very minute particles of a brownish or greenish-brown mineral scattered through many rocks such as granite, basalt, etc. It is important because it contains phosphorus.

51. **Pyrites.** There are several different kinds of pyrites, all of which are sulphides, iron pyrites being sulphide of iron; copper pyrites, sulphides of copper, etc. Iron pyrites has a bright luster varying from a silver to a gold-like appearance, and has often been mistaken for gold or silver by people not acquainted with the ores of precious metals; in fact, it is sometimes called "fool's gold."

KINDS OF ROCKS

52. **Classification.** The geologist divides rocks into three classes from the way in which they are formed. These are: *Igneous,* those which have solidified from a molten condition; *sedimentary,* those which were first formed as sediment and then solidified into rocks; and *metamorphic,* those which were first formed as distinct igneous or sedimentary rocks and then subjected to various processes such as the chemical action of water in dis-

solving some of the substances, or by pressure, distortion, and heat, as in mountain building processes.

53. Igneous Rocks. The most common and best known igneous rocks are granite and basalt, but the geologist classifies igneous rocks into a number of different types, which differ chiefly in their chemical and mineral composition. The most important factor in this classification is the relative proportion of silica which the rock contains. Since silica is an acid-forming element, those rocks which are high in silica, either on account of the relatively large proportion of the silicate minerals or the quartz they contain, are spoken of as acid rocks. Basic igneous rocks contain no free quartz, but are composed of minerals having a relatively low percentage of silica, and therefore a correspondingly high percentage of metallic or basic elements such as iron, magnesium, and sodium,

54. Kinds of Igneous Rocks. *Granite* is an acid igneous rock consisting chiefly of quartz and feldspar, the latter usually of the orthoclase type, with more or less mica and hornblende and always a very small proportion of apatite.

Syenite is similar in composition to granite, but contains little or no free quartz.

Diorite is a rock of intermediate composition containing chiefly plagioclase feldspar and hornblende with a small proportion of biotite. *Gabbro* is a still more basic rock similar to diorite; while *basalt* is one of the most basic rocks, containing chiefly plagioclase, pyroxene, and olivine.

55. Structure of Igneous Rocks. As already stated, igneous rocks were formed by the solidification of molten matter below the earth's surface. Frequently, this molten matter broke through crevices in the surface rocks and flowed out as broad surface flows. Since the basic rocks remain liquid at much lower temperature than do the acid rocks, they often flow for great distances over the surface, producing broad lava sheets. One of the most notable of these is that which formed the surface rocks of a large portion of eastern Washington and Oregon and western Idaho. The acid rocks, such as granite, are usually found in large areas, where they have been brought to the surface by the erosion of the overlying rocks. When a molten mass of a composition that produces granite does come to the surface it cools so quickly that crystallization does not take place and an uncrystallized or glass-like mass is formed. *Obsidian* is the name given to this kind of rock. When the molten matter cools near the surface, there may be time enough for some minerals to crystallize, such as quartz, while the remainder is crystallized very poorly or not at all. This then produces a *porphyry,* of which quartz porphyry is the most common.

It frequently happens that molten igneous rocks break through cracks in the overlying rocks, which may be of either igneous or sedimentary origin, forming veins and dikes.

56. Sedimentary Rocks. As the name implies, sedimentary rocks were formed in water. Three kinds may be distinguished: First, those which were formed by mechanical means, being deposited as sediment which was carried in suspension in the water; second, those which were formed by the secretion of lime carbonate in shells and skeletons of animals; and third, precipitates, or new compounds formed by the union of substances in a solution. The new compound is precipitated because it is less soluble than the material from which it is formed.

Sedimentary rocks of mechanical origin include conglomerate sandstone, and shale. These sediments were laid down either in the ocean, chiefly within a comparatively short distance from the shore, or in large bodies of fresh water. They have been solidified into rocks by compression and by the cementation caused by relatively small quantities of matter being carried into them in solution and deposited.

57. Formation of Limestone. Limestone was chiefly formed in ocean water at moderate depths, where coral and shell fish lived in vast numbers. These animals secrete calcium carbonate in their skeletons and shells, which accumulated and were ground more or less into a general mass of lime carbonate, with which was mixed various amounts of fine sediment brought out from the land. When the proportion of this sediment was small, it left the limestone quite pure; while if the mechanical sediment predominated and there was a relatively small proportion of lime carbonate, it formed a calcareous *shale.*

58. Precipitates. The third class of sediments, those which are chemical precipitates, comprise but a small proportion of sedimentary rocks. They are formed chiefly by the precipitation of lime carbonate in water from springs which, when it comes to the surface, is raised in temperature and is therefore able to hold less of the carbonate in solution. Silica is also precipitated chemically in this way. Gypsum, rock salt, and other salt masses were formed by evaporation of solutions containing them.

59. Arrangement of Sedimentary Rocks. In the great Mississippi Valley the sedimentary rocks are in a nearly horizontal position, as they were formed in a great interior sea which once covered a large part of the area now comprising the United States. In this sea there were several large islands, one of which now forms a part of northern Wisconsin and Minnesota; another the Ozark region, while others form the region now occupied by the Appalachian Mountains, a large V-shaped area southeast and southwest of the Hudson, and small areas in the present Rocky Mountain region. Since there occurred oscillations or alternate elevations and depressions it happens that sandstone and limestone are found superimposed on each other. As this great inland sea was gradually being filled by sedimentary rocks, buckling of the crust produced at different periods the Appalachian, the Rocky, and the Sierra Nevada ranges of mountains. The Appalachians were formed early, and in general contain only the early sedimentary rocks, while the Rocky and Sierra ranges were formed much later and contain sedimentary rocks of comparatively recent origin. In these mountainous regions the sedimentary rocks are found tilted or folded.

60. Metamorphic Rocks. The effect of heat, and of compression, solution, and various other processes to which both igneous and sedimentary rocks have been subject, has often been so great as to profoundly change their character, in regard to both the chemical composition and the structure. When these changes have been very great, the resulting rocks are quite unlike those from which they were derived and are therefore called metamorphic rocks, meaning rocks which have been given a changed form. In some cases it is comparatively easy to determine what the original rock was, while in others it is impossible to do so.

61. Kinds of Metamorphic Rocks. Among the more common metamorphic rocks are gneiss, schist, quartzite, slate, and marble. *Gneiss* and *schist* are similar to the original igneous rocks in that they are composed of silicate minerals, and differ from them chiefly in that the compression and contortion which they have passed through have produced a layered structure, not found in unaltered igneous rocks, such as granite. *Quartzite* was formed from sandstone by the deposition of silica in the space between the grains of the rock, completely transforming it into a solid mass. *Slate* was formed from shale by heat and the compression produced in the process of mountain upheaval. The slaty structure was developed at right angles to the direction of compression and is therefore usually at a high angle, often nearly a right angle, with the original bedding plane of shale sediment. *Marble* was formed from limestone by heat and the action of moisture contained in the rock, permitting the complete recrystallization of the calcium carbonate.

SOIL FORMATION

62. Agencies. The formation of soil began whenever rock came to the surface. This process is in part simply a mechanical breaking up of the rock, or *disintegration*, and in part a chemical change, or *decomposition*. Both of these processes are classified together as *weathering*. Disintegration of rock is very largely due to the expansion and contraction of the rock produced by changes in temperature. Since the different minerals of which igneous and many metamorphic rocks consist have different rates of contraction on cooling and expansion on heating, such rocks have a great tendency to break apart. At high altitudes, as on mountain ranges, very sudden changes of temperature occur on account of rapid radiation of heat between night and day. The tendency for rocks to break into small, loose fragments and small particles is very great. The German traveler, Meyer, says that on the peak of Kilimanjaro the mere passing of a cloud cutting off the sun's rays would cause a drop in temperature of from 30 to 40 degrees in 15 or 20 minutes, and that the splitting of rock produced a continual noise. The expansive force of freezing water is also a great factor in breaking off particles of rock.

63. *Chemical Processes.* Along with this disintegration which causes the mechanical breaking up of rock there are many chemical processes. *The chief chemical soil-forming agency is the action of water containing carbon dioxid in solution.* When minerals like feldspar, mica, and hornblende, which contain potassium, sodium, calcium, and magnesium, are acted upon by such water, a chemical decomposition takes place, in which the basic elements of the original minerals combine with carbon dioxid to form carbonates, while a portion of the silica with the alumina combines with some water, forming *kaolin*, or chemical clay. In this way, we have a mixture of undecomposed or unweathered rock or mineral particles and new salts of different kinds.

64. *The Action of Water.* Most of these salts are more or less soluble in water, so that if the rainfall is sufficient they will be dissolved and carried away by percolating water as rapidly as formed. A large part of the calcium, potassium, sodium, magnesium, and part of the silica of the original rock is removed, while a mixture of unweathered rock particles and kaolin accumulates as a surface layer of soil. This surface layer of soil is further subjected to erosion by water, in which sedimentary material is carried off in suspension. Wind is also a powerful eroding and transporting agent. Another active transporting agent is ice.

65. Classification on Basis of Origin. This material carried away by the agents mentioned is frequently laid down as a soil layer in other portions of the earth's surface. It is therefore possible to distinguish between soils which were derived from the rocks immediately underneath them, and are therefore called *residual soil*, and those which were transported by various agencies, which are called *transported soils*. This latter group may further be subdivided in accordance with the agency doing the work. The most important classes of soil, on the basis of mode of origin, are the following: (1) residual, (2) glacial, (3) loessial, (4) alluvial, (5) colluvial, and (6) humus.

CLASSES OF SOILS

66. Residual Soils. As previously explained, residual soils are formed by the weathering of rocks, in which chemical decomposition, removal in solution, and erosion play important parts. When a residual soil is formed from granite, the quartz grains, being insoluble and not subject to decomposition, are left as grains of sand. Feldspars are more or less decomposed into kaolin, or chemical clay. The soluble carbonates are carried away in solution in regions of sufficient rainfall, but collect as alkali salts in areas of deficient rainfall.

Sandstone is composed largely of quartz grains; when a soil is formed from this kind of rock, a mere physical disintegration or breaking up into loose sandy soil occurs.

When limestone is weathered, a very large part of the lime or magnesium carbonate is dissolved by carbonated water and carried away in solution through underground or surface streams to the ocean. Most of the soil which remains consists of the fine sediment deposited with the limestone as an impurity; therefore, residual soils from limestone have a very fine clay texture. Frequently, considerable silica collects in sharp, angular particles or masses, producing flint or chert deposits in the limestone. These angular masses remain as unweathered material in limestone soils. The well-known chalk or limestone formations of England contain a large quantity of this sharp, angular stone.

Fig. 3. Residual soil from Shaly sandstone, Dunn County, Wisconsin. Note the shallow layer of soil underlaid by rock in place.

67. Glacial Soils. Glacial ice now exists on a relatively small portion of the earth's surface, and is known to us chiefly from descriptions of travelers in Greenland, Alaska, and some of the higher mountain regions. In these places, glacial ice is very active in transporting

Fig. 4. Cathedral Spires, Garden of the Gods. Showing the way hard and resistant rocks withstand weathering and erosion, while the softer rock surrounding it has been carried away, causing the development of sharp spires.

soil and rock. When the ice melts, masses of mixed rock and soil are left along its front and sides. The rocks are frequently smoothed and striated where they have been pushed along over underlying rock by the moving glacier. Large areas of northern North America and Europe are covered by soils which resemble those now being formed by glaciers, proving that these countries were at one time covered by great flows of ice which came down from the north, where it accumulated as a result of continual winter with heavy precipitation of snow.

68. *Effect of Glacial Action on Soils.* In this action of the ice, the chief process was that of pushing along some of the residual soil previously existing, mixing it with fragments of rock brought from considerable distances northward, grinding off underlying rocks, and filling erosion channels and valleys. Most of the soil pushed along in this way at the bottom of the ice was not carried any great distance. Glacial soils covering the larger areas of granite rocks consist largely of residual granite soils, and on the sandstone areas, of sandy soils mechanically mixed but otherwise not much changed. On the limestone areas, the rock was soft and greatly different chemically from the residual soil on the surface. Much of the surface limestone rock was ground to a fine soil and intimately mixed with the residual soils originally covering such limestone sections. It is thus seen that glacial soils sometimes differ but little from the original soil, as in the case of granite, sandstone, or shale, while in the case of limestone they are very different. The residual soils on limestone are largely free from lime, while glacial soils over limestone are often abundantly

supplied with this substance. This fact has a great influence on their agricultural value.

69. *Effect on Topography.* The topography of a glaciated section is very different from that of an unglaciated section. The well-defined systems of drainage which existed before glaciation were greatly changed. The sharp, angular hills were worn off and glacial drift was deposited on the hills and in the valleys, producing irregular undulating surfaces. Frequently smooth oval hills were formed, with their long axes in the direction of the movement of the ice. These are called *drumlins.* Along the border of the ice long lines of irregular hills, with deep, undrained pits, were formed. Such accumulations are called *moraines.* When the ice melted, great quantities of water were produced, causing erosion, separation, and transportation of soil material. The soils thus formed during and after the glacial period will be de-

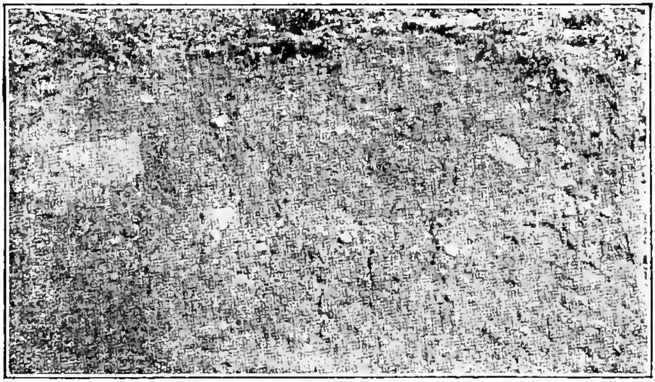

Fig. 5. Showing unstratified glacial till or boulder clay. Note the angular fragment of stone and depth of fine soil.

scribed with other similarly formed soils under the head of alluvial soils.

70. *Periods of Glacial Action.* When geologists came to study these glacial deposits carefully, they found that those in the southern and southwestern portions of the area covered by the ice showed evidences of being much older than the deposits in the northern portion. The older sections are deeply eroded, so that they contain few lakes or marshes, and the soil is so weathered that practically all of the limestone has been dissolved and carried away, just as in a residual soil. In fact, full study has shown that ice sheets flowed down from the north at four or five periods, widely separated in time. These ice periods have been named from certain states in which the soils belonging to the periods are well defined; the Kansan is the oldest, then the Iowan, the Illinoisan, and lastly the Wisconsin. These four different sheets did not all cover exactly the same territory, the earlier ones extending somewhat farther south and west than the later ones. In the eastern portion of the country, the extent of the different sheets was about the same. On account of these differences in age, there are some old glaciated areas where the soil has become very similar to a true residual soil, while those of the last period are still quite distinct in character.

71. Loessial, or Wind-Formed Soils. The activity of wind as a transporting agent is well shown by the clouds of dust blown in storms. Such dust storms are frequent in prairie sections. The fact that wind works on all exposed soils, no matter what the topography, makes the result of its action very great. Close observation of boulders and smaller stones exposed on the surface of the ground, especially in the Western states, shows the effect of wind-blown sand in wearing them off. There are areas of soil in many parts of the world, such as the Mississippi Valley, the valley of the Rhine, and in parts of China, which show on careful examination that they were formed by the accumulation of wind-blown dust. These soils are found extensively in Illinois, southwestern Wisconsin, Iowa, eastern Kansas and Nebraska, northern Missouri, and still farther south along the Mississippi. These soils are alike in being made up largely of silt and having a small amount of true clay and very little sand. They are peculiar in that they will retain a vertical face when exposed, as in a stream bank or ravine; cellars and wells are frequently dug which retain their walls without masonry protection. The bluff which Grant found so difficult of ascent at Vicksburg was of this soil.

72. *Location of Loessial Soils.* On account of the general trend of the wind from the west and southwest, a considerable portion of these loessial soils probably came from that direction. Coming as they did from a region of little rainfall, they have a larger proportion of lime and the other basic elements than true residual soils, or even glacial soils, and are therefore usually very fertile. These areas of loessial soils in the Mississippi Valley as a rule lie south and west of the area of the Wisconsin glaciation, and overlie the glacial deposits of the earlier glacial periods. There are, however, small local areas of loessial soils overlying the Wisconsin drift.

73. *Adobe Soils.* The adobe soils found especially in the mountainous sections of the West and Southwest are similar in many respects to loessial soils. Being formed in the regions of small rainfall, they usually contain more or less alkali salts, which give them great plasticity when wet and tenacity when dry, thus changing their physical properties. The adobe soils are not entirely of wind origin, since there is usually some material brought down from the higher lands by temporary streams formed by the melting of mountain snows.

74. Alluvial Soils. Alluvial soils, as the name implies, are soils which have been formed by deposition in water. These are of two general classes, those connected with streams and those formed in standing bodies of water, chiefly lakes. The quantity of sediment which a stream can carry depends on its size and velocity, and increases very greatly with increases in either of these factors. As a result, the stream erodes its channel where it runs most swiftly, and deposits the eroded material where its current is slackened by lower grades. A great increase in volume of water, coming from heavy rains or from the melting of snows in spring, also increases the power of streams to carry larger quantities of sediment in their swifter portions than can be carried by the more slowly moving current on lower grades farther down. Consequently, some of this material is deposited, raising the bed of the stream and compelling the water to find new channels on either side of the old as it becomes filled. This leads to a cutting under of the banks and the lateral shifting of the stream, developing the winding channels so common in the lower portions of valleys. Often so much sediment is deposited in the channels that in times of freshets the streams break over their banks and flood the lowlands, often covering considerable areas. The comparatively slow movement of such overflows permits

Fig. 6. Streams are constantly shifting their courses by cutting in on the outside of the curve and building up on the inside, as the one in this illustration is doing.

fine sediment to be deposited, thus building up what are called *flood plains.*

75. *Effect of Stream Flow on Texture.* We thus have deposits of alluvial soil along the lower courses of all streams. These alluvial soils vary greatly in texture. Frequently they are very sandy, as when deposited in a current which moves at a moderate rate; again, they are of a very silty character, when the motion of the water is quite slow. In still other places the sediment is largely composed of clay; here, bodies of water which have escaped from the main channel have been practically at rest for some time, gradually soaking away and evaporating and leaving their load of the finest material as a deposit of clay. Great river systems, such as the Mississippi, have much land along their courses which has been built up by this process and which is therefore of alluvial character. Usually the alluvial soils on the upper stretches of such river systems consist largely of silt or even of fine or coarse sand, while those on the lower stretches are much finer, containing a relatively large proportion of clay.

76. *Alluvial Deposits by Glacial Streams.* Streams formed by the melting of the ice during and especially toward the close of the glacial periods carried immense quantities of sediment derived from the glacial material, and so filled up valleys and channels which had been formed by previous erosion. Many valleys of the northern portion of our country, such as those of the upper Mississippi and its tributaries, have been filled to depths of from 50 to 200 or more feet with coarse sand and gravel brought by such glacial streams. Great deposits filled up the channels to such an extent that the lateral shifting previously described developed broad flood plains from 2 to 4 or 6 miles in width. Since the ice period, the streams flowing in these valleys have in most cases eroded channels of from a few feet to as much as 100 feet in depth in these broad glacial flood plains, leaving them as terraces. Sometimes these plains have been left in two or more stages, thus making primary, secondary, or even tertiary terraces. Soils formed in this way are usually fine and silty on the surface, but deeper down often grade quite suddenly into coarse sand or gravel. Very frequently, the water-holding capacity of such soils is so low as to greatly lessen their agricultural value.

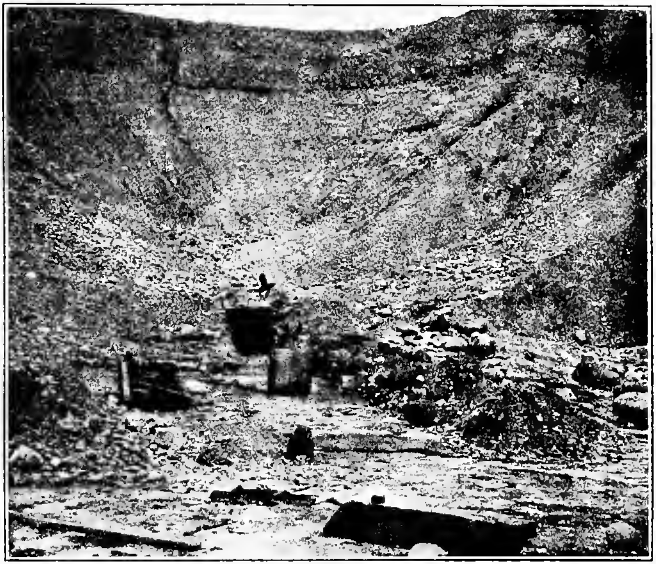

Fig. 7. Gravel pit in glacial deposit, showing stratification of sand and gravel. Such soils are very low in water-holding power.

77. *Soils Formed in Still Water.* The second class of alluvial soils includes those deposited in standing bodies of water, chiefly lakes, and are therefore often called *lacustrine* soils. Soils of this character occur over large areas where standing bodies of water were formed by the melting of glacial ice and which were later drained as the outlet wore deeper and deeper. All of the Great Lakes were raised to a higher level at this time. Considerable tracts of alluvial soil now found along their shores were deposited before the cutting down of the Niagara River lowered them to their present level. Such alluvial soils are usually of much finer character than those in stream valleys. They lack the gravelly or sandy subsoil characterizing the valleys, though it sometimes happens that at the mouth of streams entering lakes there are sections where sandy or even gravelly soils were deposited. The broad, level terraces along the shores of Lake Erie and Lake Huron and the heavy red clay along the upper Wisconsin shore of Lake Michigan, Green Bay, and small portions of Lake Superior, were formed in this way.

Even more interesting than these terraces along the shores of lakes still existing, are the areas of lacustrine soils formed by lakes which existed near the close of the glacial period but which have since entirely disappeared. One of the best instances of this kind is that known as glacial Lake Agassiz, which covered a large area in northwestern Minnesota and eastern North Dakota and extended northward into Canada. Thousands of square miles in that section have a heavy silt or clay soil which was deposited in this broad, shallow lake that has now entirely disappeared.

78. Colluvial Soils. As new soil is formed on the slopes of hills and mountains, it is impossible for it to remain exactly on the spot on which it is formed. There is a gradual downward creep, caused by the expansion due to the freezing of water. Rains and melting snows carry the soil down short distances and then leave it; where the slope is very steep, the pull of gravity produces slips and slides when the soil is soft and plastic. All soils on such slopes are therefore more or less transported and mixed. They are neither strictly residual nor alluvial. They are formed by the interaction of several factors, and should be classified separately from the other well-defined types. Such soils are called *colluvial*, though of course they usually partake of the nature of the residual soils, but are more or less modified by other additional agents.

79. Humus and Humus Soils. As pointed out at the beginning of the chapter, practically all soils contain some matter formed by the decomposition of vegetation. This matter, which is called *humus*, is of the very greatest importance in its influence on the agricultural value of the soil. It is therefore well worth our while to examine carefully into the factors which determine the amount of humus which is collected in soils; for we find that while in some soils there is very little humus, in others the supply is large, some soils being almost entirely composed of vegetable matter.

80. Formation of Humus. This humus consists of vegetable and animal matter which has only partially decayed, but which has lost its structure and has been changed over into a black, paint-like substance that coats the soil grains and gives the black color to the soil. When vegetable matter is exposed on the surface of the soil for an indefinite length of time, it becomes completely decomposed. The carbon, hydrogen, and oxygen it contains are transformed into water vapor and gases, which pass off into the atmosphere; while the nitrogen and the mineral elements such as calcium, potassium, etc., form inorganic salts, which are largely dissolved and carried to the soil by water. No humus whatever will collect under these conditions. When, however, vegetable matter is protected from free access of oxygen of the air, it undergoes more or less of a physical change in which the black, waxy humus is produced. From this fact, it is clear that the humus formed in soils will depend not only on the quantity of vegetation which is present, but also on the conditions which affect its oxidation and decomposition.

ACCUMULATION OF HUMUS

81. Influence of Climate. Clay soils, which retain more moisture than sandy soils, usually develop more humus. In wet locations such as marshes, more humus or vegetable matter collects than in dry situations. Since warm temperatures promote decomposition of organic matter, while cool temperatures usually retard it, larger quantities of humus are developed in the soils of cool countries than in those of warmer regions.

82. Influence of Character of Vegetation. Probably the most important factor in determining the amount of humus which will collect in soils is the character of the vegetation. Since the part of a plant above ground is exposed to favorable conditions for total decomposition, while the root system is much more protected, it is chiefly from the roots that the humus of soils is derived. Moreover, the fine roots of grasses and other small vegetation are more largely transformed into humus than the coarse roots of trees. It is a matter of very general observation, therefore, that the soils of prairie regions are black to a considerable depth, having a large content of humus, while those of wooded sections are as a rule very low in humus. The leaves falling at the close of the season's growth are largely decomposed before the end of the succeeding season brings a fresh supply, and even the fallen logs and the roots are completely rotted away and form little humus.

83. Influence of Lime. Another factor influencing the collection of humus is the presence or absence of lime carbonate in the soil. There is a tendency for humus to be of an acid character, but if there is lime present in the soil, this acidity is neutralized. The acid humus is more soluble and is therefore often largely dissolved and carried away in water as it is formed, while if lime carbonate is present humus accumulates. Since soils formed in regions of moderate or low rainfall are usually well suppled with lime, and since the vegetation in such sections is chiefly grass, the soils are usually abundantly supplied with humus. These are the conditions under which prairie soils have been developed the world over.

84. Maintenance of Humus Supply. In the practical management of soils, as will be pointed out later, the maintenance of a good supply of humus is of the utmost importance. The knowledge of the way this humus is formed in nature is a great help in forming rules for its protection and development under cultivation.

85. Formation of Humus Soils. Whenever the conditions for the collection of vegetable matter are so favorable that a large quantity collects, the resulting soil is termed a humus soil. Many shallow lakes and ponds have been entirely filled up by vegetation, chiefly sphagnum moss, growing on or near the surface of the water and falling to the bottom, and so gradually building up a deep bed. As this collects, and the under portions are more or less compressed, it changes somewhat in character and is gradually transformed into peat. Mixed with the peat, which is derived chiefly from the moss, there are other forms of vegetation such as the remains of water-loving trees, sedges, etc. As the true peat comes to the surface and the water is somewhat dried out, other forms of vegetation appear, and it often happens that dust and water-borne sediment add considerable silt and earthy matter. Soils formed in this way are called *muck* or peat. The term muck is applied to those soils which, while largely composed of vegetable matter, have still more or less earthy matter mixed with them. Probably in part on this account, they have decomposed somewhat more, so that they are usually heavier and of a blacker color than the true peat, which consists almost exclusively of vegetable matter and is usually quite brown when dry.

SOIL AND SUBSOIL

86. Division on Humus Basis. In regions of moderate temperature and rainfall, the surface soil down to a depth varying from a few inches to 2 or 3 feet or even more, usually contains considerable humus, and is therefore of a darker color than the material below this depth. When such is the case, the darker surface portion is called the *soil*, and that underlying it is known as the *subsoil*. It frequently happens that there is quite a sharp line between the soil and the subsoil. In many cases, however, there is so little organic matter that the difference is not marked. This is particularly true in sandy soil and in all soils of very warm countries except marsh soils in such climates. High temperatures cause so rapid a decomposition of the organic matter that it cannot accumulate.

Fig. 8. Road cut showing dark surface soil filled with roots and organic matter underlaid by light-colored subsoil.

87. Division on Tillage Basis. There is another somewhat different use of the terms soil and subsoil. The term soil is frequently used to apply to the upper portion which is tilled, while the soil below that depth is called subsoil irrespective of whether or not there is a difference in color.

INFLUENCE OF CLIMATE ON SOILS

88. Effects of Climate. We have seen that the processes of soil formation, leaching or the accumulation of the resulting soluble salts, the erosion of the surface, and the formation of humus, are all profoundly influenced by the climatic conditions. In fact, the climatic influence determines the character of a soil to an even greater extent than do the underlying rocks from which it came. So profound is this influence that it is quite possible to classify soils on the basis of the climatic conditions under which, or perhaps more accurately speaking, by which, they are formed. When the climate of a region is fully known, many of important characteristics of the soil can be predicted with considerable certainty, though there will always be some variation in the soils of any climatic section caused by the variation of the rocks from which they were derived.

89. Formation of Prairies. Some of the more important soil classes as produced by distinct climatic factors may be mentioned. Prairie soils occur in many parts of the world, notably the western Mississippi Valley states and portions of central and southern Russia, of the Argentine Republic, and of the southern table-land of Africa. Prairie soils are characterized by a comparatively level surface into which streams have cut well-defined channels. They have a large proportion of humus, produced by the slow decay of the fine roots of prairie grasses. Fibrous-rooted grasses constitute the main part of the native vegetation of these areas. The moderate rainfall of these regions permits of some accumulation of soluble salts, so that such soils are practically never acid in the virgin condition and usually contain a considerable quantity of lime, though not enough is present to produce a distinctly alkaline soil.

90. Effect of Tropical Climates. The soils of tropical sections, which usually have excessive rainfall, are characterized by a very small proportion of soluble matter, since it is removed as rapidly as formed. These soils are usually very low in organic matter, due to the rapidity of its decomposition, and commonly have a distinctly red color on account of the completeness of the oxidation of the iron, which is present in all soils, and the thoroughness with which it is diffused through the soil.

91. Effect of Arid Climates. The soils of the arid portions of the world are characterized by their very small content of organic matter, on account of their extremely scanty vegetation, and the accumulation of water-soluble salts, due to the weathering of the soil in the absence of sufficient rainfall to carry the salts away. These conditions produce what are known as *alkali* soils. Such soils occur wherever the annual rainfall is less than 12 or 14 inches in countries of moderate temperature, and 20 inches in countries of high temperature. They are found in large areas in western United States, west central South America, eastern Africa, and in India, Arabia, and Australia.

92. Effect of Moderate Rainfall and Temperature. Regions of moderate to heavy rainfall fairly well distributed through the year, and of moderate temperatures are found to be characterized by the small to medium content of organic matter, owing partly to the fact that here forests usually predominate. The residual soils of such countries are usually low in their content of soluble salts and especially of lime carbonate, there being sufficient rainfall to cause considerable leaching, though this is not as excessive as in the case of the humid soils of the tropics. Since, however, considerable areas in the countries of this climate have been covered by glacial ice, which has profoundly modified the soils, as heretofore described, they often contain large areas in which the soils are abundantly supplied with lime.

CHAPTER III

PRIMARY RELATIONS OF SOIL AND PLANT

93. What the Plant Requires of the Soil. In Chapter I the conditions which plants require for their growth were stated. The manner in which these conditions are supplied by the soil will now be discussed. The soil is the source of most of the chemical elements essential to plant growth, but these can be taken up by the plant only when dissolved in water, and water is also necessary to carry these substances to the growing parts of the plant and for their assimilation into the plant tissue. It is therefore necessary for the plant to have a widely-branching root system to absorb water and the chemical substances needed. Moreover, the development of these roots requires oxygen at their growing points. The soil, therefore, must contain a supply of the right elements; must be permeable to the roots; must contain sufficient moisture; and must also contain air, or at least oxygen.

94. Permeability of the Soil to Roots. Since it is essential that plants growing on most soils permeate them to a depth of from 1 to 5 or even 10 feet in order to obtain the necessary plant food and water, the permeability of the soil to these roots is a matter of great importance. When a hardpan is developed by the deposition of salts once held in the soil, or when the soil is so fine-textured or compact that roots are unable to make their way through it, the plant is greatly retarded in its growth. There are great differences in root systems of plants produced in different soils. When growing in loose, sandy soils most plants develop an abundant root system, while when growing on heavy clay soils they have comparatively meager roots. Nursery stock, such as apple and cherry trees, grown on rather light soils, are much better supplied with roots and are therefore more valuable than when grown on heavier clay soils.

A very important object in the cultivation of a soil, therefore, is that of making it as permeable as possible where it is naturally impermeable. Subsoiling, in which the soil below that reached by the ordinary plow is stirred, is very helpful in this respect. Clay soils require much more care to render them permeable to roots than loam or sandy soils. Cultivation for this purpose will be discussed in a later chapter.

95. Water-Holding Capacity. Since plants require large quantities of water, varying, as we have seen, from 300 to 700 or 800 pounds for each pound of dry matter produced, the availability of water for their growth is a matter of extreme importance. Since the roots must permeate the soil in order to obtain the chemical substances necessary for plant growth, and since these roots must have air at the growing points, the soil must not be so thoroughly saturated with water that the air is excluded. Roots of plants can grow well only in that portion of the soil and subsoil from which a part of the water has been withdrawn, so that the remainder is held only as films around the soil grains, leaving some space for air. The power of soils to hold water in this form is therefore an extremely important factor in determining their productivity. Since rain comes so irregularly during the growing season in practically all important agricultural countries that there are often several days or weeks between rains, plants must depend on the stored supply, so that one important function of the soil is to act as a reservoir for moisture.

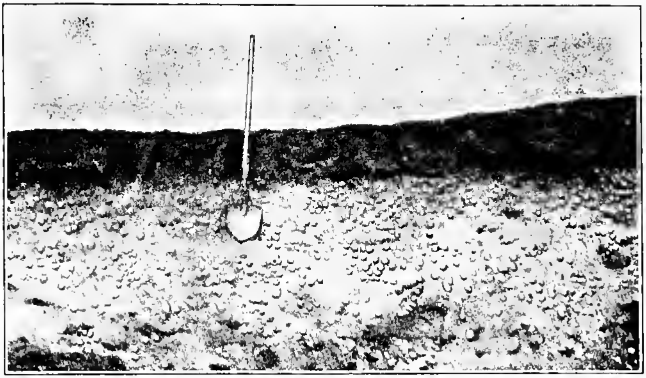

Fig. 9. Shallow surface soil underlaid by coarse gravel. Soils of this character may have a good surface appearance, but cannot withstand drought.

96. The Revolving Fund of Soil Fertility. Most agricultural plants are annuals, their growth from germination to the production of seed taking place within a single growing season. It is then of the utmost importance that they have a good supply of the necessary food material readily available to draw on as quickly as germination has taken place. Such a supply is not produced rapidly enough by the extremely slow processes of soil and rock weathering, as they have been explained in Chapter II. On virgin soils, where native vegetation only is growing, the plants, on dying, fall to the ground, and the rapid decomposition of this vegetable matter forms a supply of available plant food for the succeeding plants. When cultivated crops are grown, portions of them, as the roots and stubble, are practically always left to act in the same way. Moreover, a part of some of the elements which are taken up by the plant during its rapid growth is returned to the soil during the ripening period (Sec. 17). There is formed in this way a *revolving fund* of matter needed for plant growth.

97. Losses and Gains. This fund suffers some losses and profits by some additions. There are losses by the removal of crops, by leaching of the soil and subsoil, and by erosion of the surface soil, which is richest in soluble matter. There are gains by the weathering of the rock particles of the soil and by fixation of nitrogen from the atmosphere. When the losses exceed the gains, the difference must be made up by the use of fertilizers. The fertility of the soil which is removed in products sold

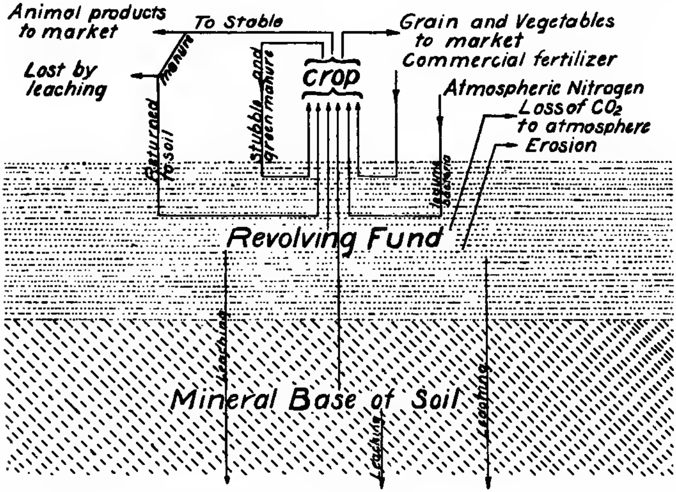

Fig. 10. The factors influencing soil fertility are complex and closely interrelated, as this figure shows.

from the farm may be either in vegetable form, as when grain or hay is sold, or in animal form, as in the sale of fat stock or dairy products. The bones of all animals, for example, contain phosphorus. All these relations are expressed in the accompanying illustration.

98. Value of the Rotating Fund. A full understanding of the value of this rotating fund to soil fertility is of the utmost importance. While the rock particles of most soils contain a considerable supply of the essential elements, they can be thought of only as a storehouse from which very small amounts may be withdrawn from year to year. Rapid growth of crops during the early part of the summer season must ordinarily depend almost entirely on the revolving fund. The vegetable matter left in the ground in the form of roots and stubble or returned in the form of animal manure is a very important portion of this fund. Under favorable conditions, it decomposes and sets free most of its content of the essential elements with sufficient rapidity to supply the needed material for good growth.

In addition to the plant food held in this vegetable form, there is in most soils considerable matter in the form of water-soluble salts held so intimately on the surface of the soil particles that it is not readily washed away. The fine root hairs of plants, however, by coming in most intimate contact with the soil grains, are able to absorb these salts.

99. The Principal Limiting Factors. While all of the essential elements and physical conditions mentioned in Chapter I are absolutely necessary for the growth of crops, only a few of the essential elements are apt to be deficient in ordinary soils. Others are usually so abundant that we need give no particular care to them. Nitrogen, phosphorus, and potassium are so deficient in some soils that they must be given special attention. Moreover, soils not well supplied with lime will become acid. This acidity is injurious to the growth of certain plants which have the power of obtaining nitrogen from the air, so that when lime is deficient it must be supplied to keep soils in a fertile condition. Deficiency in the supply of any one of these essential elements or essential conditions will prevent the crop from making its best growth, and it is very commonly true that the maximum yield of

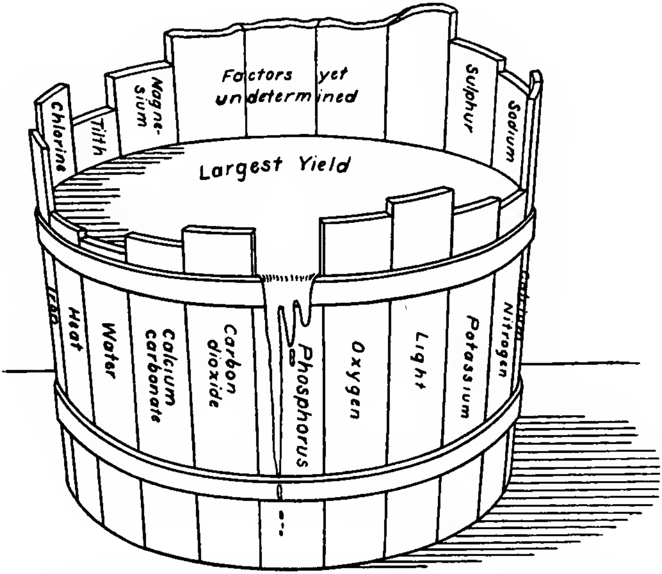

Fig. 11. Just as the height of the lowest stave determines the amount of water the barrel can hold, so the yield of a crop on a field is determined by that element or condition which is least satisfactory.

any particular field is determined by some one factor, which thereby becomes a *limiting factor* for that soil. This may be the supply of nitrogen, phosphorus, lime, moisture, oxygen, or some other essential.

100. Illustration of Limiting Factors. The accompanying illustration devised by Dr. Dobenecks is intended to illustrate this principle of limiting factors. Just as the quantity of water which the barrel can hold is determined by the height of the shortest stave, so the yield of any particular field is determined by the supply of that substance or degree of condition which exists in the smallest proportion to that needed for maximum growth. It is therefore of utmost importance that the farmer determine the limiting factor or factors in his soil, and as far as possible apply a remedy. This diagnosis of the soil's condition is as important in agriculture as the diagnosis of disease is in medicine.

CHAPTER IV

NITROGEN

101. Kinds of Nitrogen Compounds in the Soil. With the exception of the small amounts of nitrogen annually added to the soil by the rain (in the form of ammonia or nitric acid), the soil nitrogen is entirely of organic origin. Most of the nitrogen in the soil is in the humus or partially decomposed vegetable matter. Under normal conditions, all soils also contain small but varying amounts of nitrate nitrogen as well as a very small quantity of ammonia compounds formed from the nitrogen of the humus. Before humus nitrogen is formed and finally converted to nitrates, the fresh vegetable matter containing proteins, the principal nitrogenous substances in all plants, must pass through various processes of oxidation and decay. These stages constitute the *nitrogen cycle.*

102. The Nitrogen Cycle. Nitrogen forms a large part of the most valuable food stuffs built up by plants, namely, the proteins. The amount of nitrogen in the form of nitrates in the soil at any one time is very small, yet most plants require their nitrogen food in the form of nitrates. The preparation of this supply of nitrogen by the hosts of soil bacteria and other minute plants constitutes a most interesting chapter in our study of the feeding of crops.

When plants die, their 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 a great residue of partly oxidized vegetable matter is returned to the soil as manure. This vegetable matter or animal refuse is now attacked by putrefactive bacteria which break the proteins down into simpler compounds. Still other bacteria attack these compounds, with the production of a still simpler product, ammonia. Ammonia-making, then, is the first step in the threefold process of nitrate-making or *nitrification*. This ammonia furnishes a good supply of food for the nitrate-makers, while a third class of bacteria use the nitrites as food, making therefrom nitrates. This nitrate is what the chemists call 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 make nitrates, but make instead nitric acid, which immediately unites with lime, magnesia, or potash, to form the corresponding nitrates. The addition of lime carbonate to soils furnishes the necessary lime for the formation of calcium nitrate.

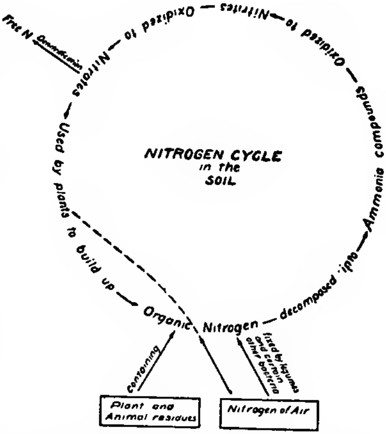

Fig. 12. Nitrogen goes through many changes and combinations in the soil and the plant.

FACTORS INFLUENCING THE RATE OF NITRIFICATION

103. The principal factors influencing the building of nitrates are:

(1) Aeration.
(2) Temperature.
(3) Moisture.
(4) Reaction of the soil.
(5) Character of the raw material.

In the paragraphs that follow, the manner in which different phases of these factors affect the process will be pointed out.

104. Aeration. The nitrate-makers require an abundance of oxygen, and are therefore largely confined to the first 4 or 5 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 water and absence of air, in fact, cause loss of nitrates.

105. 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 temperature 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 or Minnesota. In the warmer climate of our Southern states, organic nitrogen is quickly changed to nitrates, which may be entirely 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.

106. Moisture. A certain amount of water is required for the normal activity of all life processes. The making of nitrates by the soil bacteria is a life process and water is therefore necessary. Oxygen, however, is equally essential for life processes and must not be excluded from the soil by excessive amounts of water. When all the space between the soil grains is full of water, as in a saturated soil, no air can get to the nitrate-makers, and they refuse to work. Under such conditions actual loss of nitrogen occurs, as will be pointed out in Sec. 139.

107. Reaction of Soil. Nitrification is 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 nitrogen to crops. It is likely that under these peculiar conditions plants are able to utilize, to some extent at least, other forms of nitrogen, especially ammonia compounds. There are undoubtedly, also, tiny local zones in acid soils where sufficient base is present to permit nitrification.

108. Character of the Organic Matter. Some of the organic matter in soils decomposes very rapidly, and is called active humus. Other portions of the organic matter resist decay, and constitute inactive humus. For this reason, when a piece of land is cropped for several years without the addition of farm manure or other organic matter, the humus most easily acted on is used first and nitrates are formed rapidly. After a few years, when the active humus is exhausted, the process of nitrification becomes much slower and crops suffer for want of available nitrogen. Fresh, succulent vegetable matter like that in clover roots and tops is easily transformed into nitrates, so that a clover sod when plowed and cultivated usually becomes rich in nitrates. The chemical composition of the organic matter, too, determines the rate of nitrification. Highly nitrogenous compounds usually decay more rapidly than those in which cellulose predominates. For this reason clover sods may be expected to nitrify more rapidly than timothy sods, and such, indeed, is the case.

109. Organic Matter in Manure. Certain types of organic nitrogenous compounds resist decay more than other types. The solid portion of the excreta of farm animals, for example, is much more slowly converted into nitrates than the liquid manure. All of the nitrogen compounds of the food that are broken down by the digestive juices are absorbed by the blood, used in the body, and finally excreted in the urine as urea, a compound closely related to ammonia. This urea is quickly changed to ammonia in the manure by the action of a special group of urea bacteria. The more resistant part of the food excreted in the solid portion of the manure is low in its total nitrogen content and resists the action of soil bacteria as it resisted the action of the digestive juices. In general, substances that are easily converted into ammonia are easily converted into nitrates.

In order to get this more resistant organic matter into an available form, gardeners and other growers of intensive crops compost their manure. When agriculture is intensive, and large quantities of available plant food are needed in a single season, the question of the relative availability of nitrogen in fertilizers becomes of decided moment.

NITROGEN CONTENT OF SOILS

110. **The total nitrogen content** of soils varies from as low as a few hundredths of one per cent to as high as 3 per cent. From data furnished by the Wisconsin Soil Survey, the following figures represent about the average quantities of nitrogen in soils of that state:

Table IV. Percentages of nitrogen in various Wisconsin soils and pounds of nitrogen in the surface 8 inches of 1 acre of these soils.

	Per cent	Pounds in surface 8 inches
LIGHT-COLORED SERIES		
Clay loams	.14	2800
Loams	.10	2000
Sands	.06	1500
DARK-COLORED SERIES		
Clay loams	.25	5000
Loams	.25	5000
Sands	.10	2500
PEATS	3.00	10,500
MUCKS	1.00	10,000

Soil Report No. 1 of the Illinois agricultural experiment station gives the following quantities of nitrogen in the surface 7 inches of 1 acre of various soils of Clay County, a county typical of southern Illinois.

UPLAND PRAIRIE SOILS		
Gray silt loam on tight clay	2790	pounds
Brown silt loam on clay	3320	"
UPLAND TIMBER SOILS		
Light gray silt loam on tight clay	1580	"
Yellow silt loam	1540	"
RIDGE SOILS		
Yellow silt loam	3890	"
Gray red silt loam on tight clay	2720	"
SWAMP AND BOTTOM LAND SOILS		
Drab clay	4180	"
Deep peat (in 1,000,000 lbs.)	16,970	"

The common corn belt prairie soils contain from 4000 to 6000 pounds of nitrogen to the acre in the surface soil. Shutt has reported the virgin prairie soil of Manitoba to contain as high as 20,100 pounds of nitrogen, while Kedzie states that the jack-pine plains of Michigan contain only 740 pounds of nitrogen to the acre of surface soil.

CLOSE USE OF NITRATES BY PLANTS

111. Nitrates in Cropped and Uncropped Soils. When a crop is growing upon a soil where nitrate-making is in progress, the crop utilizes this soluble food quite completely unless too much is manufactured. Lyon and Bizzell[1] analyzed the winter (October 1, 1910 to May 1, 1911) drainage waters from three sets of large cylinders and found the following quantities of nitrates expressed as pounds of nitrogen per acre: From soil on which no crop had been grown the preceding season, 108.8 pounds; that on which corn was grown, 8.0 pounds; that on which oats was grown, 8.4 pounds. Corresponding quantities of the bases, especially lime, were found. Although large quantities of nitrates are lost in the fall and winter drainage, it should be noted that analyses of soils at regular periods show that the process of nitrification occurs largely in the middle of the summer. It is interesting to note that the results show that the nitrogen in the corn crop plus the nitrogen in the drainage water amounted to 151 pounds to the acre, while in the case of the oat crop the amount was only 103 pounds to the acre, showing that the corn plant was able to get 48 pounds to the acre more nitrogen than the oat plant.

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[1] Journal of Industrial and Engineering Chemistry, Vol. III, No. 10, p. 743.

They suggest, as have other investigators, that the corn plant stimulates nitrate production, that it uses other forms of nitrogen, or that both causes operate.

112. Effect of Poor Nitrate Supply. Plants quickly show the effects of the poor nitrate supply, although they will feed upon the supply on hand until it is so small that chemical analysis can scarcely detect it. Every farmer has noticed the yellowing of corn plants or of young spring grain after a few days of cold, wet weather. Such weather causes a slow rate of nitrification or even a loss of nitrates. It has been shown that soils under oats that were turning yellow contained only

Fig. 13. The growth of the rape in the right-hand jar is due to the large amount of nitrates developed in the soil while in the warm greenhouse. The poor growth in the left-hand jar shows the low amount of nitrates developed in a field soil during the fall.

0.086 pound of nitrogen as nitrates to the acre, while where the oats were still green there were 0.87 pound to the acre. Although the total quantity in either case is small, yet the delicate feeding apparatus of a plant responds to the difference.

NITROGEN FIXATION

113. Fixation by Bacteria on the Roots of Legumes. The diagram (Fig. 12) 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 clover, alfalfa, and other legumes.

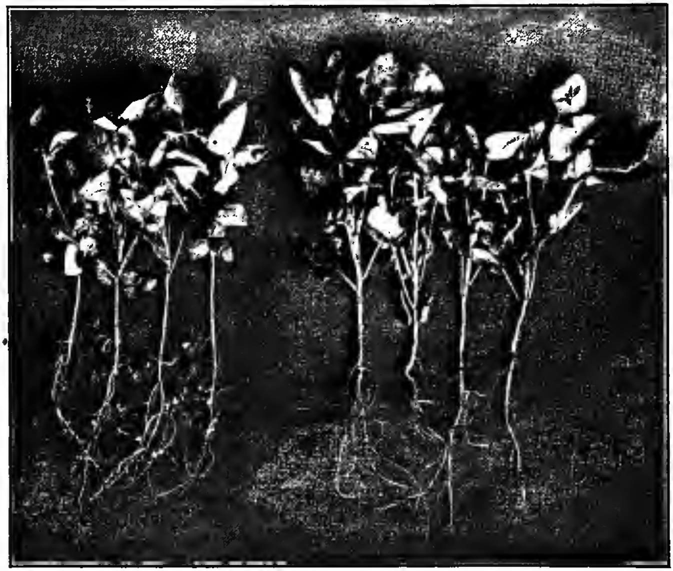

Fig. 14. Soy beans showing the development of nodules (on the left) due to inoculation, and absence of nodules (on the right) on the uninoculated plants.

The nitrogen of the air is transformed by these bacteria into organic (protein) nitrogen. Whether this organic nitrogen is directly absorbed by the plant, or whether it first passes through all the stages of oxidation as does

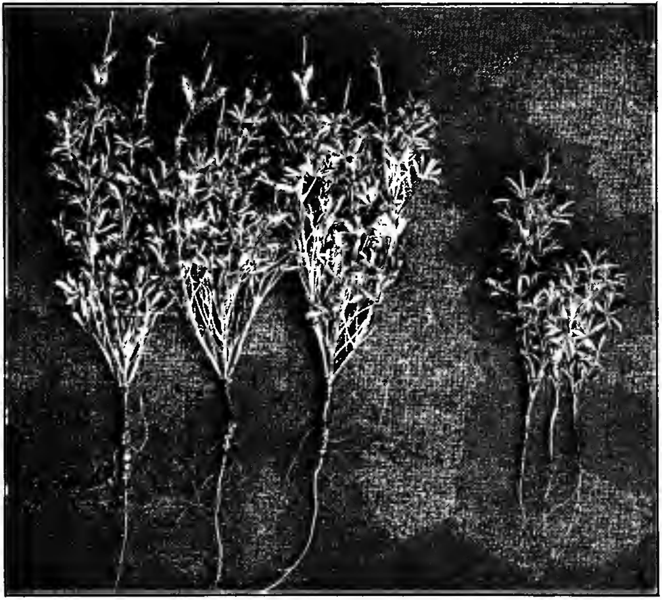

Fig. 15. Yellow lupin. The strong growth of the three plants on the left was due to the fixation of nitrogen by nodules, which appear as rough wart-like growths on the root. The right-hand plants were without nodules and so without ability to fix nitrogen. Both were grown on sandy soil of low fertility.

the 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. The relation of these nodules to the ability of the legumes to obtain nitrogen from the air was first shown by Hellriegel and Wilfarth, two German scientists, in 1886.

114. Independent Nitrogen Fixation. Some nitrogen is fixed in soils by unattached bacteria. These bacteria get their energy from the oxidation of soluble carbohydrates in the soil. That considerable quantities of nitrogen are actually fixed in this manner is known. Much of the gain in fertility of untilled soils must be due to this process, yet we lack sufficient data from different sources to make any general statement as to the economic importance of this kind of fixation.

115. Amounts of Nitrogen Fixed by the Growth of Legumes. An experiment conducted by Frank T. Shutt of the Canadian Experimental Farms supplies excellent field data as to the amount of nitrogen added to soils by the growth of red clover. The soil to the depth of 8 inches was removed from a plot in the field, and in its place there was substituted a poor sandy loam containing .0437 per cent of nitrogen. This plot was then fertilized with superphosphate at the rate of 400 pounds to the acre and muriate of potash at the rate of 200 pounds to the acre. The plot was seeded to red clover and the clover cut annually and allowed to rot on the soil. The plot was stirred to the depth of 4 inches every other year and the clover reseeded. Samples of soil to the depth of 4 inches were taken every two years. The results obtained follow:

Table V. Nitrogen added to the soil by continuous cropping with clover, as shown by a Canadian experiment.

	Nitrogen in dry soil	Acre content of nitrogen in the surface 4 in.
	Per cent	*Pounds*
Before growth of clover	.0437	533
After two years of clover	.0580	708
After four years of clover	.0608	742
After five years of clover	.0689	841
After six years of clover	.0744	908
Increase in nitrogen due to six years of clover	.0307	375

The average addition of nitrogen per year was 62½ pounds, but the entire crop was returned to the soil. Since, however, only one-third of the nitrogen of the red clover plant is contained in the roots and stubble and two-thirds in the tops, it is evident that if the hay had been annually removed, the average annual gain to the soil would have been only 20 pounds, or about four-sevenths of the amount required by a 20-bushel crop of wheat.

116. Fixation of Air Nitrogen Varies with Amount of Nitrates in Soil. The soil used in this experiment was a very poor one, and it is likely that under such conditions the clover obtained more nitrogen from the air than if it had been grown in a more normal soil containing four to five times as much nitrogen. When soils contain soluble nitrate nitrogen in abundance, legumes will feed upon these nitrates the same as other plants, instead of drawing their nitrogen from the air through the agency of the nodular bacteria.

On fairly productive soils about one-third of the nitrogen used by legumes well supplied with nodules is obtained from the soil, and only two-thirds from the air. Now if two-thirds of the nitrogen in the plant is removed in the hay, as is the case in clover and alfalfa, it is clear that the growth of these legumes, when the hay is entirely removed, adds little or no nitrogen to the soil, though the nitrogen removed in the hay is a clear gain from the air. Some legumes leave less than one-third of their nitrogen in the soil. It is only by the return of the tops either by plowing them under *or by feeding the hay and returning the manure* that clover-growing can restore soil fertility. Nitrogen and organic matter may be added to soils in this way, but no amount of clover-growing can increase the stock of lime and phosphorus on hand in the. soils.

117. Nitrogen Content of Tops and Roots. The following table, compiled from the work of the Delaware station, shows the pounds of nitrogen to the acre in the tops and roots of the important legumes and the percentage of the total nitrogen contained in the roots. These crops were all seeded on July 22 and harvested on the dates indicated.

Table VI. Nitrogen in tops and roots, and the proportion in the roots of important legumes.

Crop	Nitrogen in tops	Nitrogen in roots	Proportion of nitrogen in roots
	Pounds	*Pounds*	*Per cent*
Red clover, Nov. 22	69.8	33.2	32
Alfalfa, Nov. 20	54.8	40.4	42
Cow peas, Nov. 7	65.2	4.3	6
Soy beans, Nov. 11	130.9	9.3	6.5
Vetch, Nov. 19	108.0	13.2	11
Crimson clover, Nov. 20	128.2	6.2	6

The nitrogenous matter in the roots of legumes is rapidly decomposed and nitrified so that an abundance of nitrates is formed the first year after a clover or alfalfa sod is broken, and hence its apparent increase in fertility.

118. Conditions for Maximum Nitrogen Fixation. 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 the essential mineral elements.
(4) A sufficient inoculation with the bacteria associated with the particular legume to be grown.

119. Soil Inoculation. After the first three of these conditions have been provided, we must still be sure that our soil is well inoculated. In the North Central states it is seldom 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 a lack of inoculation. The upland acid soils of Wisconsin rarely contain the necessary alfalfa organisms. Even in Nebraska, where alfalfa is more generally grown than in Wisconsin or Minnesota, Alway recommends inoculation of the soil in order to obtain an even stand. 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 yet known of inoculation 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 effective.

120. Method of Inoculation. When a field is to be inoculated, the inoculating soil should be spread and harrowed in before it becomes dry. Drying the soil tends to kill many of the bacteria. If a small portion of a field is first well inoculated, and a stand of the legume established, 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 has often finally been grown successfully by constantly sowing a little seed 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. When such annual legumes as soy beans or cowpeas are to be grown, inoculation may be effected by mixing the inoculated soil directly with the seed in the drill or planter.

121. Effect of Inoculation on Composition. Alway and Pinckney of the Nebraska station selected alfalfa plants from different parts of the same field and, after carefully washing out the roots, found that the poor, unhealthy plants as a rule bore no nodules. Roots and stems were analyzed. They found that not only was the total weight of the inoculated plants from 3 to 50 times as heavy as the uninoculated, but that they contained about twice as much nitrogen. Shutt, in the Annual Report of the Canadian Experimental Farms for 1909, states the yield of dry hay to the acre on inoculated fields to be 7200 pounds, and on uninoculated, 2520 pounds. The inoculated alfalfa contained 17.81 per cent of protein, and the uninoculated, 15.62 per cent. The corresponding figures for carbohydrates were 36.72 and 40.75 per cent.

CALCIUM REQUIREMENTS OF LEGUMES

122. Quantity of Calcium Used. Legumes require more calcium as plant food than do other crops. Study of the accompanying diagram (Fig. 16), will show that a 4-ton crop of alfalfa removes from the soil twenty times as much calcium as the grain and straw of a 30-bushel crop of wheat. The total supply of calcium in some soils is so low that legumes will find calcium carbonate beneficial both as plant food and as a neutralizer of acidity. In this connection, Hopkins[1] states: "It is of interest to note that thirty crops of clover of four tons each would require 3510 pounds of calcium, while the most common prairie land of southern Illinois contains only 3420 pounds of total calcium in the plowed soil of an acre."

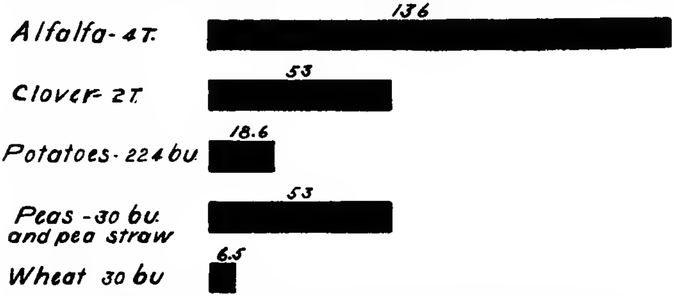

Fig. 16. Certain legumes are often called lime-loving plants, on account of the large amounts of lime they require for their growth.

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[1] C. G. Hopkins, *et al*, Soil Report No. 2, Illinois Experiment Station, p. 38.

123. Effect of Lime on Composition. Lyon has compared the alfalfa, the weeds, and the soil extract from each of the halves of ten plots of clay loam soil, one half having been limed four years before with 3000 pounds of quick lime to the acre. A determination of the lime requirement of the unlimed portions showed a need of 4000 pounds to the acre of lime for the surface foot of soil. The average results were as follows:

Table VII. Comparison of production of alfalfa hay and of nitrogen on limed and unlimed soils.

	Yield of hay	Alfalfa in mixed hay	Nitrogen in pure alfalfa	Nitrogen in the weed fleabane	Nitrates in dry soil
	Pounds	*Per cent*	*Per cent*	*Per cent*	*Parts per million*
Limed.	103.1	70	3.30	1.70	8.08
Not limed.	74.4	60	2.52	1.40	4.27

The above table shows that liming increased the yield. At the same time the proportion of nitrogen and hence of protein in the crop was increased. The nitrogen content of a nonleguminous plant when it is grown with a legume is of interest as well as of practical value. The same investigators have shown that the nitrogen content of timothy is increased when grown with alfalfa. The common practice of growing timothy with clover undoubtedly furnishes a better timothy hay than when the timothy is grown alone.

ACID SOILS AND THEIR TREATMENT

124. Relation of Acidity to Soil Nitrogen. Acidity of the soil hinders nitrogen fixation by the legumes and is, therefore, especially harmful when this class of crops is grown. Besides this harmful effect, acidity makes the process of nitrification very slow. Liming the soil always hastens the process of nitrate-making. The test for acidity will be described in the chapter on Soil Analysis (Sec. 180).

125. Detection and Causes of Acidity. Soil acidity is commonly indicated by the growth of such weeds as common sorrel, horsetail, and corn spurry. Two of these are shown in Fig. 18. The causes of soil acidity are not very well understood. It is, of course, always associated with a lack of lime in the soil. It is probable that the oxidation of the vegetable matter in upland soils in the absence of sufficient lime gives rise to acids. Peat marshes that develop in regions devoid of limestone are always acid, on account of the large quantity of vegetable matter in them.

Fig. 17. The use of lime on acid soils being sown to clover or alfalfa, is very profitable.

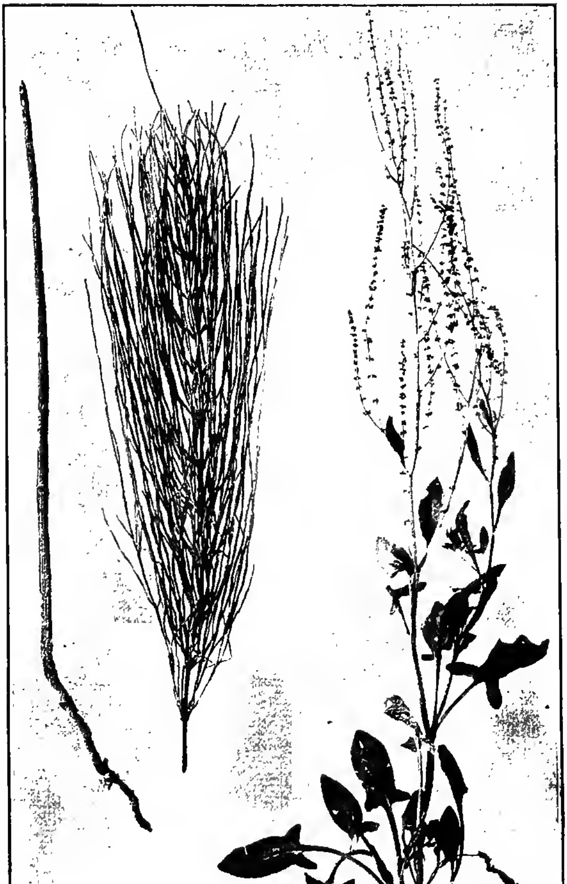

Fig. 18. Sorrel (on the right) and Horse Tail Rush are good indicators of acidity.

The use of ammonium sulphate as a nitrogen fertilizer, unless supplemented with lime at frequent intervals, has also been found to cause acidity.

126. Effect of Acidity Upon Different Kinds of Plants. Not all plants are injuriously affected by an acid condition of the soil. We have already stated that certain weeds are practically a sure indication of an acid condition. Cranberries and certain marsh grasses demand an acid soil. 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 often makes a good stand on fields too acid for the growth of red clover. Large yields of potatoes have been obtained on acid soils where suitable amounts of phosphorus and potassium were present.

127. The Remedy for Acid Soils. The remedy for acid soils is the application of some form of lime; this treatment is practical only when it may be expected to yield a profit on the investment. It will pay well to neutralize the acidity of worn acid upland clay and clay loam soils, and also of many of the residual sandy soils formed from sandstone that never contained much lime. Peat soils are ordinarily so strongly acid that the cost of the quantity of lime necessary for its neutralization is prohibitive. The principal reason why we lime soils is to aid in the restoration of nitrogen. Peats fortunately contain enormous quantities of nitrogen so that liming is hardly necessary on such soils.

128. Forms of Lime. The forms of lime, that is, of calcium compounds, that are available for use in neutralizing acids are as follows: Ordinary quick lime, ground limestone, marl, and various by-products, including lime refuse from beet sugar factories, marble dust, and shell refuse.

129. *Lime.* Ordinary lime is available either as the fresh burned, air-slaked, or water-slaked (hydrated) lime. Lime should never be used on land in the unslaked condition, but should be completely water-slaked. It is well to be sure that air-slaked lime is free from any unslaked material, because caustic lime has a burning effect on the organic matter in the soil. For the lighter soils, such as sands and sandy loams, apply at the rate of 10 to 15 bushels of fresh lime to the acre, which is equivalent to nearly twice that quantity of water- or air-slaked lime; for the heavier soils, such as the clays and clay loams, 30 bushels of fresh lime may be used. On account of the danger of burning out organic matter, it is preferable to use lime in the carbonate form, that is, in ground limestone, wherever it is available.

130. *Ground Limestone.* Ground limestone and marl are both carbonate forms of lime and should be applied in rather heavy applications of from 1000 to 2000 pounds to the acre. They are best applied in the fall before seeding to clover. On soils notably deficient in lime, this application should be repeated every four of five years 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 through a sieve with 40 meshes to the linear inch, though it may be held on a 60-mesh or finer sieve. If much coarser than this, much heavier applications should be used, but this is unprofitable where a long haul is necessary.

131. *Marl and Lime Refuse.* Marl occurs as a deposit in marshes and in the bottom of old lake beds. It is usually a rather pure lime carbonate, but of course is very wet. It should be dried so that it crumbles readily or should be finely crushed. Lime refuse from beet-sugar factories is an excellent material for neutralizing soil acidity. It contains considerable moisture and as a general rule should therefore be well dried before it is purchased. This lime refuse consists largely of carbonate of lime and should be applied at about the same rate as ground limestone or marl.

132. The Application of Lime. All forms of lime are best applied with some kind of lime spreader or fertilizer drill. A manure spreader can be adapted for use in spreading lime, provided the bottom of the spreader is covered with a layer of strawy manure or similar coarse material. To prevent the dust from blowing about, the spreader should be covered with a canvas. It is also a good plan to construct a hood over the rear end of the spreader, so that the lime will be forced to fall directly downwards. Lime should be applied after plowing and should then be thoroughly mixed with the soil by harrowing. If applied in the fall it is not always desirable to harrow the field, and in such cases it may be left on the rough furrows and be thoroughly worked in the following spring.

LOSSES OF NITROGEN

133. Causes of Loss. Nitrogen may be removed from the soil by: (1) leaching, (2) cropping, (3) denitrification, and (4) erosion. The relative importance of these processes varies greatly under different conditions of climatic, topographical, and textural conditions.

134. Leaching and Cropping. We have noted that the greater part of the nitrogen in the soil is in combination with vegetable matter in different stages of decay. The nitrogen compounds stored up in organic combination are comparatively insoluble in water, but when these compounds are converted into nitrates, the soil nitrogen is in a very soluble form; in fact, more soluble than any other form of plant food in the soil. It is indeed fortunate for the farmers in areas of considerable rainfall that nitrogen is not entirely converted into nitrates, or their supply of this most valuable of plant foods would be entirely lost. It is evident from what we know of the nature of nitrogen compounds, that any treatment of the soil which promotes nitrification will cause a loss of nitrates by leaching. Soils constantly cultivated are therefore more subject to this loss than soils kept in sod. Where soils are annually supplied with large quantities of easily nitrified organic matter, such as is the practice in the growth of tobacco and truck crops, nitrates may be manufactured in excess of what the plant can use, and losses by leaching may occur.

135. *Nitrogen in Drainage Waters.* The amount of loss of nitrogen by leaching may be measured by an analysis of the drainage waters from fields under examination. The drainage waters from that portion of the Broadbalk (Rothamsted) wheat field receiving annual applications of farm manure to the amount of 15.7 tons have carried away annually nearly 50 pounds of nitrogen, an amount considerably larger than the average amount annually removed by the wheat yield of 37.5 bushels. As a general average for the Broadbalk field for the different kinds of nitrogen fertilizers applied, there is an annual loss of nitrogen of 55 pounds to the acre unaccounted for by crops, as shown by analyses of the soil and a knowledge of the amounts of fertilizers added and crops removed.

136. *Beneficial Effect of Leaching.* Some loss of soluble salts from certain soils is necessary, for unless this does occur the soil solution may become so concentrated as to actually retard the germination of seeds and the growth of crops. Recent investigations at the Colorado station show that nitrates are accumulating so rapidly in certain Colorado soils that orchard trees are being killed. Good underdrainage with irrigation seems to be the logical remedy for such a condition.

137. Denitrification. As the word indicates, denitrification 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, insufficient cultivation, or cultivation when too wet—all of which are causes of insufficient aeration—tend to promote denitrification. Undecomposed organic matter, such as poorly-rotted strawy manure, contains large numbers of denitrifying bacteria. Organic matter in large quantities seems to be necessary for the activity of these organisms. Applications of excessive amounts of farm manures may result, therefore, in loss of nitrates already on hand. Some of the large losses of nitrogen from trucking soils should therefore be attributed to denitrification. Lipman, of the New Jersey station, however, states that applications of 16 tons of cow manure and 320 pounds of nitrate of soda to the acre caused no loss of nitrates by denitrification. The use of moderate amounts of well-rotted manure in ordinary farm practice will prevent any danger of loss of nitrogen by this process.

Losses of elemental nitrogen from manure heaps may occur through direct oxidation of ammonia to nitrogen and water, owing to excessive aeration and absence of moisture in the surface layers of the heap. Under soil conditions, however, ammonia is soon converted to nitrates, so that loss of nitrogen in that form could not occur.

138. Loss by Erosion. Whenever soil material containing organic matter is carried away by erosion, its quota of nitrogen is also lost. In addition, surface waters carry away certain amounts of soluble organic matter. Although on very level land these losses may be quite insensible, yet on rolling land they must be appreciable. Hopkins[1] is of the opinion that considerable amounts of both nitrogen and phosphoric acid are lost in this manner. His statement follows: "Land that has sufficient slope to provide any surface drainage will suffer some erosion if such drainage occurs when the land is not covered with vegetation. Whenever roily water leaves a field, some soil goes with it, and the loss of a tenth of an inch in three or four years is not improbable, even for nearly level land, if annually cultivated, especially if torrential rains sometimes occur."

139. Amount of Nitrogen Losses. The losses of nitrogen that may occur in even as short a time as a quarter of a century are well illustrated in the following table showing the losses of nitrogen that have occurred in a Rothamsted field:

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[1] Soil Fertility and Permanent Agriculture, p. 414.

Table VIII. The nitrogen account in pounds to the acre of an unfertilized field and two fertilized fields for twenty-eight years.

Soil treatment	In soil 1865	In soil 1893	Loss or gain	Added by rain and seed	Added by manure	Removed by crops	Unaccounted for
	Pounds	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*
No manure......s	2722	2437	285 loss	167	0	428	24
Mineral fertilizer and ammonium salts............	3034	2971	63 loss	167	2408	1212	1426
Farm manure (20 tons)...........	4343	4976	633 gain	167	5600	1361	3773

The above table shows that under exhaustive cropping with no return of fertility, the crops account for nearly 95 per cent of the nitrogen lost; under treatment with mineral fertilizers and ammonium sulfate, for nearly 46 per cent; while on the plot where 20 tons of manure were applied, only about 27 per cent of the nitrogen lost is accounted for in the crops. Had the manure been applied at the rate of 10 tons to the acre, it is likely that its nitrogen content would have been more economically used.

In a study of the nitrogen content of virgin and cropped soils reported by the Wisconsin station, the conclusion was reached that in clay loam soils of moderate fertility more than 80 per cent of the nitrogen lost is removed by crops. Recent results at the same station indicate that there is a considerable loss of nitrogen above that removed by crops when soils have been heavily fertilized with farm manure and have been farmed without rotation to some intensive cultivated crop like tobacco or truck crops. In an investigation in the maintenance of nitrogen under truck farming conditions in soils naturally high in nitrogen, less than 23 per cent of the nitrogen lost is accounted for by the crops. The amounts of manure applied and the average period of cropping are approximately that reported in the Rothamsted data; therefore it seems to be well established that heavy applications of organic manures result in large loss of nitrogen.

NITROGEN FERTILIZERS

140. Sources of Soil Nitrogen. The two most important sources of soil nitrogen are farm manure and the air. When we recall that nitrogen in commercial fertilizers is rated at from 15 to 18 cents per pound, we can appreciate how very valuable are these two sources of nitrogen. Average farm manure contains about five-tenths of 1 per cent of nitrogen. Using the above valuation, an application of 10 tons of farm manure to the acre or the nitrogen remaining in the soil as the result of a good crop of clover, provided the clover is entirely returned to the soil, is worth $18.

141. Commercial Fertilizers. The important commercial fertilizers containing nitrogen are sodium nitrate (Chile saltpeter); ammonium sulfate, obtained as a by-product in the manufacture of coke and gas; dried blood and other packing house products; and electrically-fixed nitrogen, which is not yet of commercial importance in the United States. 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 by growing legumes.

142. Uses of Commercial Fertilizers. Salts like sodium nitrate and ammonium sulfate are very soluble in water and therefore tend to leach out of the soil, unless absorbed by a growing crop. Ammonium sulfate is retained by the soil more completely than sodium nitrate. Continuous use of sodium nitrate tends to develop a puddled condition in clay soils, making them too retentive of water. It should be alternated with stable or green manures in order to prevent any such condition. The continuous use of ammonium sulfate will cause soil acidity. When ammonium sulfate is nitrified, lime is required, both to neutralize the nitric acid formed, and the sulfuric acid set free. Fields manured with ammonium sulfate should receive applications of limestone at intervals in order to prevent this acid condition. The fertilizer is a valuable one; it contains more nitrogen, pound for pound, than does sodium nitrate.

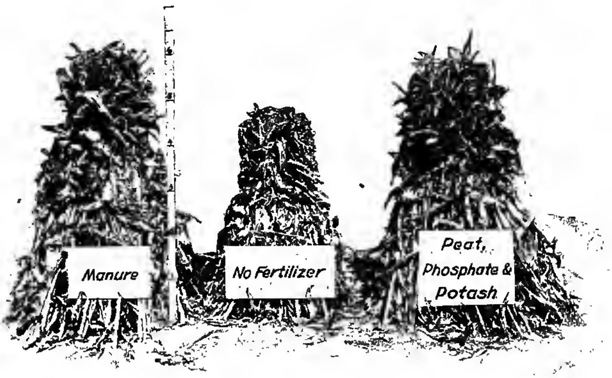


Fig. 19. Showing that peat, the chief fertilizing element of which is nitrogen, supplemented with commercial phosphate and potash fertilizers, may be equal to a heavy application of barnyard manure. This crop is on extremely poor sandy soil. The yield on the manured plot was 25.3 bushels; on the plot which received no fertilizer, 10.0 bushels; while on the plot that received peat the yield was 28.5 bushels.

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

Dried blood is ordinarily applied at the rate of 300 to 400 pounds to the acre. Dried blood becomes available to the plants more slowly, and for this reason there is not so much loss by leaching. The more slowly-available organic nitrogen fertilizers are preferable for use in very sandy soil, in which leaching is an important problem.

143. Peat. Peat marshes furnish an important nitrogen fertilizer. Peat in the dried condition may contain from 2 to 3 per cent of nitrogen, and is well adapted for 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. The more thoroughly rotted the muck or peat is, the better fertilizer it makes.

CHAPTER V

PHOSPHORUS AND POTASSIUM

144. Occurrence and Amount of Phosphorus. The element phosphorus occurs chiefly in the mineral apatite and in practically all rocks from which the soil is derived. The total amount of phosphorus in most soils varies between .02 and .15 per cent, though it not infrequently is as low as .01 or even less, and in a few cases is over .15. The total amount 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.

From tables already given (see page 22) it will be seen that crops remove from 5 to 30 pounds of phosphorus from an acre annually, and that the total supply of this element, which varies from 400 to 3000 pounds in the surface soil on virgin land, is in many cases sufficient only for from 50 to 200 years. Moreover, this element occurs chiefly in the grains of cereals, which are used directly for human food or for animals that are later used for human food, and is thereby removed from the land. It is therefore absolutely necessary to return this element to the soil as a fertilizer in some form, if the fertility of the soil is to be permanently maintained.

145. Condition of Availability. Not only is the total amount of this element in many soils very small, but in many cases only a comparatively small part of that amount is in a condition that it can be absorbed by plants. Most of the phosphorus in the rocks is in the form of tri-calcium phosphate in the mineral apatite, but when soils are formed from these rocks, the phosphorus may change its combinations, forming other more insoluble phosphates of iron and aluminum. If there is a large amount of lime carbonate present in the soil, a larger amount of phosphorus will enter into combinations with the lime than if only a small amount of this element is present. When there is a deficiency in lime, as is the case when soils become acid, the phosphorus tends to combine with iron and aluminum to form less soluble and therefore less available compounds. For this reason, as well as for others, it is desirable to maintain soils in a non-acid condition.

The change of the less soluble phosphates into more soluble forms is very greatly influenced by the presence of organic matter, especially of a fresh or readily decomposable character. The carbon dioxid set free in the decomposition of the organic matter, when it is all in the soil moisture, reacts chemically with the phosphates in such a way as to produce more soluble forms. The addition of lime and organic matter to soils which have a good total supply of phosphorus, but in an unavailable form, is therefore very helpful in making it available. These substances must be constantly present in order to insure that some phosphorus is kept in a form usable by plants.

SOILS DEFICIENT IN PHOSPHORUS

146. Marsh Soils Need Phosphorus. Certain classes of soils are found, as a rule, to be deficient in available phosphorus or in the total supply present. Phosphorus is likely to be a limiting factor in the growth of crops in marsh soils, very sandy soils, and on worn clay loam soils.

Marsh soils, especially those of a distinctly peaty nature, contain a comparatively small quantity of this element. It is true that the amount when expressed as per cent seems large, but when it is remembered that such soils weigh but one-quarter or one-fifth as much per cubic foot as clay loam or sandy loam soils, it will be seen that the total amount in the soil of an acre is very much less than in the latter cases. In those marshes which are acid because of the absence of sufficient lime carbonate to neutralize the acidity caused by the decomposition of the organic matter, the phosphorus apparently goes into insoluble forms, as previously stated. It is a matter of experience that such soils are very deficient in available phosphorus and require the use of phosphate fertilizer to permit them to produce good crops.

147. Very Sandy Soils Need Phosphorus. Sandy soils, which are largely made up of quartz grains, are generally low in the total supply of this element, as they are in most other essential elements; and moreover, the coarseness of the grains reduces the amount of surface exposed to solution by the soil moisture. In addition to this, such soils are ordinarily low in organic matter. For all these reasons, sandy soils are very commonly found to be deficient in available phosphorus and frequently in their total supply.

148. Worn Clay Loam Soils Need Phosphorus. Many clay loam soils have little organic matter and become strikingly deficient in available phosphorus. This is particularly true of the extensive areas of clay loam soils of the Central and Eastern states which have been cropped to small grains for many years. They have, to a great extent, become acid, and their organic matter, which was frequently small in amount at the beginning, has been exhausted. Both of these conditions retard the change of unavailable phosphorus compounds to the more usable forms.

LOSSES OF PHOSPHORUS FROM THE FARM

149. Chief Causes of Loss. Since the amounts of phosphorus in the soil are often small, it is important to study carefully the losses of this element. There are three chief ways in which phosphorus is lost from the farm: (1) In the products sold, (2) in the leaching of the soil, and (3) by erosion.

Fig. 20. The larger shock of corn was due to an application of a phosphorus fertilizer on land which had been cropped about 30 years without manure. Other essential elements were still fairly abundant, and phosphorus was the limiting factor.

150. Loss by Sale of Farm Products. The losses in the products sold vary greatly of course with different classes of farming. Where stock is kept, phosphorus is sold chiefly in the bones of animals, those of a full-grown cow containing about 9 pounds; a horse, 10 pounds; a pig about 1 pound, and a sheep 1 pound.

Dairy products contain relatively small amounts of phosphorus. Milk averages about .07 pound of phosphorus per hundred pounds, and butter .05 pound. The chief sale of phosphorus from the dairy farm, therefore, is in the milch cows sold. When considerable feed is bought, this tends to balance the losses in products sold.

Bran and other concentrates are especially high in this element, and it frequently happens that the phosphorus purchased in the feed on dairy farms, or even on other stock farms, is more than sufficient to balance that sold.

From the data given in the above paragraphs and in tables on pages 22, 23, the students should be able to calculate with approximate accuracy the losses and gains taking place on any given farm, so far as sales and purchases are concerned. Since only a part—and usually only a small part—of the phosphorus in the feed consumed by animals is left in their bodies, while most of it is excreted in manure, the stock farm is the system best adapted to conserve this element. The sale of crops directly removes much larger amounts, as shown in the tables on pages 110, 111.

151. Loss from Manure by Leaching. Whenever manure is exposed to the weather there is considerable loss of each of the important fertilizing elements. Under a rainfall of 25 to 40 inches, uncovered piles of manure exposed throughout the summer lose on the average about half their nitrogen and phosphorus, and three-fourths of the potassium. When covered and kept compact, the loss of phosphorus may be reduced to as little as 5 per cent. The average loss of this element by leaching of manure is probably not less than 15 per cent of that contained in the fresh manure.

152. Loss from Soil by Leaching. Most of the phosphorus in soils is in the forms which are only slightly soluble in water, and hence are little subject to loss by leaching. Moreover, when a fertilizer containing phosphorus in readily soluble form, as it is in acid phosphate, is added to the soil, it is largely converted into a much less soluble form. For this reason, the loss of phosphorus by leaching is very small as compared with the loss of nitrogen. It is even commonly supposed that there is no loss of phosphorus by leaching. However, it has recently been shown that under certain conditions the loss is considerable. When there is much organic matter decomposing rapidly in the soil, the carbon dioxid so formed and dissolved in the moisture of the soil reacts with the insoluble phosphates in such a way as to render them much more soluble. As we have seen, phosphorus contained in manure piles is quite subject to loss by leaching. The phosphorus contained in manure is kept in a soluble condition, and when the manure is applied on sandy and gravelly soils of low fixing power, the loss may be considerable. In fine clay soils, the large surface exposed tends to fix the phosphates.

When special crops which require very fertile soils are grown, as in the case of tobacco, sugar beets, etc., and when this fertility is secured by the use of very heavy applications of barnyard manure, the loss by leaching, if the soil is at all of a sandy nature, may be quite important.

153. Loss by Erosion. The finer portion of any soil, that is, the clay and fine silt, is richer in phosphorus than the coarser or sandy portion. When sidehills are eroded by heavy downfalls of rain, it is the finer portions of the soil that are chiefly removed; the organic matter, or humus of the soil, is also relatively rich in phosphorus, and being lighter than the earthy portion, especially sand, is more largely removed by erosion. In this way, it comes about that the erosion of the sidehills has the effect of carrying off the portion of the soil which is richest in this element. Erosion is unquestionably a very important source of loss of this element.

154. Loss and Gain of Phosphorus of the Farm. As an illustration of the effect of the processes just mentioned, the following balance sheet showing the income and outgo of phosphorus on two different types of farms, is given. The first is that of a good dairy farm of 100 acres, with the amount of stock and the usual crops grown on such a farm in the dairy sections of the northern United States. On such a farm, practically all the sales are of dairy products, and we have included the sale of only barley from eight acres in addition. The stock sold includes the old cows which would be replaced each year to maintain the herd, and either veal calves or steers which would be the equivalent of five other full-grown

Fig. 21. The erosion of sidehills removes large quantities of available phosphorus as well as of the other essential elements, by removing the organic matter and finer portion of the soil which are richest in these substances.

animals. Hog raising in connection with dairying is very profitable and very commonly practiced. An estimate is therefore made of twenty hogs sold annually. Assuming that each dairy cow is fed 1000 pounds of bran during the year, 10 tons would be necessary. The total amount of phosphorus brought to the farm would therefore be 260 pounds, but this is subjected to the average loss of 15 per cent by leaching of manure before it is returned to the soil. From this total it is evident that even on such a farm, where the greater part of the crops grown are fed and where considerable phosphorus is purchased

Table IX. Exchange of phosphorus on a 100-acre dairy farm.

		Phosphorus	
I. Consumed on farm by 20 milch cows, 10 neat other cattle, 20 hogs, and 4 horses:			
1. Clover	16 acres	195	
2. Clover and timothy	16 acres	150	
3. Corn	16 acres	175	
4. Oats	8 acres	70	
5. Straw, 10 tons		20	
6. Pasture and wood lot	35 acres		
Total		610	
Loss, about 15 per cent, in food consumed			90
II. Sold from the farm each year:			
1. Barley	8 acres	50	
2. 3 cows		25	
3. 5 neat cattle		45	
4. 20 hogs		20	
Loss in products sold		140	
III. Feeds purchased:			
10 tons wheat bran		260	
Loss, about 15 per cent, on feeds purchased		40	
Total loss			270
Gain on feeds purchased			260
Net Loss			10

in concentrated feeding stuffs, the loss equals the gain. This does not include losses by erosion or by leaching of the soil, which cannot be estimated with any degree of accuracy. It is evident, therefore, that even on such a farm the total supply of phosphorus is being at least slowly reduced, rather than increased, as is very commonly supposed.

Table X. Exchange of phosphorus on a 100-acre grain farm.

		Phosphorus	
I. Consumed on farm by 6 milch cows, 5 horses, 10 hogs, and 4 neat cattle:			
1. Corn	10 acres	120	
2. Oats	25 acres	195	
3. Clover 4. Clover and timothy	15 acres	130	
5. Straw	35 tons	55	
6. Pasture and wood lot	25 acres	...	
Total		500	
Loss, about 15 per cent, on feeds consumed			75
II. Sold from farm each year:			
1. Barley	25 acres	165	
2. 10 hogs		10	
3. 3 neat cattle		20	
Total loss on products sold		195	
Total loss to the farm			270

In the table showing the losses and gains on a grain farm, we have taken as an illustration a 100-acre farm on which only enough stock is kept to operate the farm. In order not to make the case extreme, we have supposed that ten hogs would be sold annually, and three cows or the equivalent weight as steers or calves. On this farm it is evident that the losses of phosphorus are large, even though the table does not include the losses by leaching or erosion. Any such system of farming can be permanently maintained only by the purchase of phosphorus in some form of fertilizer. It would be entirely impracticable and unnecessarily expensive to attempt to maintain the phosphorus by purchasing it in the concentrated feed stuffs. Fortunately, at present it is entirely possible to purchase, at reasonable expense, phosphorus fertilizers to maintain the supply in the soil on such farms.

COMMERCIAL PHOSPHORUS FERTILIZERS

There are three chief commercial sources of phosphorus fertilizers: (1) The bones of animals killed at the stock yards, (2) mineral deposits, (3) basic slag from furnaces in which iron ores containing phosphorus are reduced.

155. Bone Phosphorus Fertilizers. The immense number of cattle, hogs, and sheep brought to large centers, such as Chicago, Kansas City, and South St. Paul, and there converted into packed meat, produces as a by-product an immense amount of bone, containing large quantities of phosphorus. It is very desirable that this should be returned to the farm as a fertilizer. Such bone is treated in either of two ways: (1) It may be simply finely ground, in which case it is sold as *raw ground bone;* (2) the bone may be steamed under high pressure so as to remove fat and oils, and then finely ground. In this case it is known as ground *steamed bone meal.* Since the fat and oil is of no value as a fertilizer, while it has value for other uses, it is desirable to remove it, and increasing quantities of the bone are being so treated. The raw bone meal contains from 3½ to 4½ per cent of nitrogen, and from 9 to 11 per cent of phosphorus; the steamed bone meal contains from 2 to 3½ per cent of nitrogen, and from 8 to 12 per cent of phosphorus.

156. Mineral Phosphates. Fortunately nature has stored immense quantities of phosphorus in mineral deposits where they can be mined and used as fertilizers. Such deposits have been found in several places in this country, chiefly in Florida, South Carolina, Tennessee, and recently very large deposits have been found in Utah and adjoining states. This mineral phosphate is chemically the same as that in bones; that is, as tri-calcium phosphate, but is very much less soluble in the moisture of the soil and hence less available to plants. For this reason most of this material which is used as a fertilizer is first treated with an equal weight of sulphuric acid, forming what is called *acid phosphate.* Since the mineral phosphate contains from 10 to 15 per cent of phosphorus, the acid phosphate manufactured from it contains but half these amounts. This acid phosphate, however, is readily soluble, and hence immediately available to crops. It costs at Chicago approximately $15 per ton.

On account of the expense of this treatment with sulphuric acid, many experiments have been made to determine whether or not the untreated rock phosphate could be used directly as a fertilizer. These experiments taken as a whole, show that when this mineral phosphate is very finely ground and a sufficient quantity of it thoroughly mixed with organic matter which is decomposing rapidly, the carbon dioxid so formed is able to render a sufficient amount of phosphorus soluble to supply the needs of growing crops. On lands which are often robbed of their phosphorus, an application of a ton of this finer ground untreated rock phosphate per acre, either with barnyard manure or a green manuring crop, will furnish enough available phosphorus for a good growth of crops. The phosphate rock should be thoroughly mixed with the soil and the organic matter by plowing and disking. Since the untreated finely-ground rock phosphate costs very much less than the acid phosphate, and contains twice as much phosphorus, it is a much cheaper source of this element when proper conditions for its becoming available can be supplied. Except under these conditions, either acid phosphate or ground steamed bone meal should be used. After the first heavy application previously mentioned, half that quantity applied every 3 to 5 years will maintain the supply in the soil. The amount to be used should be determined by estimating the losses in products sold, as shown in the various tables given.

POTASSIUM

157. Amounts of Potassium in Soils. Soils vary greatly in their content of the element potassium. Clay and clay loam soils usually contain from 1 to 2 per cent of this element, while sandy soils have from .2 to 1 per cent; and soils largely made up of organic matter, such

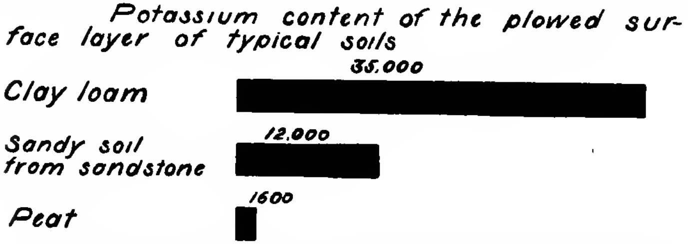


Fig. 22. The amount of potassium in clay soils is usually very large, though it requires chemical changes to make it available; while in sandy and peat soils the small amount must often be supplemented by fertilizers.

as peat and muck, run as low as .02 to .5 of one per cent. Assuming the weight of the surface soil over an acre to a depth of 8 inches to be 2,000,000 pounds in the case of clay, 2,500,000 in the case of sand, and 500,000 pounds in the case of muck and peat soils, it will be seen that these soils contain on the average from twenty thousand to forty thousand pounds per acre for the clay loams, five thousand to twenty-five thousand for the sands, and from only one hundred to twenty-five hundred for peat and mucks. It will be seen, therefore, that only on the peat and muck soils, as a rule, is the total supply of potassium at all likely to be exhausted. Not only is the amount of this element in the soil large, but there is an equally great amount in the subsoil.

158. Availability of Potassium. Notwithstanding the fact that most soils are abundantly supplied with this element, in many cases it is so unavailable that crops actually suffer for the need of a sufficient supply. Most of the potassium in the soil exists in silicate minerals which are not soluble in water. The potassium in these minerals becomes soluble only after the extremely slow chemical decomposition known as *kaolinization.* This process is largely effected through the action of the carbon dioxid contained in soil moisture. In soils having comparatively coarse grains, as do sandy soils, the amount of surface exposed to this chemical change is so small that the rate is often too slow to supply the rapid growth. It frequently happens, therefore, that sandy soils require potassium fertilizer, as well as nitrogen and phosphorus fertilizers, to permit them to support a strong growth of crops.

In the muck and peat soils, the total amount of potassium is very commonly so low that fertilizers containing this element must be regularly supplied. Moreover, these soils contain unusually large amounts of the element nitrogen, and are low only in phosphorus and potassium. It is much more economical to use farm manures, which contain all three of these elements, on upland soils, and to supply only the phosphorus and potassium (as commercial fertilizers) on muck and peat lands.

159. Loss of Potassium from the Farm. From a study of the composition of different parts of plants, as given in the table on pages 22, 23, 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 much less loss of this element from the farm than is the case with phosphorus. Hay is one of the chief crops commonly sold which removes considerable quantities of this element. Sugar beets and tobacco also feed heavily upon this element. A large part of the potassium in the tobacco is found in the stalks of the plant, which are commonly left on the farm to be used as fertilizer.

160. Potassium Fertilizers. The chief source of the potassium fertilizers at present on the market are the mines of the famous Stassfurt regions in Germany. From these extensive deposits crude potassium salts are mined, and these are used either directly as fertilizers (the chief of which is kainit), or they are concentrated and converted into chlorides or sulfates. The kainit contains from 11 to 13 per cent of potassium; while the chloride, commonly called muriate, and the sulfate contain about 45 per cent of this element. The chloride, or muriate, is somewhat cheaper than the sulfate, and is equally good for most crops; but for potatoes and tobacco and some other truck crops, the sulfate is preferable, as it produces a better quality than does the muriate.

Potassium im Common Fertilizers

	Pounds to the ton
Muriate of potash (potassium chloride)	850
Sulfate of potash (potassium sulfate)	850
Kainit	200
Wood ashes	100
Farm manure	8

All of these potassium fertilizers are very readily soluble in water and hence available to crops, and may be applied on any land at the time of preparation for seeding. There is, however, relatively little loss of potassium from the soil by leaching, so that they may be applied in the fall, and sufficient quantity may be used at one time for two or three seasons' growth, though it is ordinarily better to apply the amount that is needed from year to year. From 100 to 200 pounds of either the sulfate or muriate is sufficient for most crops, but the amount to be used must be determined by the kind of crop and the fertility of the soil in other respects. The soil kept in highly fertile condition in regard to nitrogen and phosphorus, having good water-holding capacity, and producing a heavy crop of tobacco or cabbage, will require 200 to 300 pounds of the high-grade potassium fertilizer, while an ordinary crop of small grain would require but 100 pounds.

CHAPTER VI

SOIL ANALYSIS

HISTORICAL DATA

161. Early Investigations Concerning the Feeding of Plants. The first accurate knowledge of the feeding of plants was gained when Sénébier, a Swiss, showed that the plant obtains its carbon from the carbon dioxid of the air. The Frenchman, De Saussure, made similar studies and found that the increase in dry weight of plants was largely due to the taking in of carbon. It was not until 1804, however, that De Saussure arrived at the second great fact in plant nutrition, that the ash constituents of plants are derived from the soil. His discovery is the fundamental basis upon which any intelligent study of soil fertility rests. The great Frenchman did not arrive at the whole truth, for he believed and taught that plants obtain their nitrogen from the ammonia in the air or from the humus in the soil. The first great English teacher of agricultural science, Sir Humphry Davy, believed and taught as did De Saussure. The first great German chemist to study agricultural problems, von Thaer, who lived and taught about this time, believed that plants fed directly upon the humus or "humus juices" of the soil.

162. Boussingault's Work. Von Thaer's ideas were largely overthrown by the work of the French farmer, scientist, and experimentalist, Boussingault. From 1834 to 1838, this energetic experimenter on his little farm in

Alsace was weighing his crops and weighing the manures put back. He soon found that plants get immensely larger quantities of carbon each year than could possibly be obtained from the humus in the soil. Boussingault was led to believe, too, that plants get their nitrogen from the soil, although he found certain cases where plants removed more nitrogen than had been supplied in the manures.

163. Liebig's Theory. In 1840, the great master of agricultural science, the German chemist, Baron Justus von Liebig, published his book on "Organic Chemistry in Its Application to Agriculture and Physiology." In this work, Liebig reviewed what had been accomplished by previous investigators and by the scientists of his time. He stated that plants get their carbon from the air and their ash from the soil. Liebig so emphasized the importance of the ash constituents of the plant that his ideas on the subject of plant feeding have been called "Liebig's Mineral Theory of Plant Nutrition." This German master actively defended the idea that crops get their nitrogen from the ammonia of the air.

164. The Lawes and Gilbert Experiments. About the time that Liebig was actively championing his ideas on the feeding of plants, a young English farmer, John Lawes, began a series of experiments on his family estate, Rothamsted Manor. These experiments, started over seventy years ago, were destined to revolutionize the ideas of both farmers and scientists concerning the feeding of plants, and to establish many farm practices on the firm basis of scientific fact. About 1843, Lawes engaged the services of a young chemist, Joseph Henry Gilbert, a pupil of Liebig's. Lawes and Gilbert disagreed with Liebig on the question of the nitrogen feeding of plants. They soon found that at least the common cereals and roots obtain their nitrogen as well as their ash constituents from the soil, but they were unable to account for the fact that certain crops such as clover and beans removed more nitrogen from the soil than had been furnished in the manure. Lawes and Gilbert conducted careful pot tests with these plants, but could not detect that they got any nitrogen from the air. They showed conclusively, however, which of the mineral elements were essential and which were nonessential.

165. Hellriegel and Wilfarth's Discovery. The whole question of the nitrogen feeding of plants was not understood until 1886, when Hellriegel and Wilfarth discovered that the legumes obtain nitrogen from the air by means of the bacteria in their root nodules.

CHEMICAL ANALYSIS OF SOILS

166. Early Studies. On the basis of what they knew concerning the feeding of plants, chemists began to investigate the composition of soils and crops in order to ascertain as far as possible what were the requirements of the different crops, and how these requirements could be met by different soils. The German chemist, Wolff, in particular, made hundreds of analyses of crops, determining the amount of ash and its composition.

167. Chemical Composition of a Soil. When the chemist subjects a soil to a complete analysis, he determines not only the amount of essential elements it contains, but also the amount of nonessential elements with which they are mixed or combined. In the diagram (Fig. 23), the largest cube represents a cubic foot of ordinary clay loam soil; the second largest represents the proportion of essential elements, while the tiny cube in the corner shows the ratio that the nitrogen and phosphorus (the plant foods most likely to be deficient) bear to the total supply of essential elements and to the total soil mass. The tiny cube is only one four-hundreth of the largest cube. A large part of the cube of essential elements represents iron, an element which is always present in all soils in sufficient quantity for the needs of an immense number of crops.

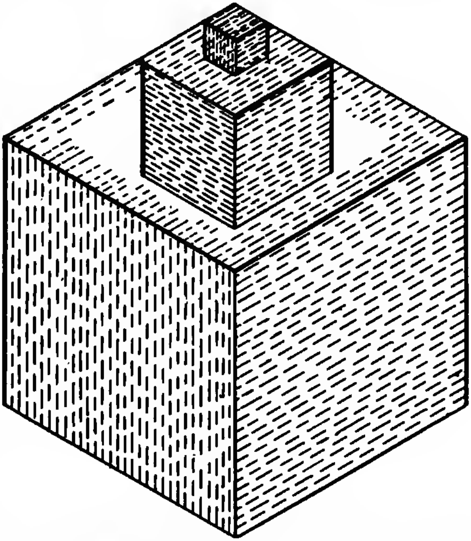


Fig. 23. Essential and nonessential elements in soils. The smallest cube represents the supply of nitrogen and phosphorus, the second cube the total supply of essential elements, while the rest of the large cube represents the nonessential elements.

As the supply of food in the soil is reduced by the removal of crops, the amount that can be set before future crops in a single season will tend to be less. Only a very small part of the stock of food in the soil becomes available in a season. If a soil is uncropped, the supply of available food tends to accumulate to some extent.

168. Methods of Determining Available Food Supply. Ever since chemists have been analyzing soils they have been trying to find a method which would determine the "available" plant food. Certain methods that have been proposed have been fairly successful within certain limits, but no generally useful means has ever been devised. The factors that influence the quantity of plant food which becomes available in a single year are so varied and complex that we can scarcely expect a universally successful method. These influencing factors are, the total supply of plant food in the soil, the texture of the soil, the amount of decaying organic matter in the soil, the extent to which the climate aids soil weathering processes, and perhaps many other undetermined factors.

Plants require their food supply in a water-soluble form, or at least in a form soluble in the solution around the root hairs. In order to estimate the quantity of available plant food in a soil, some investigators have tried extracting soils with pure water, others have used

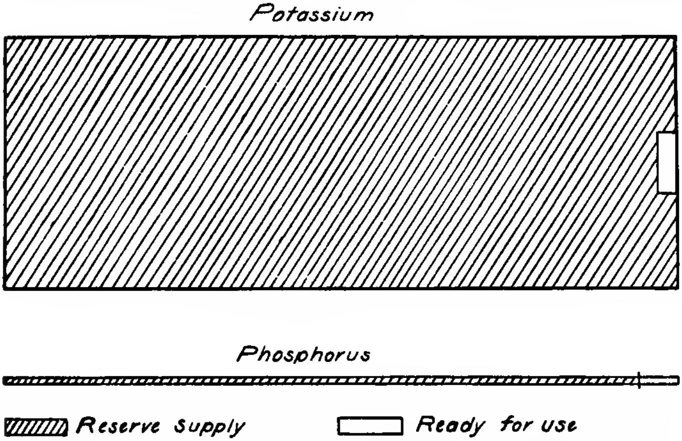


Fig. 24. The comparative amounts of potassium and phosphorus in the soil and the relative amount of each available at any one time.

carbonated water, while still others have used very dilute acids. The English chemist, Dyer, has suggested the use of 1 per cent citric acid solution.

169. Available and Reserve Food Supplies. In the application of practically any available method, we may well look upon the material dissolved as *plant food ready for use*, and upon the insoluble as the *source of the available supply.* We might divide this now insoluble material into a part that will become available within perhaps a few hundred years, that which will require thousands of years of weather, and that which may never be of use. The factors influencing availability are so complex, however, that any such division has little value. The total and the available supply of phosphorus and potassium in a Pennsylvania clay loam soil are shown herewith.

Phosphorus		
Ready for use	62.8	pounds
Reserve supply not yet ready for use	1040.2	“
Total supply	1103.0	“
Potassium		
Ready for use	173.5	pounds
Reserve supply not yet ready for use	55,775.9	“
Total supply	55,949.4	“

The same relations are expressed graphically in Fig. 24. The figure also shows how large is the supply of potassium in soils in comparison to the supply of phosphorus.

170. The Scope of Soil Analysis. A chemical examination of a soil sample should include the following determinations:

(1) Reaction of the soil, whether acid, alkaline, or neutral.

(2) Total organic matter.
(3) Total phosphorus.
(4) Total nitrogen.
(5) Limestone present (amount of carbonates).
(6) Limestone required (a measure of the acidity of the soil).

In the case of humus soils, such as peats and mucks, and sandy soils from sandstone, a determination of the total potassium should always be made. In such cases, the total supply of calcium and magnesium may also be so low that their determination becomes of value.

171. The Value of Soil Analysis. Analysis of individual samples of soils from isolated areas has little value. A. D. Hall states that "Soil analysis, even by the most refined method, is chiefly of value when the analysis of the particular soil under question can be compared with a number of analyses of similar soils on the same type of land, so as to ascertain its relative deficiencies or excesses, and interpret them in the light of what has been ascertained beforehand about their type of soil by experiences or by field trials." Soil analysis may very properly serve as a guide to field trials and experiments.

The chemical analysis of soils by state soil surveys as practiced in Wisconsin, Illinois, and other states, furnishes data with which comparison of individual analyses can be made. In fact, the information obtained by a good soil survey will often make unnecessary any extensive analysis of a soil submitted by a farmer. Comparison of the soil submitted to the state laboratory with others of the same physical type, a study of its location on the soil map, and a few simple chemical tests, may make unnecessary the more complete chemical examination.

172. Variation in Chemical Composition of Soils. In order to show how soil analysis may be helpful, we will discuss the composition of a few soils, and show how they differ from other soils.

COMPOSITION OF A "PLAINFIELD SAND"

	Per cent	Pounds to the acre 8 inches
Phosphorus	0.031	620
Potassium	1.59	39,750
Nitrogen	0.067	1,675
Limestone present		None
Limestone required		8,000

In the particular county in which this area was mapped by the Soil Survey, there are about 150,000 acres of land resembling this soil type. How can we use the above analysis as a guide to the management of this soil? In the first place, we should compare it with other sandy soils known to be fertile so as to ascertain to some extent its deficiencies. Three striking features of the analysis appear. The soil is low in phosphorus, low in nitrogen, and is so acid that at least 4 tons of ground limestone to the acre are needed. Nitrogen and organic matter can be built up by the growth of legumes, provided the necessary limestone and phosphorus are supplied. The potassium supply is abundant, and enough will probably become available if the soil is well stocked with decaying organic matter.

173. Composition of a Silt Loam. C. G. Hopkins *et al*, in Soil Report No. 1 on Clay County, Illinois, soils, reports the following composition for a "white silt loam on tight clay," an upland timber soil.

ANALYSIS OF AN ILLINOIS WHITE SILT LOAM

	In acre 6⅔ inches
Phosphorus	400 pounds
Potassium	29,380 "
Nitrogen	1,120 "
Limestone present	None
Organic carbon	16,980 "
Lime carbonate required	840 "

The subsurface sample (6⅔ to 20 inches) required 8200 pounds of lime carbonate, while the subsoil (20-40 inches) required 25,320 pounds of lime carbonate to correct the acidity. The report states that "In nitrogen and phosphorus this is one of the poorest soils found in the state. . . . With no provision to make plant food available, the crops produced on this type are often not worth raising."

174. Composition of Peat Soil. The composition of a peat soil deserves careful examination, for analyses of peats are apt to be misinterpreted. The following is the average of a number of analyses of a Sheboygan County, Wisconsin, peat soil, expressed in percentages and in pounds to the acre for the surface 8 inches. The surface 8 inches of peat weighs about 350,000 pounds to the acre.

COMPOSITION OF PEAT SOIL

	Per cent	Pounds to the acre 8 inches
Phosphorus	.157	550
Potassium	.485	1,697
Nitrogen	3.390	11,865

We notice at once that a peat differs from both the sand and the clay loam in its low content of phosphorus and potassium. The percentage of phosphorus is high, but the actual amount is low, on account of the light weight to the acre. The amount of total potassium contained in this soil is enough for only twenty-one 65-bushel crops of corn, provided it could all become available. Actual field tests uniformly show that deep peat soils require potassium fertilizers. Contrast the amount of nitrogen in this soil with the amount in the two soils previously considered, and note the great stock on hand. Of course not all the nitrogen in peat is immediately available, nor is its rate of availability as rapid as in the more mineral soils. Good drainage, cultivation, and light applications of active manures such as horse manure, will furnish sufficient nitrogen for good crops of corn and potatoes, long after the total supply of nitrogen in sand and clay soils is entirely exhausted. Peats are largely organic matter, so that any careful determination of the organic matter in them is hardly necessary. When peats are more thoroughly decomposed and mixed with silt and clay from the subsoil or the surrounding land, the percentage of organic matter becomes less, while the amount of potassium usually becomes greater. Shallow peats and mucks are therefore usually higher in mineral matter than deep peats.

175. Importance of Care in Soil Sampling. When the miner wishes to know the amount of gold in an ore he submits a fair sample of the ore to an assay chemist. He takes drillings or samples from different parts of the vein or outcrop and mixes them thoroughly. When the chemist receives this sample he submits it to a still further grinding and quartering or "riffling" process until the small quantity from which he expects to obtain the tiny gold "button" is truly representative of the whole. When the soil chemist undertakes a determination of the total phosphorus in a soil he usually employs 2 grams of soil. Two grams of soil are only 1/453,600,000 of the surface 8 inches of an acre of clay loam soil. If the chemist is to make an accurate report on material when his sample is only one part in over four hundred million, he must be absolutely sure that this tiny fraction is as nearly representative as mechanical means and man's ingenuity will permit. Soil phosphorus is more valuable than the miner's gold, for it is an essential element in the food supply of every plant and animal.

176. Taking Soil Samples. Samples for chemical analysis should consist of at least ten composite cores or vertical slices from different parts of the field under examination. The surface soil is ordinarily sampled to the depth of plowing, or an arbitrary depth can be adopted. The Illinois station has adopted 6⅔ inches as representative of the surface soil, while the Wisconsin station uses 8 inches. Subsoil samples should always be taken down to the depth of 3 to 4 feet. The subsoil should be examined as to its structure, permeability to water, etc. Chemical analysis of the immediate subsurface sample is a wise procedure, although not always necessary.

If the field is uneven, samples from ridges and knolls should be kept separate from samples taken in ravines and in flats; that is, the sample should be representative of the same general topography. If the sample is taken from a cropped soil, the different samples should represent as far as possible the same cropping history and manurial treatment.

177. Sampling Instruments. The King soil tube, shown in Fig. 25, is perhaps the best device for obtaining soil and subsoil samples. When this tube is used, there is little danger of mixing the subsoil sample with portions of the surface soil. Where the King tube is not available, the soil auger, shown in Fig. 26, is a handy device. The extension auger consists of an ordinary 1½-inch auger welded on to a steel rod and fitted with a gaspipe handle. When samples are taken for laboratory examination they should be placed in clean cloth or stout paper sacks and plainly marked with some distinguishing label. The student is advised to obtain a soil auger and collect samples of soil and subsoil from the different soil areas in his vicinity.

Fig. 25. The King soil tube, used for collecting samples of soil. The heavy hammer is used to drive the brass tube into the soil, while the cutting edge with the small diameter cuts out a core of soil which slides readily up into the tube.

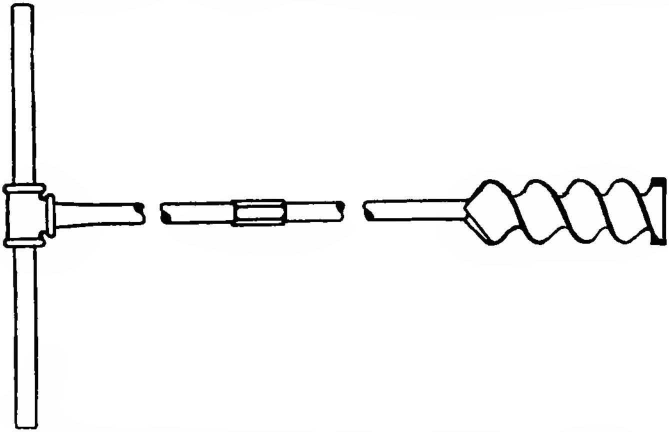


Fig. 26. An auger supplied with extension and handle for use in collecting soil samples. The small tip used to start the auger in wood should be cut off when the auger is to be used for soil sampling.

178. How the Chemist Obtains a Representative Sample. When the soil reaches the chemical laboratory it is usually air dried, crushed in a mortar by means of a rubber-covered pestle, and sifted through a 20-mesh sieve (20 holes to the linear inch), so as to separate the "fine soil" from the coarse gravel, etc. The fine soil is then quartered repeatedly until a sample of about 100 grams is obtained. This smaller subsample is then reduced to a flour-like powder in an agate mortar or grinding machine. From this smaller pulverized subsample the chemist can take a true sample of the soil. We have dwelt upon sampling of soils in some detail in order to emphasize the fact that as a general rule soil samples taken in a haphazard fashion by untrained men are not likely to represent faithfully the area studied.

179. Simple Chemical Tests. The first tests to which a soil should be submitted are the litmus paper test for acid and the test for carbonates. With due precautions, these tests may be used by anyone, even though not a trained chemist. These tests are of particular importance because upon the absence of acidity and the presence of limestone depend the successful growth of our valuable legumes such as clover and alfalfa.

180. *Litmus Paper Test.* The litmus paper test is best applied to the moist field soil before it is air dried. Use a sensitive grade of blue litmus paper. With a clean knife or stick, divide a lump of soil into two portions and insert the litmus paper, pressing the portions of soil against the paper. Allow the soil and paper to remain in contact from five to ten minutes. If the soil is acid, red spots will appear or an entire reddening of the paper will occur.

Precaution. Use a pointed wire or forceps in handling the litmus paper. Never handle the moist paper with the hands, for the *perspiration may be acid.*

181. *Carbonate Test.* The presence of carbonates may be detected by the bubbling which follows treatment with dilute hydrochloric acid. Unless the quantity of carbonates present is very small, bubbling and evolution of carbon dioxid gas will occur. The soil should be moistened with water first in order to drive out the air bubbles. The dilute acid used should consist of about one part of concentrated hydrochloric acid and five parts of water.

ANALYSIS OF SOILS BY PLANTS

182. Growth of Plants May Show Needs of Soils. Since the farmer or the student who has neither the facilities or the training to undertake any but the simplest chemical tests can not perform the more difficult determinations used in soil analysis, we will present another scheme whereby one may question the soil, as it were. We have already learned that certain elements and certain amounts of them are necessary for the best growth of all crops. If a soil does not contain sufficient phosphorus, or, if what is often true, the amount that becomes available in a single season is too small, we should expect that applications of phosphorus fertilizers would increase the yield. If, at the same time, the supply of available potassium is too low, we might expect the use of potassium fertilizers to further increase the yield. Of course, if both are lacking, we must supply both before we can expect normal yields. You will recall that the capacity of the barrel is determined by the shortest stave (Sec. 99). The principles just stated are employed in pot and plot fertilizer tests.

183. The Pot Test. Great care should be exercised in taking the sample of soil for this test. Never select a field sample for fertilizer test while the soil is very wet. The soil is usually taken to the ordinary depth of plowing, using a spade. The same precautions that have been outlined under sampling soils for chemical tests should be employed in this case. About a grain sack full or a half-barrel of soil is necessary. Obtain 8 clean 2-gallon butter jars. Fill the jars to within 2 inches of the top with the thoroughly mixed soil sample. Number the jars from one to eight. Apply the following fertilizers, mixing them into the surface 3 or 4 inches of soil. It is a good plan to remove about a double handful of soil from each jar and first mix this amount with fertilizer, using a clean dish. This well-mixed portion of soil should then be thoroughly mixed with the rest of the soil in the jar. Following is the treatment each jar should receive:

Jar No. 1......Blank (no fertilizer).
" " 2......2 grams nitrate of soda.
" " 3......2 grams acid phosphate.
" " 4......2 grams potassium sulfate.
" " 5......2 grams nitrate of soda plus 2 grams acid phosphate.
" " 6......2 grams nitrate of soda plus 2 grams potassium sulfate.
" " 7......2 grams acid phosphate plus 2 grams potassium sulfate.
" " 8......1½ grams acid phosphate plus 1½ grams potassium sulfate plus 1½ grams nitrate of soda.

After these fertilizers are applied, the jars should be watered well and allowed to stand about a week before planting. Cultivate the soils with a clean stick, keeping a separate stick in each jar. Now plant about six kernels of corn in the center of each jar. When the corn comes up, it should be thinned to three stalks to the jar. Keep the jars in good light. If they are kept out of doors, they should be moved in when rains occur. Apply water from time to time in sufficient quantity to keep the soil in good workable condition. The jars do not necessarily require drainage provided not too much water is applied. Fig. 27 illustrates the results of a pot test of a clay loam soil that was badly in need of phosphorus. The unlabelled jar received no fertilizer. "N" indicates nitrogen in nitrate of soda; "K," potassium in potassium sulfate; and "P," phosphorus in acid phosphate. The commercial fertilizer, calcium acid phosphate, is a good form of phosphorus fertilizer for use in these tests. Note that the results of this test show a marked need of phosphorus.

Fig. 27. A very distinct answer to the inquiry as to the cause of poor growth on the field from which the soil in these jars was taken. K stands for potassium, P for phosphorus, and N for nitrogen. Note that only the plants receiving phosphorus made good growth.

184. The Plot or Field Test. Since the pot test requires considerable care, and since the root systems in the jars are badly crowded, it is well to run a similar test on a larger scale in the field. The best plot to select is usually an acre in the middle of one end of a field. Ten one-tenth acre plots may be used, making each plot 2 rods wide and 8 rods long. The following diagram shows the most desirable location for a soil test plot. This insures the same plowing, cultivation, and handling for the fertilized plot as for the rest of the field. Corn is an excellent crop to grow on test plots, because the small plots can be easily harvested separately. The plots should be arranged as follows:

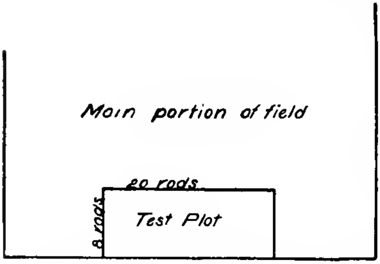


Fig. 28. The small plot should be a part of the larger field bearing the same crop.

185. Plan for Plot Experiment with Fertilizers.

Plot No. 1......No fertilizer.
" " 2......Dried blood.
" " 3......Steamed bone meal
" " 4......Potassium sulfate.
" " 5......No fertilizer.
" " 6......Dried blood and bone meal.
" " 7......Dried blood and potassium sulfate.
" " 8......Steamed bone meal and potassium sulfate.
" " 9......Dried blood, steamed bone meal, and potassium sulfate.
" " 10......No fertilizer.

Apply the blood meal at the rate of 500 pounds to the acre. (Nitrate of soda at the rate of 125 pounds to the acre may be substituted for the blood meal). The steamed bone meal and the potassium sulfate may be used at the rate of 200 pounds to the acre. If the soil is acid, one-half of each plot should be limed with ground limestone at the rate of 1000 pounds to the acre. The following diagram shows the arrangement of test plots.

Since only small quantities of fertilizers are required for each of these test plots, it is a good plan to mix each lot with several times its weight of dry soil. Broadcast the fertilizers by hand, selecting a quiet day, so that the wind will not carry them over into the wrong plots. As soon as the fertilizers are sown, each plot should be harrowed lengthwise in order to mix the fertilizer with the surface soil. Do not cross-harrow the plots.

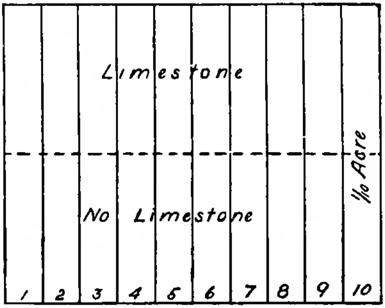
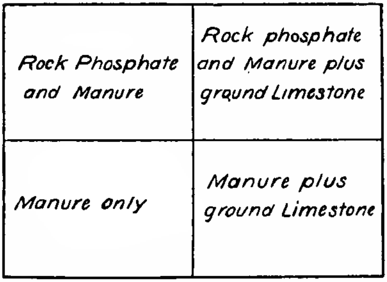


Fig. 29. This diagram shows a good arrangement of these plots and a good ratio of width to length.



Rock Phosphate and Manure	Rock phosphate and Manure plus ground Limestone
Manure only	Manure plus ground Limestone

Fig. 30. A good way to lay out an experiment field.

When it is not desired to run as complete a test as outlined above, it is well to increase the size of the plots used and reduce their number.

Each plot in the above test should be at least one-half acre in size. Apply ground limestone to one acre and omit it in the other. The limestone should be applied in the fall and thoroughly worked into the soil. The rock phosphate may be mixed with the manure (Sec. 207) and applied in the spring. The manure used should be of the same general character on all plots, the rock phosphate being omitted from two of them.

In judging the results of a field soil fertility test, the crop should be weighed or measured. An increase of 10 per cent in the yield of oats, for example, will not be detected by the eye, yet it may be sufficient to warrant the expenditure of money for fertilizers.

CHAPTER VII

FARM MANURES

186. Value of Manure. The fertilizer available to a greater or less extent on every farm is stable and yard manure. Progress in farming methods has been marked just so far as a careful, economical use of farm manures has been practiced. Wasteful handling of this precious by-product has been the rule rather than the exception. Professor F. H. King, in his "Farmers of Forty Centuries," in describing the conservation of fertility by the farmers of China, Japan, and Korea, has said: "Manure of all kinds, human and animal, is religiously saved and applied to the fields in a manner which secures an efficiency far above our own practices." Although this country may never be placed in such economic stress as is the Orient, or if so placed may strive for other solutions of the fertility problem, yet we may learn wonderful lessons in thrift and economy from those ancient peoples.

THE PROCESS OF MANURE MAKING

187. Changes Occurring in Manures. Since the manure heap is so necessary on every farm where farm animals are kept, let us consider the nature of the processes going on in that heap. Ordinary farm manures consist of three classes of material, the solid manure, or dung; the liquid manure, or urine; and the litter. These materials are organic in origin; that is, they are compounds of carbon, hydrogen, oxygen, and nitrogen primarily, but contain also all the other essential elements used by plants. After the dung and urine have left the animal and are mixed with the litter, important chemical changes, effected very largely by bacteria, occur in this mixture. The important changes that occur are:

(1) Changes in the carbon compounds; that is, in the cellulose (fibre) and carbohydrate material; and
(2) Changes in the nitrogen compounds; that is, in the partly decomposed proteins of the dung and in the urea of the urine.

Since manure when properly cared for is usually moist, air is excluded. Consequently, the most important changes occurring are brought about by types of bacteria that can live without free oxygen (anaerobic).

188. Changes in the Carbon Compounds. The chief change in the carbon compounds of the manure, such as the straw, is brought about by anaerobic organisms producing:

(1) Carbon dioxid, marsh gas and hydrogen; and
(2) Dark brown humus substances as the residual material.

It is only when the manure heap becomes dry, especially on the outside, where air can penetrate, that the organisms dependent upon free oxygen become active. In such cases carbon dioxid alone is produced. A. D. Hall states that during the making of manure about a quarter of the original dry matter is thus lost by conversion into either marsh gas or carbon dioxid. When manure is stored, and especially if it is not kept moist, this loss may amount to one-half of the original dry weight.

189. Changes in the Nitrogen Compounds. (1) *The urine.* The urine contains the soluble, highly nitrogenous compound, urea. Urea is attacked by the urea-fermenting bacteria and very quickly converted into carbonate of ammonia. This carbonate of ammonia very readily splits up into free ammonia and carbon dioxid, so that in this manner considerable nitrogen is lost, even when the manure is given the best of care. The loss of ammonia to the air is considerably reduced when peat instead of straw is used as litter. The best conditions for the retention of ammonia are obtained when the straw and manure are firmly trodden under the feet of animals and kept sufficiently moist to exclude the air. Hall states that where litter was cleared away from under the animals and thrown into a loose, open pile, the loss of ammonia often rose to as high as half of the nitrogen given in the feed. Frequent stirring of the manure hastens this fermentation, a principle used by gardeners in preparing manure for hot beds and for the growth of mushrooms.

(2) *The dung, or solid excreta.* Putrefactive bacteria attack the undigested or partly-digested proteins, breaking them down into simpler substances. Another change that takes place to some extent is the reconversion of soluble nitrogen compounds into insoluble proteins, making up the bodies of the bacteria themselves. This is of some significance when we remember that manure contains enormous numbers of bacteria. Losses of nitrogen occur from the solid part of the manure just as they do from the urine, but not to so great an extent.

LOSSES FROM MANURE

190. Percentage of Loss. After the manure is made, much loss may occur by leaching. The dark brown liquid flowing away from a manure heap is really a humus solution formed by the action of the carbonate of ammonia on the organic matter in the manure. Nitrogen is lost, too, as ammonia, or as free nitrogen resulting from the direct oxidation of ammonia to water and nitrogen. In experiments conducted at the Woburn experiment station, in England, there was an average loss of 15 per cent of the nitrogen fed where fattening steers (Sec. 198) were kept in box stalls having cemented sides and bottom, and where enough litter was kept to absorb the liquid excreta. When manure thus made was kept under cover until spring, a further loss of from 15 to 18 per cent of the nitrogen was discovered. Maercker, in Germany, studied the effect of trampling manure by cattle, and found that untrampled manure showed a loss of 35.5 per cent of its nitrogen within a period of one month, while trampled manure lost only 13.2 per cent of its nitrogen. In a similar experiment at the Pennsylvania station, trampled manure lost 5.73 per cent of its nitrogen, and untrampled 34.12 per cent. An experiment by Stutzer showed, that in twenty-one weeks loosely stored manure had lost 58 per cent of its organic matter and 34 per cent of its nitrogen, while compacted manure had lost only 28 per cent of its organic matter and 15 per cent of its nitrogen.

FACTORS INFLUENCING THE VALUE OF MANURE

191. The Factors Enumerated. Having studied the process of manure making, we will now study in more detail the factors influencing the value of manure. These factors are:

(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.

192. Food of the Animals. 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, both of which are low in nitrogen and phosphoric acid, will produce a manure much lower in value than if fed bran and clover hay, or substances relatively high in nitrogen and phosphoric acid.

Hall[1] has compared the composition of manure made by two lots of steers, one lot of which received roots and hay only, and the other lot roots, hay, and linseed cake, the latter being a nitrogenous concentrate. Some of the results obtained appear in the following table:

Table XI. Nitrogen in manure from two lots of steers, to one of which linseed cake, a feed rich in nitrogen, was fed.

	Dry matter	Total nitrogen	Nitrogen as ammonia	Insoluble nitrogen
COMPOSTED	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Roots and hay only	23.6	0.577	0.046	0.464
Cake, fed	24.03	0.716	0.079	0.541
NOT COMPOSTED				
Roots and hay only	25.3	0.589	0.125	0.411
Cake, fed	25.5	0.815	0.377	0.405

As a general rule in these experiments, the manure from cake-fed animals contained nearly 40 per cent more nitrogen than that from the other lot. This extra nitrogen is largely in the highly available forms, in ammonia, urea,

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[1] A.D. Hall, Fertilisers and Manures, p. 203.

and amide compounds, those parts of the manure arising from the animal's digestion of the oil cake. Amides or animo compounds are nitrogenous compounds formed by the partial digestion of proteins. When such manures are used on the soil, the richer one will usually result in the production of the larger crop. Like all easily available nitrogenous manures, however, the cake manure showed its greatest benefit the first year after application.

193. Proportion of Fertilizing Material in Feed Recovered in Manure. The best statement of the facts in relation to the amount of material recovered has been made by Hopkins[1], who says: "As a general average for dairy farming, cattle feeding, and sheep feeding, it is shown that practically one-third of the organic matter, three-fourths of the nitrogen, and three-fourths of the phosphorus contained in the feed and bedding are recovered in the total manures. Nearly all of the potassium may be recovered except that sold in milk."

194. Age of the Animals. Young animals are constantly removing from their food, nitrogen to build up muscle and body tissues, and calcium and phosphorus to build up bones, while mature animals that are just maintaining themselves remove comparatively little of these fertilizing constituents. Therefore, manure from mature animals is more valuable than that from young and growing animals.

195. Kind of Animals. The following table adapted from Wolff shows the percentage composition of fresh manure from various animals, and its value to the ton, figuring nitrogen at 15 cents a pound, phosphorus at 2.18 cents a pound, and potassium at 4.15 cents a pound.

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[1] C. G. Hopkins: Soil Fertility and Permanent Agriculture, p. 206.

Table XII. Average composition of fresh manure from different animals, and value per ton at stated prices for different fertilizing elements.

	Nitrogen	Phosphorus	Potassium	Value per ton
	Per cent	*Per cent*	*Per cent*	*Dollars*
Cow	0.44	0.070	0.332	1.89
Horse	0.58	0.120	0.440	2.55
Pig	0.45	0.083	0.497	2.14
Sheep	0.83	0.400	0.556	3.39

Table XIII, which is republished from Bulletin 56 of the New York (Cornell) station, shows the quantity and value of manure produced to the 1000 pounds of live weight of animals of different kinds.

Table XIII. Quantity of manure produced daily to each 1,000 pounds of live weight of common domestic animals, with daily and yearly value of this production.

	Daily production	Daily value	Yearly value
	Pounds	*Cents*	*Dollars*
Sheep	34.1	7.2	26.09
Hogs	56.2	10.4	37.96
Calves	67.8	6.7	24.45
Cows	74.1	8.0	29.27
Horses	48.8	7.6	27.74

Henry[1] has compiled the following table of average quantities of excrement voided by farm animals in twenty-four hours:

Table XIV. Quantities of solid and liquid excrement voided by different animals daily.

Animal	Solid excrement (dung)	Liquid excrement (urine)	Total
	Pounds	*Pounds*	*Pounds*
Horse	33	8	41
Cow	49	19	68
Sheep	2	2	4
Pig	4	3	7

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[1] W. A. Henry: Feeds and Feeding, 1910, p. 246.

196. Liquid and Solid Manure. The liquid portion of the manure is of different composition than the solid portion. Urine contains a high percentage of nitrogen, but only a trace of phosphorus. Most of the phosphorus is found in the solid excrement, while the potassium 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 Hall shows the comparative composition of liquid and solid excrement:

Table XV. Comparison of composition of liquid and solid manure from different animals.

	Water	Nitrogen	Phosphorus	Potassium
	Per cent	*Per cent*	*Per cent*	*Per cent*
Horse—Urine........	90.0	1.52	trace	0.746
Solid excrement..	75.0	0.55	0.152	0.083
Cow—Urine.........	91.5	1.05	trace	1.128
Solid excrement..	86.0	1.43	0.052	0.033
Sheep—Urine........	86.5	1.31	trace	analyses not
Solid excrement..	57.6	0.72	0.192	given
Pig—Urine..........	97.6	0.50	0.061	0.581
Solid excrement..	76.0	0.48	0.252	0.298

An examination of Tables XV and XVI will show that the urine from sheep and horses contains much more nitrogen than the urine from cows and pigs. Sheep and horses also produce a drier manure. On account of this dryness and their richness in nitrogen, fermentation takes place much more rapidly in these manures than in the "colder" cow and pig manures.

197. Character of the Product. Manure from milch cows is relatively lower in nitrogen and phosphorus than manure from beef animals or from animals which are fed a maintenance ration only. Vivian estimates that a cow giving a yield of 5000 pounds of milk removes fertilizing materials in the milk amounting in value to $4.98. Hall[1] presents another valuable table showing the nitrogen and other elements digested and retained from 100 pounds of linseed cake fed to fattening oxen and to milch cows respectively:

Table XVI. Nitrogen, phosphorus and potassium in 100 pounds of linseed cake, with the pounds of these elements retained and the pounds voided in the urine and dung by fattening oxen and by milch cows when fed this cake.

	Nitrogen	Phosphorus	Potassium
	Pounds	*Pounds*	*Pounds*
Content of 100 lbs. of linseed cake	4.75	0.872	1.162
When fed to fattening oxen:			
Retained in meat	0.21	0.061	0.017
Voided in urine	3.88	0.039	0.913
Voided in dung	0.66	0.772	0.232
When fed to milch cows:			
Retained in milk	1.32	0.218	0.116
Voided in urine	2.75	0.031	0.872
Voided in dung	0.66	0.623	0.174

198. Character of the Litter. The Rothamsted station has made some interesting studies of litter, the material which absorbs the liquid manure and at the same time increases the amount of vegetable matter in the manure. The usual material at hand is straw, although in cities and on some farms shavings are used considerably. Peat moss or dried decayed peat is beginning to be used to some extent. Peat has an advantage over

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[1] A. D. Hall: Fertilisers and Manures, p. 180.

straw as an absorbent, as it will take up about ten times its own weight of water, while straw will absorb only two or three times its own weight. Peat also holds the ammonia better, thus keeping the air of the stables purer. An experiment (unpublished) at the Wisconsin station showed two or three times as much ammonia in the stable air where shavings were used as where peat was used. The Rothamsted station reports an experiment where at the end of 6 days stable air over straw litter contained sixteen times as much ammonia as stable air over peat moss. Peat also is high in nitrogen, average Wisconsin peat usually containing about 3 per cent nitrogen when dry. This nitrogen adds to the value of the manure, although it does not decay as rapidly as straw and is therefore not as immediately available.

The straws from different grains produce manures of different texture. Coarse wheat or rye straw will make a loose manure, while oat straw will tend to produce a more compact fertilizer. Finely cut corn stover is of more value as bedding than the coarser stalks. Shavings, being usually resinous in character, decay but slowly, and may be harmful in light soils. Their antiseptic properties may even retard the decay of the manure itself. The principal objection to shavings is that it is difficult to obtain a compact manure, so that there may be great losses of both carbon and nitrogen from fire fanging. The conservation of nitrogen by the use of litter has been shown by Muntz and Girard, of France, in the following experiment:

	Loss of nitrogen Per cent
Cow manure, no litter	59.0
Cow manure, litter	50.2
Cow manure, litter	44.2
Cow manure, abundant litter	40.8

CARE OF MANURE

199. Essentials. Enough has already been said about the factors influencing the value of manure to permit the deduction of the two essentials in the care of manure; namely:

(1) Keeping it compact,
(2) Keeping it moist.

200. Losses from Exposure. Results at the Ohio station[1] 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.

Frank T. Shutt, of the Canadian Experimental Farms, exposed a heap of 2 tons of manure, the organic matter of which had a dry weight of 1938 pounds and contained 48.1 pounds of nitrogen, to the action of the weather for four months, from April 29 to August 29. During this short time the quantity of organic matter was reduced to 655 pounds and the nitrogen to 27.7 pounds.

201. Handling Manures and Use of the Manure Shed. Because of losses due to exposure in the yard where leaching and objectionable fermentation may take place, it is more economical to use other methods in handling manures. In order to prevent the losses that must surely occur when manure is exposed to every rainfall, a manure shed is an advantage. An important item to be considered in the construction of a manure shed is its handy

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[1] Ohio Experiment Station Bulletin 183.

location with reference to the stables and also to the fields. The shed should have a tight floor slightly below the level of the yard, and a tight roof. The floor may be constructed of cement or of puddled clay.

The invention and use of the modern litter carrier offer the farmer the means whereby he can secure a deep, compact pile of manure and thus reduce the inevitable losses to a minimum. We have already noted that the first essentials in the construction of the manure heap are compactness and moistness. There is some danger that the manure in the shed may become somewhat too dry, unless it is frequently trampled by animals. The manure from the cow stables, especially where the liquid manure is carefully saved, is not likely to suffer much loss by becoming too dry. Horse manure, as already stated, is a dry manure and is best mixed with the manure from the cattle barns in order to keep it moist.

202. Direct Application of the Manure to the Field. Whenever fields are available and not so rolling as to cause a rapid surface drainage, it is most economical to haul the manure to the fields as soon after it is produced as possible. In the great corn and grain belts of the United States, where considerable stock is kept, the fields are not always available all the year round for the immediate application of the manure. On this account, the manure produced should be carefully saved as we have indicated in the preceding paragraph. Where young stock is kept, the deep stall method of storing manure is an excellent way of preventing losses by leaching. The deep stall could hardly be recommended as sanitary where dairy cows are kept.

We should always bear in mind in the handling of manure, that any method of storage or preservation yet devised fails to prevent certain apparently inevitable losses of both organic matter and nitrogen; hence the quicker manure is taken to the field after it is produced, the less is the danger of loss in this manner. Of course it is not advisable to apply manure to rolling land on deep snow, for in such cases losses will occur by leaching in the field and perhaps even more by erosion.

203. Top Dressing Manure vs. Plowing Under. Probably two-thirds of the farm manure that is produced in Europe is applied as a top-dressing. Most of this manure has been carefully composted and is therefore easily worked into the soil. The practice of top-dressing plowed lands with manure is not at all common in this country, yet it has certain features to recommend it. When we recall that the nitrogen in manure is easily and quickly changed over into nitrates that are readily washed out in the drainage waters, it would seem advisable to have most of this valuable plant food formed as completely in the surface layers of the soil as possible.

The Chinese practice the application of composts to the surface of practically all their fields, which are noted for their wonderful fertility.

Where manure is coarse and unrotted and contains large numbers of weed seeds, it is perhaps more desirable to plow it under than to apply it as a top-dressing. Manure can be more safely plowed under on heavy soils than it can on light soils because it is not as rapidly oxidized and leached. The practice of using well-rotted manure as a top-dressing on grass fields is quite common in parts of the United States. This practice tends to promote a rapid vegetative growth, and consequently may increase the amount of crude fiber produced, while not materially increasing the production of more valuable constituents in the hay. No hard and fast rule can be laid down concerning the relative merits of top-dressing and plowing under, because we do not yet have sufficient experimental data.

204. The Manure Spreader. Wherever farm manure is produced in any quantity the manure spreader should be as necessary a piece of machinery on the farm as any other. Not only is it a labor saver, but it insures an evenness of application that cannot possibly be obtained by hand spreading. The old method of hauling manure in the winter and distributing it in small piles to be spread by hand in the spring, is highly objectionable. American fields are noted for their unevenness of fertility, while foreign fields are remarkable for their even fertility.

Professor King states that wheat or rice on any one farmer's holding in China is always all of the same height. One farmer's field may be less fertile than that of another, but the amount of fertility is so evenly distributed that the only difference noticeable between the two fields is in the height of the crop. The manure spreader is one of the best contrivances for obtaining this even distribution of fertility.

205. Composting. Composting manure consists essentially in carrying along further the process described in Sec. 188. As usually practiced, it consists in the mixing of manure, soil, and other nitrogenous organic matter and allowing it to ferment, so that the plant food becomes more quickly available. Where intensive agriculture demands the production of several crops a year on the same plot of soil, as is the case in truck gardening, in greenhouse culture, or in thickly populated countries, such previous preparation of the manure and soil for "feeding the crop" becomes eminently profitable.

206. Use of Preservatives With Manure. We have already referred to peat as an aid in retaining the ammonia coming from fermenting manure. Gypsum, or land plaster, has also been used for this purpose. Gypsum is able to hold ammonia because it furnishes the material whereby the ammonium carbonate in the manure is changed to ammonium sulfate. The ammonia in ammonium sulfate does not change to free gaseous ammonia as easily in the fermenting manure heap or in the gutter containing liquid manure, as does the ammonium carbonate. There are several objections to the use of gypsum. Since it is a very insoluble compound, large quantities of it are necessary in order that enough may dissolve to combine with the soluble ammonium carbonate, while considerable quantities of the gypsum are lost to this purpose by combining with other substances in the manure. Theoretically, 11 pounds of gypsum are sufficient for a ton of manure, but in practice 100 pounds are needed, making the cost quite high. Land plaster may be of direct benefit to the soil either by furnishing the necessary calcium for legumes or by making available insoluble potassium compounds in the soil. Superphosphate and acid phosphate have been mixed with manure to retain the ammonia, but these substances have an injurious action on the feet of animals.

207. Rock Phosphate and Manure. When we study the composition of farm manure, we note at once that it is low in phosphorus as compared to its potassium and nitrogen content. Considerable rock phosphate (floats) is now being used with manure. It has no power to fix ammonia chemically, but is an absorbent for the urine. This practice places the rock phosphate where the action of decaying vegetable matter may make the phosphorus available. At the same time it affords a means whereby the rock phosphate may be more thoroughly mixed with

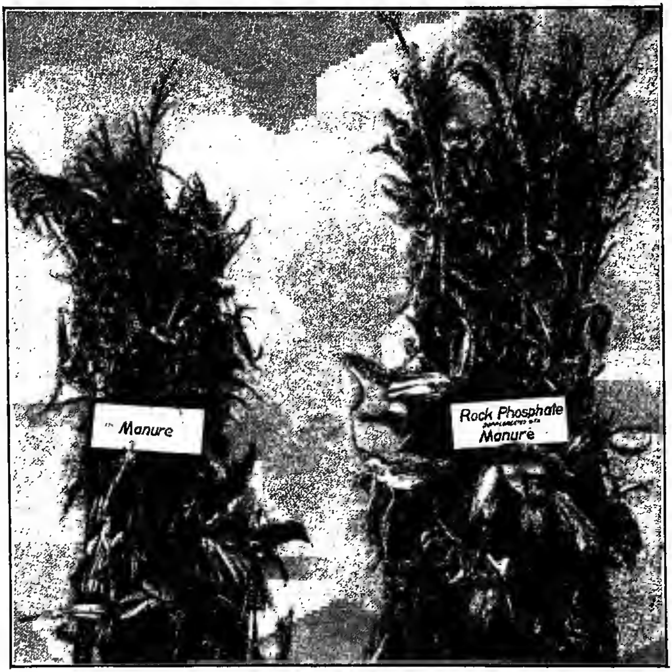

Fig. 31. Manure, while the best general fertilizer, is often inadequately supplied with phosphorus for soils deficient in this element, and should be supplemented with phosphorus fertilizers.

the soil, a potent factor in rendering available the so-called "unavailable fertilizers." One pound of rock phosphate to the manure produced daily by each animal will make 40 pounds of rock phosphate to the ton of manure, under the average conditions prevailing in the use of feed and litter (See chapter on phosphorus).

BENEFITS OF FARM MANURE

208. How Manure Improves Soils. The soil gains a threefold benefit from the application of ordinary manure:

(1) Manure adds plant food material to the soil. The decay of manure, with the production of carbon dioxid, also unlocks unavailable phosphorus and potassium from soil minerals containing these elements.

(2) Manure adds bacteria, which attack not only the manure itself, but also the soil material.

(3) Manure improves soils physically.

The first named beneficial effect needs no further discussion. That manure inoculates the soil with decay bacteria is well appreciated by those who have noted the benefits derived from comparatively light applications of manure on cold, unresponsive soils. Many newly drained marsh soils are thus benefited by light dressings of horse manure. Farm manure improves soils physically both by maintaining them in good tilth and by increasing their power to hold water. Manure is especially helpful in keeping soils loose and workable for the growth of the root crops.

Although manure adds but little to the stock of inactive humus (Sec. 297), it nevertheless does increase the water-holding capacity of soils. The Rothamsted station compared the extent to which a light rain (0.262 inches) was retained in the surface 9 inches of two fields, one manured and the other unmanured, and found that the manured plot had retaind practically all the rainfall in the surface 9 inches, while in the unmanured plot the water had gone down into the subsoil.

209. Manure and Commercial Fertilizers. An unwarranted prejudice exists in some quarters against the use of anything but farm manure to restore fertility to soils. As every farmer well knows, there is a limit to the amount of manure that can be economically produced on a farm. We have already called attention to the enormous losses that occur when manure is applied in large quantities. Excessive quantities are used largely because the crops grown are of a character that demands a large available nitrogen supply. This practice results in large losses of the nitrogen thus supplied, and also of the phosphorus. It is unlikely that manurial potassium is conserved to any greater degree than the phosphorus.

Commercial fertilizers specially high in phosphorus, used to supplement the nitrogen gained from the air by legumes, will probably result in a more economical gain than when farm manure is so lavishly used. Even artificial nitrogen fertilizers will begin to command more attention when we awake to the possibilities of getting crops started earlier in the spring.

Farm manure is most economically used when applied in light applications at frequent intervals, allowing the crop time to utilize the amount supplied.

210. Lasting Effect of Manure. The effect of an application of stable or yard manure is felt much longer than a single application of commercial fertilizer containing the same amount of plant food. Every farmer has noticed this effect of manure on a plot of soil 3 or even 5 years after its application. An experiment at Rothamsted with barley showed beneficial effects even after manuring had been discontinued for 20 years. Manure owes its lasting effect to its gradual availability and its influence on the physical condition of the soil.

CHAPTER VIII

COMMERCIAL FERTILIZERS

We have seen that there is a demand for nitrogen, phosphorus, and potassium fertilizers to be used directly by plants, and for calcium carbonate to neutralize acidity, and it is important now for us to consider the sources and supplies of these fertilizers.

NITROGEN FERTILIZERS

211. Nitrogen Fertilizers Are in Demand. Nitrogen is used in large amounts by all crops, and directly influences the growth of crops more noticeably than does any other element. There is, therefore, a great demand for fertilizers containing nitrogen. We have already seen that fixation by bacteria forming nodules on plants is a means of recovering immense quantities of nitrogen from the air. The growth of legumes is an important part of all general lines of farming; but where intensive cropping, especially in truck crops, is practiced, it is frequently desirable to keep the ground continually in such crops, rather than to rotate them with nitrogen-gathering legumes. This necessitates the purchase of large quantities of nitrogen fertilizers, especially in the truck districts.

212. The chief sources of commercial nitrogen fertilizers are: (1) Sodium nitrate, (2) ammonium sulfate, (3) cotton-seed meal, and (4) dried blood.

213. Sodium Nitrate. Sodium nitrate is found in large quantities along the western coast of South America, chiefly in Chile, and indeed this salt is often called Chile saltpeter, differing from ordinary saltpeter in that it is a nitrate of sodium, rather than a nitrate of potassium. It exists in large deposits, mixed with gypsum chloride and sulfate, from which it is separated by dissolving and recrystallizing, advantage being taken of the fact that its degree of solubility differs greatly from that of the other salts with which it is mixed.

When purified to the usual extent for use as a fertilizer, it contains approximately 15 per cent of nitrogen. About 2,500,000 tons of this salt are annually exported from Chile, and of this, about ¼ comes to the United States. A considerable part, however, is used for other than agricultural purposes, as for instance, in the manufacture of gun powder, so that the exact amount used as fertilizer is not known. It is estimated that the supply is sufficient to last from 100 to 300 years.

214. Ammonium Sulfate. Ammonium sulfate, when pure, contains about 20 per cent nitrogen. It is manufactured as a by-product in making coal gas; one ton of coal contains from 2 to 5 pounds of nitrogen. In the process of coke manufacture, the volatile gases are driven off by heating in large ovens, and this volatile gas contains the ammonia. In the ordinary coke oven no effort is made to save this nitrogen. New but expensive forms of coking ovens have been devised which make it possible to collect and save this nitrogen in the form of ammonium sulfate. At present, less than ¼ of the nitrogen is saved in the coking of coal. This amounts to approximately 100,000 tons annually in the United States. The amount saved can therefore be very greatly increased by more general use of the improved coking ovens.

215. Cotton Seed Meal. About 6,000,000 tons of cotton seed are produced annually in the United States, and when the oil is extracted, the product is known as cotton-seed meal. This contains about 7 per cent of nitrogen, as well as somewhat more than 1 per cent of phosphorus. It is therefore a valuable nitrogen fertilizer and is so used very extensively, especially in the South. It is more desirable as a fertilizer than the more soluble forms above mentioned, since its nitrogen becomes available slowly and is not subject to excessive loss by leaching. The nitrogen in cotton-seed meal, however, is in the form of protein, so that it is a valuable stock food, hence it would be more economical to use it first in this way, recovering as much as possible of the nitrogen from the manure to be used as a fertilizer.

216. Chemical Fixation. As is well known, 4/5 of the atmosphere consists of the element nitrogen. There is, therefore, an enormous supply available if it could be converted into a form in which plants can make use of it. This means that it must be combined with oxygen and some base to form a salt-nitrate. It is possible, by the use of electricity, to cause oxygen and nitrogen to combine, and this oxide of nitrogen reacting with water will form nitric acid, which again reacting with a base will form a nitrate. This process of manufacturing nitric acid is still in the experimental stage, but it seems likely to be successful. A second method by which nitrogen from the air can be secured, is through a chemical combination with calcium carbide. When calcium carbide and pure nitrogen combine they form calcium cyanamid. This is known as lime nitrogen and contains from 10 to 16 per cent of the element nitrogen. When this lime nitrogen is used as a fertilizer, it decomposes, and is finally converted into a nitrate and can then be absorbed by the plant. The manufacture of this form of nitrogen fertilizer is also in its infancy, but is very promising. It is not unlikely that the next decade will see enormous quantities of these manufactured fertilizers on the market and in use in agriculture. It should be borne in mind, however, that the use of these fertilizers, and the growing of tilled crops continually on a given piece of ground, lead to the rapid exhaustion of humus contained in the soil, and hence frequently to a poor physical condition.

217. Dried Blood. Enormous quantities of dried blood are prepared at the large packing houses and sold as a nitrogen fertilizer. The best quality of dried blood is of a reddish color, and contains from 13 to 15 per cent nitrogen. The lower grades are black in color, being mixed with varying amounts of dirt and other animal refuse, and contain only 6 to 13 per cent nitrogen.

218. Other Nitrogen Fertilizers. There are a number of other fertilizers manufactured from waste products in slaughter houses and in other lines of manufacturing, such as tanning, fish packing, etc.

PHOSPHORUS

We have seen that phosphorus fertilizers are required to replace the unavoidable losses of this element, and that these fertilizers are chiefly from two sources, namely, the bones of slaughtered animals, and mineral deposits.

219. Bone Products. One of the most important sources of phosphorus for use as a fertilizer is the bones of domestic animals. The bones of an average horse contain about 10 pounds of phosphorus, of a cow 9 pounds, of a hog 1 pound, and a sheep 1 pound. Estimating that there are killed in the United States annually approximately 10,000,000 cattle, 2,000,000 horses, 50,000,000 hogs, and 25,000,000 sheep, there should be available about 185,000,000 pounds of phosphorus for use as fertilizer. This would be equivalent to 740,000 tons of a phosphate fertilizer containing 12½ per cent of phosphorus, which is about the average of that in high-grade mineral phosphorus deposits. However, as we have already seen, bone phosphorus is of much higher value than is the untreated mineral phosphate. It is of course true that by no means are all of the bones of domestic animals recovered and used as fertilizer, but it would be entirely practicable to have them so recovered.

220. Mineral Deposits. Fortunately, the United States is rich in deposits of phosphates. This phosphate was formed in nature as a constituent of the bones of fish and other sea animals. As these animals died, their bones collected in the sediments which were later transformed into rocks, and then the phosphate gradually concentrated by chemical changes in the rocks.

Three important classes of phosphate deposits exist, namely, (1) Those of apatite, found in large quantities in a certain district in Canada; (2) in veins chiefly associated with limestone rocks; and (3) in nodular concretions which have been weathered out from a rock in which it was segregated and left as deposits of gravel and cobbles associated with stream and river beds. Apatite is very difficultly soluble even in strong acids, and so has been used only to a slight extent in the manufacture of fertilizer. The other two forms of phosphate occur in immense deposits in Tennessee and in Utah and adjoining states in this country, as well as in other parts of the world. As we have seen, this calcium phosphate is used either directly, or after treatment with sulphuric acid to form acid phosphate. Practically all of the phosphate produced in Florida and South Carolina is exported to Europe and there converted into acid phosphate and used as fertilizer. At the Tennessee mines, the finer ground but untreated phosphate is worth from $4 to $5 per ton. Railroad transportation to any considerable distance, of course, becomes a large item in its cost to the farmer. This cost for transportation is still further increased if it is converted into acid phosphate, because this practically doubles the weight for a given amount of phosphorus. It is therefore highly desirable that the untreated, finely-ground rock phosphate be used as far as conditions will permit it to become available. These conditions have been discussed in Sec. 207. The large deposits of Utah and adjoining states are chiefly on land still owned by the general government, and will probably be retained and leased to people desiring to mine and sell it. These deposits are so remote from the extensive areas of highly cultivated land that they are not now being developed.

221. Basic Slag. Many iron ores, especially those of Europe, contain considerable quantities of phosphorus. This phosphorus must be removed before the iron can be manufactured into steel. This is accomplished by a definite chemical process taking place in furnaces, in which the phosphorus is removed in a form known as basic slag. When finely ground, this basic slag can be used as a phosphorus fertilizer, and is so used in immense quantities in European agriculture. About one-half of the phosphorus used in Germany is imported in this form from Great Britain. Practically no basic slag is manufactured in the United States, though small amounts are imported and used as fertilizers, especially in Atlantic Coast states.

POTASSIUM

222. Sources. As previously mentioned, most of the potassium fertilizers used at present come from the Stassfurt mines in Germany. These mines contain practically an inexhaustible supply of this material; but of course the transportation to this country, and especially into the interior states, is expensive. Recently, attention has been called to the fact that certain kinds of sea weed contain large quantities of this element, which they gather from sea water. One ton of dry sea weed contains as high as 300 pounds of potassium, and it has been estimated that a hundred square miles of shoal water producing this weed would supply enough potash to equal one million tons of muriate of potash, the value of which would be thirty-five to forty million dollars. The production of this fertilizer on a commercial scale, however, has not yet been attempted.

Many rocks contain from 5 to 7 per cent of potassium, and while it is in the form of silicate—practically unavailable to plants—it is quite possible that these rocks can be treated in such a way as to render the potassium available.

CHAPTER IX

PHYSICAL PROPERTIES OF THE SOIL

We have so far been studying the needs of plants with reference to the essential elements and the chemical changes taking place in the soil by which these elements are supplied. The physical condition of the soil, however, influences the growth of crops as much as the chemical, and it is necessary for us now to consider the physical factors of soil fertility. Among the physical properties of the soil which influence the growth of the plants are the water supply, the mechanical condition with reference to readiness of penetration by the roots, and the access of necessary air for the growth of the roots and for the essential chemical changes.

223. Meaning of Texture. When we examine any soil in the field we find that it is made up of lumps varying in size from that of a pin head to several inches in diameter. If these lumps are dried and crushed they are found to be made up of particles or 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 "texture of soils" refers to the size of these ultimate particles, and the term "structure" to the way in which they are arranged or clustered into lumps. Both the texture and the structure of soils affect the growth of plants in many ways, and their study is therefore of much importance to the farmer.

SOIL TEXTURE

224. Mechanical Analysis. 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 particles up to coarse sand or gravel, the relative amounts of the different sized particles vary greatly. Clay soils contain a large amount of the finest grains with small amounts of medium and coarser grains, while with sandy soils this relation is reversed. Alluvial or silty soils are composed of a large amount of grains of medium size. It is customary in a scientific study of soils, to call the finest grains clay, the medium sized grains silt, and the coarsest, sand. Different investigators use somewhat different systems of classification of soils in regard to texture. The one we shall use is that worked out by the Bureau of Soils of the United States Department of Agriculture, in which soil grains are classified into seven sizes. The first or coarsest, ranging from 3 to 1 millimeter in diameter, is called gravel. Coarse sand is 1 to 0.5 mm.;

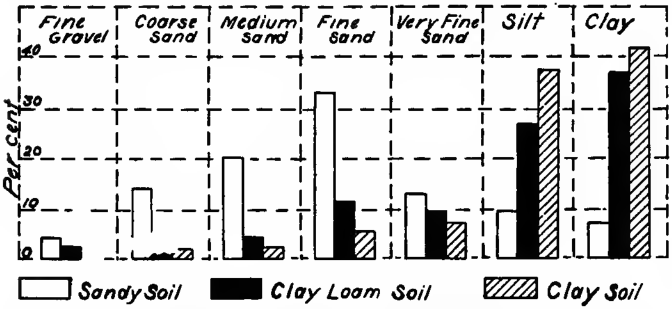

Fig. 32. This diagram represents the mechanical composition of sandy soil, clay loam soil, and clay soil.

medium sand, 0.5 to 0.25 mm.; fine sand, 0.25 to 0.1 mm.; very fine sand, 0.1 to .05 mm.; silt, .05 to .005 mm.; and clay less than .005 mm. When a soil is separated in this way into a number of different sizes of soil grains, the process is called *mechanical analysis.* The following table gives the average textures of a number of important classes of soils:

Table XVII. Average texture of important classes of soils.

Class of soil	Mechanical analysis giving average percentage of soil separates in each class						
	Fine gravel	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay
Coarse sand	5	15	25	30	10	10	5
Sandy loam	5	10	10	25	15	20	15
Fine sandy loam	1	4	5	20	25	30	15
Silt loam	1	1	2	6	10	60	20
Clay loam	0	1	2	5	15	42	35
Clay soil	0	1	2	5	12	30	50

225. Surface of Soil Grains. Some of the most important properties of the soil are dependent upon the extent of surface of the soil grains contained in a given volume of the soil. Much of the water held by soils is in the form of films surrounding the soil grains so that the amount held depends on the area of the surface of the soil grains. Moreover, the chemical processes in soils must, of course, take place on the surface of the soil grains, so that the greater the surface the greater is the area over which chemical changes occur.

The finer the soil grains in a given weight of soil the greater is the surface area. This can readily be seen by considering the surface areas of cubes of different sizes. The surface of an inch cube is six square inches. If this cube is divided into cubes of one-half inch on each edge, there will be eight of them, and the total area will be twelve square inches, or just twice that of the same volume when it existed as a single cube. If each of these eight smaller cubes be again subdivided into eight cubes, each a quarter of an inch in diameter, the surface area will be again doubled. From this we see that the surface

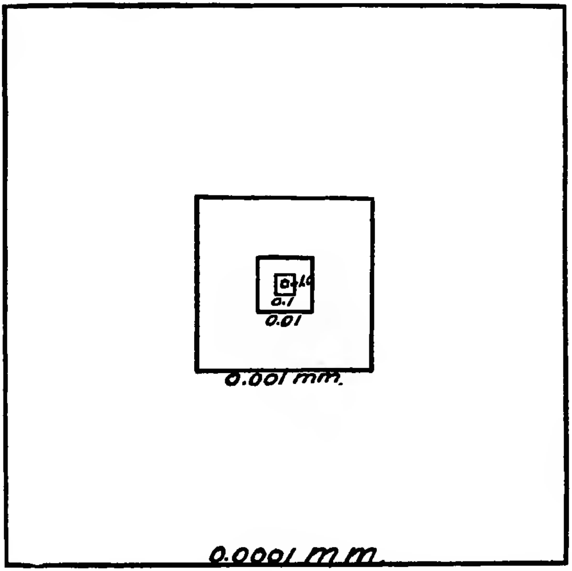

Fig. 33. This diagram shows the relative areas of the same weight of four different soils, having average diameter of soil grains of 0.1, 0.01, 0.001, and 0.0001 m. m.

of soil is greatly increased as it is broken down to finer and finer particles, and that the surface of the grains in an ounce of clay would be very much greater than in an ounce of sand. A cubic foot of coarse sandy soil has about 40,000 square feet of surface, of sandy loam 65,000, of silt loam 100,000, and of clay soil 150,000 square feet. The relative areas are expressed diagrammatically in Fig. 33.

STRUCTURE OF SOILS

226. Meaning of Tilth. By structure of soil we mean the way in which the grains are clustered together into crumbs or lumps. If these crumbs are very hard and compact, the soil will be similar in many respects to a coarse sand or gravel in that it will permit air to pass down through it freely. On the other hand, if these lumps or clusters are comparatively fine and are readily broken up, the water-holding capacity of the soil is increased and air does not so readily dry it out. Again, if a crust develops on the surface of the soil, seedling plants find it difficult and often impossible to force their way through to the light and air above, and water is much more readily lost by evaporation, as we shall see later.

When soils have developed a structure that presents a favorable condition for plant growth, they are said to have good *tilth*, while if in an unfavorable condition they are said to have poor tilth.

227. Factors Influencing Structure. The character of soil aggregates or crumb structures depends on the forces holding the ultimate particles of the soil together; that is, on their adhesion. The most important cause of the adhesion of soil grains is the presence of the films of water surrounding them. This water acts exactly like thin films of rubber, and when two grains, each having a film of water, come in contact, these films unite at the point of contact in such a way that a single film is produced surrounding the two grains and holding them together. In this way several very fine grains, such as clay or silt, are held together in clusters. A number of these clusters are again aggregated into still larger clusters by similar union of enveloping films at their points of contact.

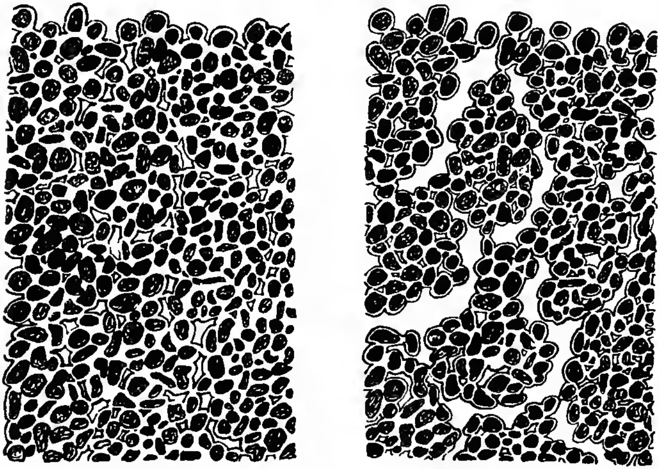

Fig. 34. Illustrating the formation of crumb structure in soils by the contractile force of water films.

When the soil has a considerable amount of moisture, these films are quite thick and the particles are free to move about over one another. As the moisture dries out, however, the films get thinner and thinner and the particles are held more and more firmly together. When this tension, caused by the thinning of the films gets too great, the film breaks and a smaller cluster of soil particles is formed. The accompanying illustration (Fig. 34), is designed to show how the development of these soil granules or crumbs occurs as the result of drying out of the soil moisture. Fig. 35 shows the formation of "mud cracks," also caused by shrinkage or drying.

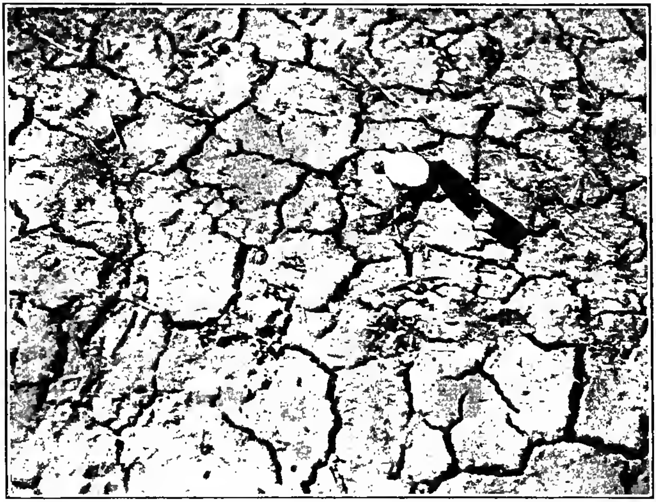

Fig. 35. Mud cracks caused by drying of wet clay. This shows how check and crumb structure of soils is produced.

Coarse soils, that is, soils made up largely of sand, have so little surface and therefore so little moisture in the form of films surrounding the grains that there is very little tendency for them to aggregate into clusters or granules. Clay soils have so great a tendency to form large lumps that much care is needed to prevent their development.

228. Soil Puddling. If a soil that contains sufficient moisture to permit the particles to move over one another is kneaded or worked, the crumb structure is broken down and the soil grains are brought much closer together. In this condition the soil is much denser and does not permit air or water to pass through it readily. There are then practically no air spaces, all of the spaces between the soil grains being occupied by water. A soil in this condition is said to be *puddled.* When such a puddled soil dries out, the soil grains are drawn together very closely and compact, more or less impervious masses are produced. Clay soils which are of very fine texture, when puddled in this way and then dried or baked, become very hard or even stony. This is the basis of the process of common brick-making. Sandy soils, on account of their coarse texture cannot be puddled in this way, the adhesion being too slight to hold them together when the moisture has been dried out.

229. Plasticity of Soil. That property of soils which permits them to be moulded or worked as above described is called *plasticity.* As we have seen, this is affected greatly by texture and the amount of moisture in the soil, but it is also affected by certain other substances in the soil. The most important of these substances is what is called *colloidal matter.* This is matter having a jelly-like character and consists chiefly of what is called colloidal clay, composed of certain iron and certain humus compounds. Even a small percentage of these colloidal substances in a soil greatly affects its plasticity.

230. Freezing and Thawing. Another factor influencing the granulation of soils is the alternate expansion and contraction caused by freezing water. Soils which have become puddled or packed into hard lumps are again broken up into a more granular structure by the action of freezing water. In the Northern states, the action of frost in producing good structure or tilth of soils is very important. In the Southern states, where frost does not extend to any depth, fine-grained clay soils often retain a very compact condition, making them difficult to cultivate and difficult for roots to penetrate.

231. Influence of Cultivation. One of the most important effects of the tillage of soils is its influence on their structure. It has been seen that if soils are worked when quite wet they are apt to puddle, so that a very dense, hard structure develops on drying. If, however, they are cultivated when in just the right condition of moisture, the larger lumps fall apart readily and a good structure, or tilth, is developed. It is of the utmost importance for the farmer to understand this influence of cultivation on tilth. (See Chap. XIV.)

CHAPTER X

THE WATER SUPPLY.

232. Importance of Water. We all know the importance of water to plants. Water is taken up by the roots, from 250 to 750 pounds, or even more, being used by plants for every pound of dry matter produced. One of the most important ways in which the soil serves the plant is by acting as a reservoir for the water which falls as rain, holding it and giving it up to the plant gradually as it is needed. No other information is more important to the needs of the farmer than the knowledge of the ways in which he can regulate and control the water supply of the plant; for if on one hand there is too much water, the necessary chemical changes can not take place, and if too little, the plant likewise suffers. The losses of water by evaporation are very important, and can be prevented by practical means.

233. Three Forms of Water in Soil. If some soil is placed in a stoppered funnel and water poured over it until it is entirely soaked and the stopper then removed, part of the water will drain away and a part will remain in the soil. The water which drains off is called drain or *gravitational water.* If the soil is examined after being drained, it will be found that the water still in the soil is in the form of films around the grains and in the small angular spaces between the grains. Since this water is held by the grains of soils in the same way that water is held in a capillary tube, it is called *capillary water.* Again, if the soil is allowed to dry in the air as completely as it will, and a portion weighed, then put in an oven and heated and again weighed, it will be seen to have lost still more water, and if it is again left exposed to the air after this complete drying, it will again absorb about the same amount of moisture that was lost in the oven. This water is called *hygroscopic moisture,* and of course is usually small in amount.

234. 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. When soil is completely saturated with water and remains in that condition, the oxygen it contained is soon absorbed and root growth stops. The soil is then said to be *waterlogged.* It is very necessary to drain off most of the gravitational water, leaving the capillary water for the plant.

235. The Amount of Capillary Water Held by Soils. Since the capillary 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, as we have seen, depends on their size, the finer the soil the greater being the area of a given amount. The amount of capillary water which can be held by a soil is therefore closely related to its texture.

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. In sandy loam and clay loam soils there is usually more capillary water in the first foot layer than in the second because there is more humus in it.

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 stoppered percolating jars or funnels, water poured on till it began to drip, then the stoppers removed and the water allowed to drain twelve hours and the water still held determined by weighing, drying and reweighing. It was found to be, for the humus soil 315 grams, for the clay loam 230 grams, and for the sandy soil 153 grams.

In the field after heavy rains have given the soil all it can hold and it has drained a few hours, approximately the amounts shown in the following table will be held:

Table XVIII. Amount of water held by sandy loam, clay loam and humus or muck soils after saturation and drainage.

	Sandy loam soil	Clay loam soil	Muck soil
First foot	3 in.	4½ in.	6 in.
Second foot	2 in.	3 in.	6½ in.

This means that all the water in the sand soil to the depth of a foot would be equal to a layer of water 3 in. deep, in clay loam to 4½ in. and in muck to 7 in.

If the soil is of a uniform character the amount of capillary water will increase downward until saturated soil is reached. This is because the water films in the soil at any point are stretched by the weight of the films below them. At 1 foot above saturated soil the films hold less strongly than they do at 2 feet and at 2 feet less than at 3, etc. The amount of capillary water decreases with the distance above saturated soil.

Sand in clay soils has the effect of allowing a rain to wet down deeper than the pure clay would, because it decreases the capacity to hold water. Hence a light rain will reach the roots of plants in a sandy soil or even in a clay soil containing some sand.

236. Cultivation to Increase Water-holding Capacity of Soils. In a region in which 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 this respect in that the loose condition of the soil tends to hold the water from winter rain and snow by enabling it to soak 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 is turned uphill, 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. The looseness of soil produced by some crops is also quite important. 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, which is best done 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 it was not.

It is important to note that any increase in the water-holding capacity of the soil produced by adding organic matter makes it possible for the soil to hold more water after each rain, so the total effect during the growing season may be several times what is indicated by a single determination.

MOVEMENTS OF SOIL WATER

237. Need of Water Movement. 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 needs of useful bacteria, 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 to increase the upward movement of water through the soil penetrated by roots, and to prevent as much as possible the loss by evaporation from the soil surface. To accomplish these objects, it is necessary to understand the movements of soil moisture and to learn how to control them.

238. Causes of Movements of Soil Water. There are three forces which cause movements of soil water. The first is the force of gravitation; second, surface tension, causing capillary movement; and third, heat. The force of gravitation, while it acts in a line toward the center of the earth, causes movements of water on even very gentle inclines in the soil as well on the surface. Capillary movement may take place in any direction. It tends to move the water from places of greater, towards places of less, thickness of water films, and to so distribute it that the films surrounding the grains are of equal thickness, for which reason the fine soils hold more water than the coarse soils. The thermal or heat movements 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 three forces act in the same direction the water will move most rapidly.

239. Ground Water. Of the water which falls on the ground, a part runs off as surface drainage, and a part sinks into the soil. Of that which sinks in, a portion is used by plants, some evaporates, while the remainder passes on down and accumulates as ground water, entirely filling the pore space between the 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 more even than the land surface.

240. 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:

(1) The size and arrangements of the soil grains.
(2) The height of water pressure.
(3) The distance the water must flow before finding an outlet.
(4) The temperature of the water.

The flow of water through sand or light soil is approximately proportional to the square of the diameter of the grains; that is, water will flow four times as fast through a soil having a given diameter of grain than through one having grains of 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 for the movement of water through heavy clay soil.

241. Capillary Rise of Water. The rate at which water will rise by capillarity in soils is greater the coarser the grain. It is also more rapid in moist than in dry soils. When there is a film of water on the grains, more water is drawn up by the surface tension of these films; but if the soil is entirely dry, there are no films and they must first be formed by the attraction between the soil grains and the water. This wetting of dry soil takes place very slowly, so that a layer of dry soil on the surface largely prevents the soil water from coming to the surface where the free movement of air and the higher temperature cause the greatest evaporation to take place. Such a layer of dry soil is called a *soil mulch.*

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. In coarse sand, water will rise by capillarity only a few inches; in a very fine sandy loam soil, it will rise several feet; while in a clay soil, it will rise at least 25 feet, and possibly much more. If the soil grains are pressed closer together, the capillary rise of water is increased.

242. Controlling the Movements of Soil Water. There are two ways in which we may control the movement of soil water. The first is by bringing it from lower layers for the use of seed during a dry spring, and second, by preventing surface evaporation. It will be seen from the preceding paragraph that the most effective means of raising water from below to the seed bed is by compacting the soil 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.

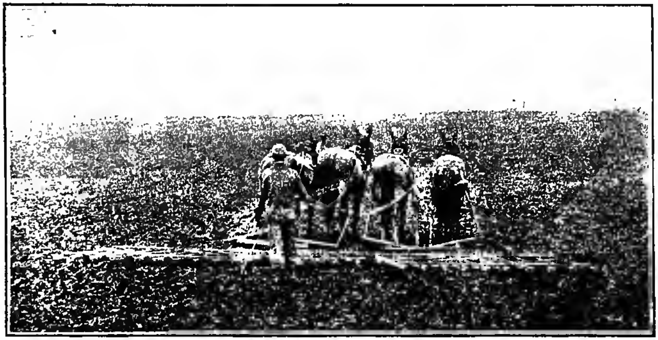

Fig. 36. The development of surface mulch rapidly requires large tools, as shown in this illustration.

The characteristics of a good mulch are that it should be thoroughly dry, loose, and not too fine. A mulch three inches thick is about as efficient as one of greater depth. There is, therefore, little 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 the loss of more water than they bring to the soil.

The conservation of moisture will be discussed more fully in the chapter on Dry Farming.

CHAPTER XI

TEMPERATURE AND VENTILATION OF SOILS

The temperature of soil is a matter of great importance for two reasons: (1) because of its influence on the germination and growth of crops; and (2) because of its influence on chemical changes, especially nitrification.

243. Temperature Requirements. Plants differ greatly with respect to temperature conditions most suitable to their growth. Some seeds begin to germinate very slightly above the freezing point, while others require a temperature of 75 to 80 degrees Fahrenheit before germination will begin. All seeds have a minimum, an optimum, and a maximum temperature; that is, a temperature below which germination does not take place, a temperature most suitable for their growth, and a temperature above which germination does not occur. Germination is extremely slow at low temperatures, often requiring five or six times as long at a minimum temperature as at the optimum. The minimum temperature for small grains is about 35° Fahrenheit, and the optimum 55° to 70°; for corn, the minimum is 45°, and the optimum 80°; for melons, the minimum is 55° and the optimum 95°.

As we have seen in the chapter on nitrogen, nitrification is caused by bacteria, a low form of plant life, which are affected by temperature the same as other plants. The rate of nitrification is extremely slow until temperature of 50° is reached, and at 70° it is twice as great as at 50°, and at 90° twice as great as at 70°.

The chief factors influencing temperature of soils are first, moisture conditions; second, compactness; and third, slope and situation.

244. Moisture Conditions. Moisture of the soil influences the soil temperature in two ways. Water itself has a relatively high specific heat; it requires about five times as much heat to produce a given increase in temperature of a pound of water as is required for a pound of sand. But the greatest influence of water comes from the fact that a large amount of heat is necessary to change the water from the liquid to the gaseous form, so that when evaporation takes place on the surface of the soil, the soil is greatly cooled. The amount of heat necessary to evaporate a layer of 1/10 of an inch of water over the surface of a field would be enough to raise the temperature of the wet soil to a depth of six inches over 30°. It is evident, therefore, that if evaporation of water from the surface of soils has a great influence in lowering their temperature, soils which are dry will warm up very rapidly by absorbing the sun's heat, while those that are wet and from which evaporation is taking place are kept cold. It is for this reason that drainage has such a marked influence on soil temperature. The difference in temperature between drained and undrained fields is frequently as great as 10 to 12 degrees, and is greater on bright, windy days, when evaporation is greatest.

Soils which naturally hold large amounts of water and permit its rapid evaporation, such as clay soils, are as a rule much colder than the soils having a low water-holding capacity, such as sands. Sandy soils quickly become dry and therefore warm up much earlier in the spring, and are for that reason more readily worked, making them better for garden or truck purposes.

In order to hasten the warming of heavy clay soils, which are ordinarily cold in the spring, it is important that they be plowed and left as rough as possible in the fall. They may even be left in a ridged condition to advantage. In this way some of the surface will become sufficiently dry early in the spring to act as a mulch, lessening the evaporation of water and therefore tending to increase the temperature.

245. Compactness of Soils. Compactness of soil influences temperature conditions in two ways: (1) It causes a more rapid upward capillary moisture, which, as we have seen, will tend to keep the surface soil cooler; and (2) on the other hand, it transmits or conducts the heat from the surface downward much better than does loose soil, and for this reason compacting soil hastens the increase of the temperature of the soil beneath the surface. Rolling, which compacts the soil to a depth of several inches, aids materially in increasing the temperature of the soil. In many cases the rolled soil is two or three degrees warmer at a depth of three inches than unrolled soil. This is sufficient to cause a material increase in the rate of germination, but it must be borne in mind that compacting the surface will cause a loss of moisture, unless a thin mulch is afterward made by harrowing.

246. Slope and Situation. The soil on the southern side of a hill is warmer than that on a level, and the latter is warmer than that on a northern slope. The reason for this is that a given amount of sunshine is distributed over a larger area on the horizontal than on a southern slope, which is more nearly perpendicular to the sun's rays. Likewise, a northern slope distributes the same amount of heat over a still larger area, and its intensity is therefore less. The differences due to slope are frequently two to five degrees.

247. Other Factors. In addition to the three factors just discussed, there are two or three other factors which influence temperature of soils. The color of soil influences the absorption of heat. It is well known that a black surface will absorb heat much more rapidly than a white surface. Dark-colored soils for the same reason absorb heat and become warmer faster than light-colored soils. Organic matter, on account of its dark color, tends to make soils warmer. Moreover, on account of its great tendency to hold moisture, it retards evaporation, which also tends to keep the soil warm. When there are large quantities of organic matter being rapidly decomposed, the heat produced by the oxidation process may be sufficient to influence the temperature of soils slightly.

248. Soil Temperature and Frosts. There is a marked connection between the temperature of the soil and the formation of frost. As the sun's heat passes through the atmosphere, about one-fourth of it is absorbed directly by the air. The remainder reaches the surface of the soil and a part is at once reflected, while the remainder is absorbed by the surface soil. Of that which is so absorbed, a part is conducted downward to warm the subsoil, and a part is immediately radiated back through the atmosphere into space. In this way the surface soil usually becomes much warmer than the air, especially on bright days when the sun is shining. At night, on the other hand, the surface soil continues to lose its heat by radiation, and this cooling takes place more rapidly than does the cooling of the atmosphere just above the soil. As a consequence, the surface soil becomes much colder at night than does the air a few feet above it. The air immediately in contact with the soil is cooled by conduction to the cold soil. For this reason, the temperature of the soil greatly influences the temperature of the air for a short distance above the ground. The air over a cold, wet soil, which is already several degrees lower in temperature than surrounding drier soil, as evening comes on and radiation continues, often reaches a freezing temperature, while the air in contact with the drier and warmer soil remains above freezing, even though the rate of cooling of the dry soil may be as great as that of the wet soil. This influence is often as great as that of air drainage in causing local frosts late in the spring.

249. Changes in Temperature in Soil. As we have seen, the heat which is absorbed by the surface of the soil is conducted downward to the subsoil. This process requires time, and as a matter of fact, the highest temperature reached at a depth of say one foot below the surface, occurs two or three hours after the highest temperature is reached at the surface. With increase in depth, the difference between day and night temperatures becomes less and less, and finally vanishes. In the same way there is a seasonal wave of temperature. The highest temperatures near the surface are reached during the hottest months of July and August, while at such depths as 20 to 30 feet, the highest temperature is reached in December and January, several months later.

The following table, taken from Lyon and Fippin, shows the changes in the soil temperatures in Nebraska:

Table XIX. Air and soil temperatures in degrees Fahrenheit.

Position	January	February	March	April	May	June	July	August	September	October	November	December
1. Air	25.2	24.2	35.8	52.1	61.9	71.0	76.0	74.5	67.6	55.5	38.7	28.3
2. Soil, 1 in.	27.3	27.7	38.2	57.5	68.7	78.1	85.1	82.9	73.8	56.7	38.7	31.6
3. Soil, 6 in.	28.6	27.8	36.6	53.3	65.1	75.7	81.6	80.1	72.0	57.8	41.5	32.0
4. Soil, 12 in.	31.2	30.2	35.4	49.3	60.7	69.9	75.7	75.7	69.2	57.8	44.7	35.2
5. Soil, 36 in.	38.5	35.5	35.8	43.8	53.5	61.3	67.4	69.8	67.6	61.3	52.2	43.3

SOIL VENTILATION

250. Forces That Cause Ventilation. We have seen that the penetration of oxygen to considerable depth in the soil is of great importance, both for the growth of roots in the soil and for the chemical changes necessary in producing fertility. This penetration of the air, or ventilation of the soil, is effected in several ways: (1) By changes in barometric pressure, (2) by diffusion, (3) by changes in temperature, (4) by drainage, (5) by winds, and (6) by rain.

251. Changes in temperature cause ventilation, because when the air in the soil is heated, it expands and a portion is forced out; while in cooling, the contraction causes some fresh air to be drawn in. Changes of temperature occurring between night and day cause some ventilation in this manner.

252. Changes in barometric pressure of the atmosphere occur in connection with cyclonic storms, every two to five days, as a rule. The difference in barometric pressure is frequently as great as the pressure of half an inch of mercury; and when the barometric pressure is increasing, the air within the soil is compressed and more forced in, while with a lowering barometer, this compressed soil atmosphere is permitted to expand and some is forced out. Winds, especially when blowing against a side hill, increase the pressure and force some air into the soil, part of which comes out again during the lulls.

253. Diffusion of the air itself is probably the greatest cause of ventilation. Whenever the composition of any one of the gases composing the atmosphere is different at one point than at another, there is a corresponding difference in the pressure of that gas, and the denser portion tends to move apart and make the composition uniform. Whenever the oxygen in the soil air is absorbed in the process of oxidation, more oxygen from the surface diffuses in. Carbon dioxid, which is produced in the soil, in the same way diffuses outward. This process of diffusion is going on constantly, tending to keep the composition of the soil air the same as that of the atmosphere, although it is frequently so slow that there are still great differences.

Drainage tends to produce ventilation of the soil, because when the water is withdrawn from the soil by under drainage, air is drawn in to take its place. Also, fresh rains contain considerable absorbed oxygen, which is carried into the surface soil.

254. Excessive Ventilation. While a certain amount of ventilation is necessary to supply oxygen and to remove carbon dioxid, it is quite possible for it to be so great as to be injurious if it causes the soil to dry out too rapidly and the organic matter to be oxidized unduly. In such cases it is desirable to retard rather than increase ventilation.

CHAPTER XII

DRAINAGE

255. Importance of Drainage. In considering the moisture content of soils, we found that the roots of growing crops require a certain amount of oxygen and that the many chemical changes necessary to soil fertility also require oxygen. For these and other reasons it is essential that land used for agricultural crops be not saturated with water. We have all noticed flat, level land usually of a clayey nature, on which crops were making very poor growth. Frequently corn on such land will germinate and grow a few inches high and then turn yellow and fail to make much further growth. This is usually because of lack of drainage. Wherever water stands in the subsoil

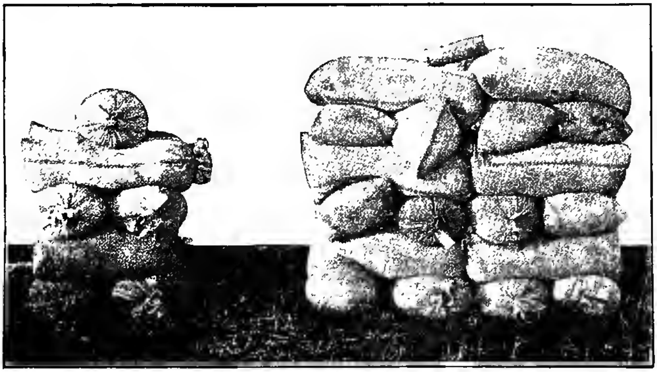

Fig. 37. Tile drainage permitting the sowing of an oat crop on very wet clay at the proper time thus securing a heavy crop as shown in the right-hand portion of this illustration, while the remainder of the field could not be sown until so late that the crop was very greatly reduced as shown in the left-hand portion of the cut.

within two feet of the surface for a considerable portion of the growing season, conditions are unfavorable for the best growth of crops, and the land needs drainage.

256. Causes of Poor Drainage. Insufficient drainage may be due, first, to an extremely fine texture of soil, as in the case of heavy clay lands; second, to the existence of an impervious hardpan close to the surface; or third, to an insufficient slope to allow underdrainage to take place.

There are in the United States approximately eighty million acres of marsh land, a large portion of which can be reclaimed to make profitable agricultural land. A large amount of flat clay land also is in need of drainage to thoroughly fit it for agricultural use.

THE BENEFITS OF DRAINAGE

257. Chief Benefits. Few persons realize the importance of drainage and the number of ways in which it improves the soil. Among the benefits of drainage may be mentioned the following:

(1) It improves the ventilation and the tilth of soils.
(2) It makes a larger amount of water available to crops.
(3) It permits the earlier working of the land and thereby lengthens the growing season.
(4) It favors nitrification and other chemical processes.
(5) It makes waste lands available for agricultural use.
(6) It makes fields uniform so that they can be managed to a better advantage.

258. Drainage and Ventilation. Drainage improves soil ventilation; that is, it increases the rate at which oxygen of the air can penetrate the soil, in two ways: (1) By removing a portion of the water and leaving air spaces between the soil grains and clusters of grains; and (2) by permitting fresh rain water to penetrate the soil to considerable depth rather than to run off the surface. Fresh rain water carries a large amount of oxygen. The roots of plants will grow in water which contains oxygen, although they cannot grow for any distance in stagnant water from which oxygen has been entirely absorbed.

259. Drainage and Availability of Water. It may appear strange that the statement is made that drainage increases the supply of water available to plants. By withdrawing a part of the water from soils so as to leave some air space, roots are enabled to penetrate down to the depth of several feet and thus to draw on the large amount of capillary water still held in the soil. If the entire pore space is filled with water, the roots penetrate to a much shorter distance, and when the water does drain away later in the season, or evaporates from the surface, the roots are left in contact with but a thin upper layer of soil from which they are able to obtain only a limited supply of water.

260. Drainage and Soil Temperature. One of the most important effects of drainage is that by withdrawing the surface water it permits the soil to become warm enough for crops to grow, and dry enough to be worked much earlier than it otherwise would be. The influence of drainage on the temperature of the soil is remarkable. As we have already seen, a given volume of water requires a much larger amount of heat to raise its temperature as compared with a like amount of solid soil, and the evaporation of the water requires a still larger amount of heat to change it from the liquid to the gaseous condition. The evaporation of water from the soil, therefore, has the effect of keeping the soil cold. When the evaporation is increased by wind blowing over the surface, the cooling effect is greatest. It not infrequently happens that the surface soil on a well drained field is ten to twelve degrees warmer than that of a poorly drained field right beside it. This warmer temperature is favorable to the germination of seed and to chemical changes essential to fertility, and lessens the chances of frost on cold nights.

The influence of moisture on nitrification and chemical changes was discussed in Chapter IV and need not be repeated here.

261. Drainage and Uniformity of Fields. The effect of drainage in making a field uniform and removing small areas which have previously been uncultivated, thus permitting the field to be worked as a whole, is a matter of great importance. This is especially true in those portions of the country which have been affected by glaciation and which commonly contain small areas of marshes and poorly drained soils scattered over what would otherwise be good agricultural land.

262. Surface Drainage. It is convenient to distinguish between the removal of surface water, or surface drainage, and the removal of the excess of soil water to the desired depth, or underdrainage. Under certain conditions, the mere removal of surface water, which can usually be accomplished very readily, is all that is practicable, yet in some cases this more or less incomplete drainage will fit the land satisfactorily for certain crops.

This surface drainage is often accomplished by the use of small shallow ditches. Frequently the laying out of long, narrow "lands" in plowing, so that the dead furrows will not be more than three or four rods apart, and opening into larger ditches, will greatly aid in the removal of the surface water. These larger ditches should usually be wide, shallow, and sodded with grass to prevent washing. When a dead furrow passes through a shallow sag, it is necessary to cut a small ditch across from the lowest point of this dead furrow to the furrow below it so as to withdraw the water. This system of surface drainage is especially adapted to heavy land which is nearly level, or to land which receives considerable surface water from adjacent higher lands. It is better adapted to land which is to be used for small grains than to land planted to crops which are to be intertilled, such as corn or potatoes. It should not be considered thorough drainage, and in most cases should give way later to a more complete, permanent underdrainage.

UNDERDRAINAGE

263. The object of underdrainage is to remove the ground water to a desired depth. This may be accomplished by the use of deep ditches, which may either be left open, or, after placing in them something which will permit the movement of water, be filled up or closed. Closed drains are very much more convenient wherever they can be used, because they permit the field operations to go on without interference; but when large quantities of water must be removed, or where an area of several hundred or thousands of acres is to be drained, it is usually necessary to have large open ditches to serve as outlets for the closed drainage.

264. Materials for Underdrains. Several different materials have been used for underdrains. In Europe quite commonly bundles of three or four small poles are tied up and laid in the bottom of the ditches and then covered. In other places, two boards nailed together in an inverted trough-like form serve as drains. Occasionally, thin, flat stones are made use of for the construction of underdrains; but by all means the most successful and permanent material is the round clay, or tile, drains. Tile clay is ordinarily baked at low temperatures like common brick; but vitrified tile, such as are used for sewerage conduits, may be used with equal success, though they are somewhat more expensive. These tile are placed end to end in the bottom of a ditch that has been given a proper grade. Although the ends are as close as the tiles permit, there is still ample space between them for water to find its way into this drainage line, and practically no water seeps through the tile even though under pressure.

265. Planning Drainage Systems. In examining a field for drainage, two considerations must be kept in mind: (1) The improvement in soil conditions which is likely to be produced, and (2) the possibilities of securing a practical drainage system. Whether or not a given piece of land can be underdrained, will depend on whether there is sufficient fall to permit the withdrawing of the water, and whether there are obstructions, such as quarry rock or too large a number of boulders to permit the digging of the necessary ditches. To determine whether there is sufficient fall, the difference in elevation between the land to be drained and the point of outlet must be determined, and from this difference in elevation we must subtract the depth at which the drains are to be placed. For instance, if the upper portion of a field to be drained is 4 feet above the level of water in a stream into which we propose to have the drain outlet run, and we desire to have the drain 2 feet in depth at the upper portion of the field, this will leave but 2 feet of fall between this point and the outlet. We must now know how much fall is required to secure the necessary flow in tiles and ditches. This will depend on the size of these drains. In open ditches some four or five feet in depth and fifteen or more in top width, there will be a good current with a fall as low as 1½ feet or 2 feet to a mile; while in a small ditch two or three feet in depth and four or five feet in top width, and in tile three feet in diameter, such as are used as mains in a drainage system, water will flow for several hundred feet with practically no fall except that which the surface of the water may have within the drain itself, and a fair current will be secured with as little fall as ½ or ¾ of an inch per hundred feet. In tile six inches in diameter, a fall of at least 1 inch per hundred feet is necessary, while in tile three or four inches in diameter, such as are used for laterals, a fall of 2 inches per hundred feet is desirable.

With these figures in mind we can determine whether drainage on any particular field is practical or not by running levels from the place where the outlet ditch or tile will empty, to different points in the field to be drained. The next matter to be considered is the means of taking the necessary levels.

266. Instruments for Leveling. The outfit for leveling must include a level of some kind and a measuring rod, commonly called a target rod. Several different kinds of levels are in use, but we need to consider only two. When only a small amount of work is to be done, a good carpenter's level can be fitted up for this use. Such a level should first be tested to determine if the bubble is properly set, by laying it on a firm, smooth timber which rests with one end slightly lower than the other. The lower end of the timber is then raised slowly until the bubble of the level is centered; the timber is then fixed in that position. Mark the position of the level on the timber and then reverse the level end for end. If the bubble remains exactly in the center, it is correctly set in the level. If not, the set screws must be used for adjusting it until it will stand in the center when the instrument is reversed.

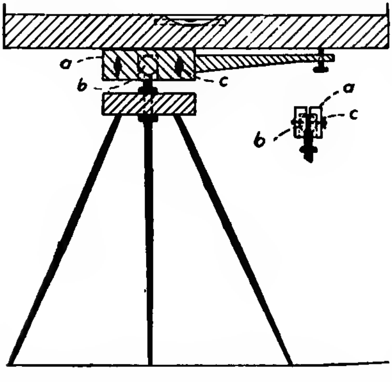

Fig. 38. A carpenter's level mounted for use in drainage work.

Such a tested level can be placed on a frame work made as indicated in Fig. 38, in which it is seen that there is a screw for bringing the instrument to a level position. The level is carried on a block marked (a), which is split and grooved so as to let in the round-headed bolt (b) on which it turns. The block is clamped onto the bolt by means of the two wing screws (c). If this instrument is to be used for much work, two sights made of thin strips of brass or other metal adjusted accurately at the ends of the instrument will be helpful in sighting with such an instrument. One having a good eye can do reasonably accurate work with it, sufficiently so for the laying of most tile drains on a few acres of land or for running small ditches to serve as outlets for surface drains. But whenever the area is of greater extent or the fall less certain, a more accurate form of level should be used. While there are several cheap so-called drainage levels on the market, there is so much danger of their getting out of adjustment without its being detected by anyone but an engineer, that it is unwise to use them. An instrument having a 12-inch telescope and costing forty-five to fifty dollars is about as small in size and low in price as can be depended on for accurate work.

267. Target Rod. With an engineer's level a sliding target rod with vernier attachment for accurate reading is used. For use with the home-made level, however, a rod ten feet in length and marked off in inches from 1 to 120, with subdivisions into eighths, may be used.

268. Use of Level. To determine the difference in the level of two points that are less than 100 feet apart, set up the instrument half way between the points, and adjust it carefully until level. Then have a second person, called the rod man, hold the target rod on one of these points, and if the rod is not provided with a regular target, have him hold a white card, which he is instructed to raise and lower until the upper edge is at the point on the rod in line with the line of sight. This height on the rod is then read and recorded. The rod man now places the rod on the other point and the level man again determines the point where the line of sight strikes the rod. The difference between the two target-rod readings is the difference in the level, the point which gave the lower reading being the higher point.

When the distance between two points is too great to permit the determination of elevations by direct sighting, a *line of levels* must be run. For this purpose, pegs are driven even with the surface of the ground and a lath or guide stick 1½ or 2 feet in length is placed beside each as shown in Fig. 39. In this way, the distance between the two objective points is marked off into sections of suitable length for measurement. Beginning at one end, the instrument is set up midway between the first and second station. The difference in the elevation is determined as before, and the process repeated between each pair of stakes.

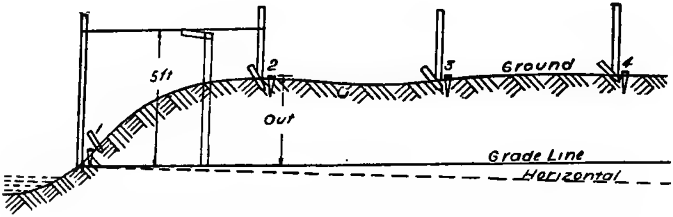

Fig. 39. A profile showing the grade stakes, finders, ditcher's square, and grade line of a ditch prepared for laying tile.

269. Form of Notes. It is essential that an exact record be made of the figures found in this work of leveling. A convenient form of record is that given in the following illustration:

Station	Back sight	Fore sight	Difference	Elevation
0.	63 5/8			100
1.	64 1/8	62 3/8	+1 2/8	101 2/8
2.	63 3/8	62 4/8	+1 5/8	102 7/8
3.		63 6/8	— 3/8	102 4/8

270. Trial Drainage Line. To determine the practicability of draining a given area, we must first run a trial line of levels from the point where the drain will have its outlet to some of the lowest points in the field to be drained. This leveling is done in the manner just described. Assuming that the bottom of a ditch for tile must not be less than 2 feet below the surface of the ground at any point, we must subtract 2 feet from the difference in elevation between the lowest spots to be drained and the outlet, in order to determine the amount of fall which can be utilized. Again, if our tile system is to include laterals, it will be necessary to have the lateral enter the main a little above the bottom so that there will be a clean drop from the bottom of the lateral into the main. When the main is 6 inches in diameter this drop should be at least 2 inches. If the main is 12 inches, the drop should be 4 inches. This drop should also be subtracted from the fall above determined. When the available fall has thus been found, we can divide it by the distance, and so determine the available grade. If this proves to be sufficient to produce a fall in the tile according to the figures given in Sec. 265, we are ready to proceed with the location of our drainage lines.

271. Locating Drainage Lines. The location of drainage lines involves two questions: First, the distance between the side lines, or laterals; and second, the general arrangement of the plan or system.

The distance between the laterals will vary with the texture of the soil, the depth at which the tile is placed, and the degree or thoroughness of drainage desired to be secured. In very heavy clay soils thorough drainage, such as would be needed for preparing such land for orchard or garden use, would require that the tile be not more than 2 to 2½ rods apart. When such land is to be used for general farming purposes, however, 3 to 4 rods is quite satisfactory. In sandy soils, which are wet because of their flat location, larger tile placed at greater distances apart should be used. Under such conditions, laterals 100 to 150 feet apart will be quite satisfactory.

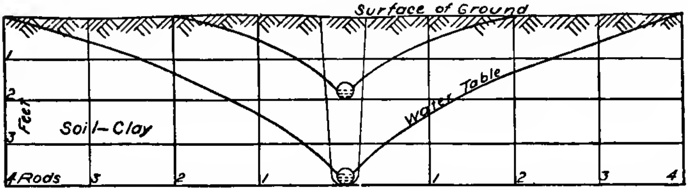

Fig. 40. Provided the structure of the soil is sufficiently open to permit the water to move readily to the tile, the deeper the tile is laid the wider will the strip drained by it be, but ordinarily water does not move laterally with much readiness in clay soils below the depth of 3½ feet.

The accompanying sketch makes it clear that the tile laid at greater depth will drain water from a greater distance than when the depth is shallow. When the drains are far apart, however, the water must travel farther in the soil and hence takes a longer time to drain off. The best average depth in most clay soils requiring drainage is 3 feet; 4 to 4½ feet is very deep; and they may be placed as near the surface as 2 feet, or even eighteen inches near the upper ends if a greater depth cannot be secured.

272. Drainage Systems. When the field to be drained is a broad, level one, the system used should include mains and laterals uniformly spaced in the way indicated in the accompanying cut. When the drainage area is an irregular one, with some natural drainage lines running across it, it is usually better to have the lines of tile follow these lines of natural drainage, as indicated in Fig. 42. In either case, an important consideration will be the capacity of tile of different sizes which can be used as the principal main.

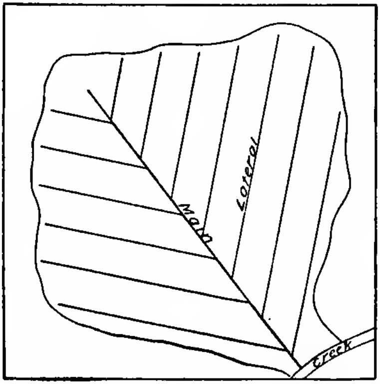

Fig. 41. A drainage system with laterals joining at regular intervals.

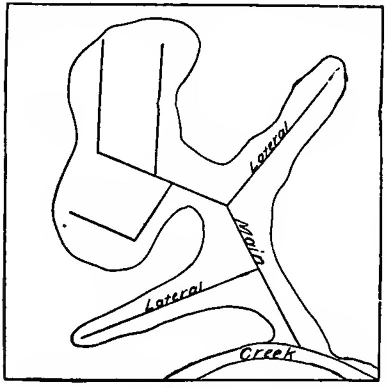

Fig. 42. A drainage system with laterals laid out in such a way as to drain an irregular marsh most economically.

273. Capacity of Tile. The area of land which can be drained by tile of different sizes depends greatly on the grade at which they are laid. At a grade of one inch to the hundred feet, a four-inch tile will drain 10 acres. With a grade of two inches per hundred feet a four-inch tile will drain 13 acres. The accompanying table indicates the size of tile which should be used as mains for fields of different areas.

Table XX. Correlation of size of tile with grade and area to be drained.

Diameter	Grade per 100 feet				
	½ in.	1 in.	1½ in.	2 in.	
	Acres of land drained				
5	17	19	21	22	
6	27	30	32½	35	
8	56	61	66	71	
10	97	107	116	124	

274. Final Leveling. Having decided on the location of all lines of tile, and having indicated them on the field with lines of grade pegs and guide stakes set up at intervals of 50 feet, one is ready to proceed with the final leveling. Beginning at the outlet on the main run a line of levels throughout the length of the main line, indicating in our notes the number of the station at which each branch drain or lateral is to enter the first line. Then returning to the points where each branch drain or lateral is indicated, run a line of levels from the main to the end of each of these.

275. Form of Record. Since we are now to determine the exact position of the line of tile when finally laid, or the *grade line,* and the depth of digging, or the *cut,* at each stake in order to run this grade line, our notes must include these items in addition to those given in simple leveling as mentioned in Sec. 268. A complete form for this purpose is shown in the following illustration:

Station	Back sight	Fore sight	Difference	Elevation	Grade line	Depth or cut
0	108 7/8			100	100	0
1	60 3/8	61 3/8	+47 4/8	147 4/8	101	46 4/8
2	61 1/8	59 5/8	+ 6/8	148 2/8	102	46 2/8
3	60 7/8	62 3/8	— 1 2/8	147	103	44
4		56 3/8	+ 4 4/8	151 4/8	104	47 4/8
100				226 1/8	200	26 1/8

276. Finding the Grade Line. In preparing to dig a ditch to grade, some means of determining its exact depth at any point must be used. The most convenient means for so doing is by using a stout cord stretched tightly between two stakes and set in such a way that the line is exactly parallel with the required grade line when the ditch is finished. In order to place this line we must first subtract the elevation of the grade line at each station, from the elevation of the grade stake at the surface. This gives the *cut*, or the depth to which the ditch must be dug at each station. If we now desire to have the line stretched so that it will be exactly 5 feet (a convenient height) above the grade line at all points, we must subtract the cut at each stake from 5 feet and measure this difference up from the grade stake on the line stake to determine the point at which the line must be tied. In starting at the outlet in the case represented in the preceding table, the cord would of course be just five feet above the stake at Station 1 and it would be five feet minus 46 4/8 inches, or 13 4/8 inches, at Station 2. In this way we are able to place the line exactly 5 feet above the grade line at all points.

277. Digging the Ditch. Use a small rope stretched along the ground as a guide for keeping the edge of the ditch straight. The most satisfactory spade for this work is one especiallly constructed for the purpose, which has a blade about 15 inches in length and which is slightly wider at the cutting edge than at the top. It is also somewhat curved to give it additional strength. When the ditch is to be 3 feet or less in depth, it is not necessary that it be more than 12 or at most 14 inches in width. When it is 4 or 4½ feet in depth, it must be 14 to 16 inches in width. Some experience is necessary to enable a man to work easily in a ditch so narrow, but it greatly lessens the amount of work in digging. The digging should proceed by a succession of levels, each about the length of the blade of the spade. When the desired depth is nearly reached, the final preparation of the bottom is done with a drain scoop, such as is shown in the accompanying cut. A so-called ditcher's square is used to determine when the bottom of the ditch is exactly parallel with the line stretched above it. This consists of an upright piece 5 feet or more in length, with a short arm at right angles.

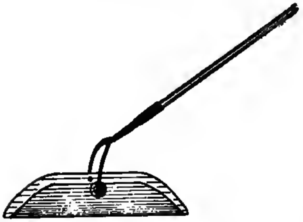

Fig. 43. A tile hoe or scoop used in preparing the bottom of a ditch for tile.

With this instrument it is very easy to determine when the ditch has been dug to the desired grade line.

278. Laying Tile. The laying of tile should begin at the lower end of the ditch and proceed toward the upper end, and care should be taken that the tile are kept well in line and that the ends fit together as closely as possible, consistent with a satisfactory rate of progress. After being laid, tile are blinded by throwing in and packing around them a thin layer of earth, preferably of clay. When it is necessary to leave a line of tile during the progress of the work, the end should be carefully closed with a board or a tight-fitting stone, so as to prevent earth from being washed into the tile by rain. After the tile is laid and blinded in this way, the ditch may be filled by any convenient method. A scraper, drawn by a team on the opposite side of the ditch, can be used, or a special scraper made by using a heavy narrow plank provided with handles may be constructed for this purpose. When the ditch or system is entirely finished, a sketch of its position should be made and some permanent stakes so placed that anyone may know its exact location if future needs require.

CHAPTER XIII

SOIL EROSION

279. Nature of Erosion. One of the most serious difficulties with which a great many farmers have to contend is that of soil erosion. By soil erosion is meant the washing off of the surface soil, which takes place partic-

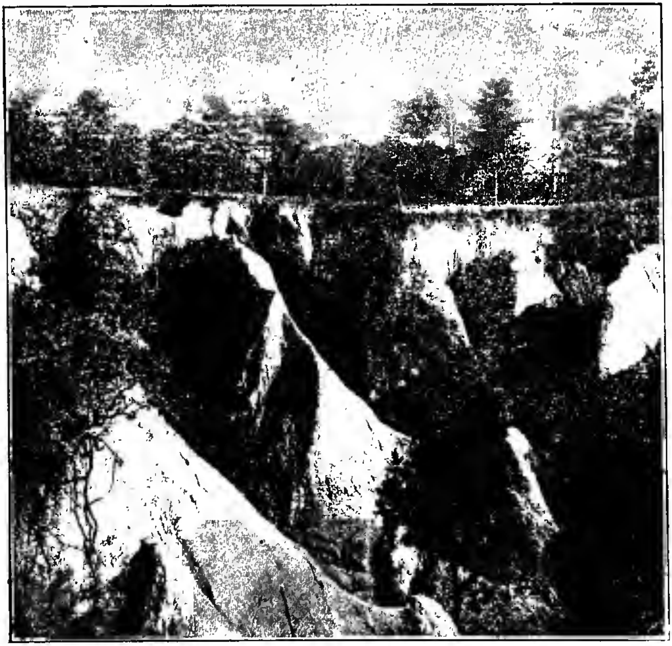

Fig. 44. Agricultural land entirely ruined by erosion which might have been prevented if proper steps had been taken in time.

ularly on the hillsides and occurs wherever there is sufficient slope to cause water to run. The evil effects of soil erosion are of two kinds: first, it reduces the fertility of the soil; and second, by the development of ravines it interferes with the cultivation of the land. In the virgin condition of the soil, that is, before it is brought under cultivation, there is very much less erosion than after cultivation begins. This is chiefly because nature has developed protecting vegetation, either of grasses, which, by their fine root system, bind the surface into a compact sod, or, if the native vegetation is tree growth, by a deep layer of mulch which absorbs the largest portion of even heavy rainfalls and allows it to seep away gradually, causing but little erosion. When, however, the surface soil is plowed and brought under cultivation, it is at once exposed to very rapid erosion. In any hilly country one can readily find banks of streams or ditches which show that from one to two or even more feet of soil have been washed down from adjacent hillsides and deposited on top of the soil originally at the surface. This original surface can be recognized by its black color.

FACTORS INFLUENCING EROSION

280. Evils of Erosion. The evil effects of erosion on fertility arise, in a large part, from the removal of the vegetable matter and of the finer silt and clay of the mineral portion of the soil. We have already learned the great importance of vegetable matter in the soil, and can readily understand how its removal by erosion greatly reduces the fertility. We have also seen that the finer part of the mineral matter of the soil, that is, the silt and clay, contains very much larger percentages of the essential elements for plant growth than does the sandy portion. For this reason, the removal of the silt and clay, which of course are carried away because they can be held in suspension by the water, while the sand cannot, removes the most fertile part of the soil. It not infrequently happens that the soil which is carried away in suspension by the water contains from two to three times as large a percentage of nitrogen and phosphorus as does the soil which is left on the eroded surface.

281. Conditions Influencing Erosion. The liability of any surface soil to erosion depends on four factors:

(1.) Texture.
(2.) Slope.
(3.) Vegetation and cultivation.
(4.) Character of rainfall.

Soils which are of coarse texture, such as sands or sandy loams, permit the water falling as rain to soak downward rapidly, so that it does not run on the surface and cause erosion, while clay or clay loams, into which water cannot soak rapidly, are very much more affected by erosion of the surface soil. This will be discussed later when describing soils of the various portions of the country, especially of the South.

282. Influence of Slope. Probably the most important feature influencing erosion is that of slope, or topography. Whenever this is so great as to cause a large portion of the rainfall to run off, serious erosion results. Hilly and mountainous countries are therefore very much more seriously affected by erosion than are level countries; in fact, the development of valleys along streams is itself the result of erosion. Nevertheless, it is very important to recognize the fact that a considerable amount of erosion may take place on land which has only a gently undulating surface. By observing the surface soil of a cultivated field having a nearly level surface, after a heavy rain, it will usually be seen that small pools of water have been formed temporarily and that a considerable amount of sediment has been deposited in them, which has been brought from surrounding, slightly higher portions of the field. It must be remembered that soil grains of the silt size will remain suspended for an hour in even perfectly quiet water, while the finest clay will remain so suspended for days, so that it is easy to understand why even gently moving water will carry considerable sediment.

The presence or absence of growing vegetation and especially the character of the root system, are other features of great importance. The fine roots of grasses are very effective in holding soil together and preventing its erosion. Hillsides having a complete covering of grass are very little affected by sidehill wash, while cultivated fields in such situations are seriously damaged.

283. Rainfall and Erosion. Another feature which greatly influences soil erosion is that of the character of the rainfall. Surface erosion is caused by that portion of the water which runs off the surface, while that which soaks or percolates down through the subsoil can, of course, produce no erosion. Wherever, therefore, the rainfall comes in the form of heavy showers, erosion is very much greater than when the same total amount of rain is distributed in gentle showers through a greater time. A heavy downpour, such as occasionally accompanies a thunder storm, may cause more erosion in two or three hours than is produced during a year when no such storm occurs. In the South, where the rainfall is of a more torrential character than in the North, erosion is far greater.

THE PREVENTION OF EROSION

284. The chief means available for the prevention of erosion are:

(1) Maintenance of a grass sod.
(2) Providing channels having gentle slopes.
(3) Increasing water-holding capacity.
(4) Drainage.
(5) Terracing.

285. Relation to Crops. Wherever soil erosion is the most serious difficulty in the maintenance of fertility, the character of crops grown must be considered. The steepest slopes should be kept grassed continually. Where the slope is somewhat less a rotation may be planned in which a tilled crop, such as corn or potatoes, is grown one year, followed by a cereal used as a nurse crop for grass, which is then allowed to remain and may be cut for hay and later used for pasture. In this way a corn or other tilled crop may be grown on land subject to considerable erosion one year in 5 or 6 with little damage. There is very much less erosion the first year in the case of a tilled crop which is on sod than there is the following year when the sod has been decomposed or rotted.

286. Providing Channels. Since washing of the soil is greatly dependent on the slope, which affects the velocity of the water, and also on the volume of the rivulet or stream, anything which can be done to draw off the surface water coming from heavy rains on lower gradients and to prevent the formation of surface streams, will lessen erosion. With this object in view, one should plow sidehills along the slope or contour rather than up and down. By laying out narrow plow lands along the slope and opening the dead furrows out into a well-grassed or otherwise protected ravine, the erosion may be much lessened. In the cultivation of check-rowed corn, the cultivation up and down the slope should be done first, so that the cross cultivation will tend to direct the water laterally rather than straight down the hill. The old-fashioned corn marker still frequently used in some sections leaves deep marks that cause little rivulets along each row, which not only cause erosion but often remove much of the planted seed.

287. Erosion and Humus. Anything which can be done to increase the amount of water which surface soil can hold will tend to lessen erosion. Development of humus and deep plowing are very helpful. Leaving the surface of the fall-plowed land just as turned, not harrowing it in the fall, is advisable. Much erosion occurs during the early spring season while the presence of the frost in the subsoil forces the water coming as early rains or melted snow to run off the surface.

288. Drainage. The removal of water from the subsoil, either by natural seepage or artificial drainage, lessens the amount which must run off the surface, causing erosion. Many hillsides which, on account of their clay soil, are naturally much subject to wash, and many even of a springy or marshy nature can be greatly protected by the use of tile underdrains for withdrawing the excess of water.

289. Terrace Method. Another method very commonly used to protect steep hillsides in countries where the dense population makes intensive cultivation of the steep slopes necessary, is the use of terraces.

The mountain slopes of France, Germany, and Italy are most favorable to the growth of grapes used in the manufacture of wine, but the cultivation of such slopes is possible only by the construction of terraces, in order to protect them from wash. In large areas of China and Japan, cultivation of the steep mountain sides is made possible in the same way. The damage resulting from the torrential rainfall in the South is also overcome to a great extent by this means.

290. Prevention of Gullies. The development of gullies by erosion on sidehills should be prevented at the earliest possible moment. Slight channels may be removed by the ordinary plowing and cultivation. When they have gone too far for this they can frequently be stopped by simple means, such as the placing of a few bound bundles of ripe grain which will clog the drainage, while the germination and growth of the seed will further protect the soil from wash. Larger ravines which must remain permanently should as far as possible be thoroughly grassed

Fig. 45. The gullies in process of development will ultimately ruin the field unless more effective means of prevention are used than are shown in this illustration.

over so that erosion will be lessened. The greatest difficulty comes when a slight vertical fall is developed, so that there is a tendency to cut under the bank. In such cases, something must be placed where the water falls, to lessen this cutting action, such as a pile of stones with as much gravel and sand as possible or a well-placed pile of tree branches. The construction of a board chute which will afford a channel through which water may be lowered without erosion from high to lower levels, will frequently pay for itself in the prevention of the further development of the gully. At other times, a second channel can be constructed and thoroughly grassed over, after which the original channel may be closed and the water forced to take the new and protected course.

CHAPTER XIV

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.

291. 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 moldboard is to break it up into larger or smaller lumps, making it more open and porous. The form of the moldboard determines the amount of this bending or crumpling. The long, slightly-curved moldboard 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 moldboard 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 with reference to its moisture content at the time of plowing has a very great influence on the tilth 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 giving a poor tilth to the soil. After plowing in the spring, it is often very helpful, in developing a good texture, to go over the ground with a planker 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 hardpan. This can be avoided by plowing at different depths different seasons. The disk plow has some advantages over the ordinary moldboard 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 disk plow, however, 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 similar attention to the amount of moisture in the soils 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.

Fig. 46. Showing the use of a subsoil plow drawn by four horses following the ordinary moldboard plow. Such deep tillage greatly improves the structure of heavy clay soils if done when the land is not too wet.

292. 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 seeds to the sun and air to dry, they 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 weeder is the most effective, but for heavier soils a light spike-tooth harrow will give better results.

293. 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, be prevented to some extent by stirring the surface of the soil so as to dry it

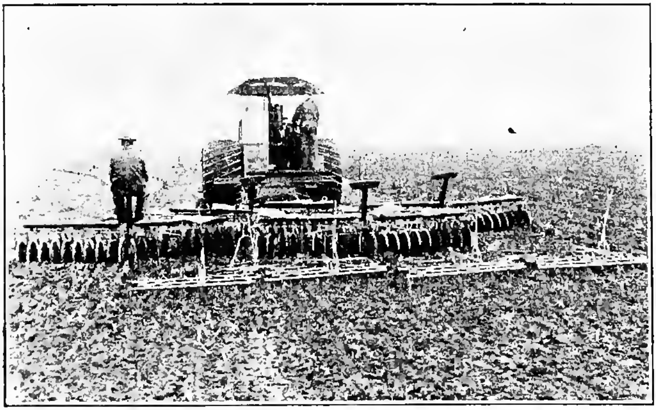

Fig. 47. Cheap and rapid cultivation is essential to success in dry-farming regions.

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 3 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 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, the ground will dry off more rapidly, and will therefore get warm enough for planting at an earlier date.

294. 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.

295. 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 more labor than the other, the expense of the extra labor reduces the net profit.

CHAPTER XV

HUMUS

In the chapter on Soil Origin (Sections 80 to 85), we have referred to the formation of humus in soils, and have briefly described the factors influencing its collection. We will now examine in more detail the chemical and physical nature of this organic soil constituent.

296. Forms of Organic Matter in Soil. An examination of the vegetable and animal remains in soils shows three classes of material that are not readily distinguished from one another. Practically all soils contain (1) entirely undecomposed vegetable matter, (2) actually decomposing vegetable matter, and (3) resistant waxy material that has accumulated as the result of the decay of many annual contributions of fresh vegetable matter. The entirely undecomposed material is of little service to the soil, except in improving the mechanical condition. On soils naturally light, too much of such material may even be harmful. Strawy manure, shavings, sawdust, coarse roots, and stubble may be mentioned as belonging to this class of material.

297. Active and Inactive Humus. The decomposing material may be called active humus; while the more resistant organic matter, as well as all fresh vegetable matter, while it is still undecomposed, may be called inactive humus. Rapidly oxidizing material is an active chemical agent, and therefore we may expect that active humus will play an important part in the preparation of plant food. The more inactive humus plays its part in influencing many of the physical properties of the soil.

298. Determination of Organic Matter and of Humus. Chemists have no means whereby they can distinguish sharply between the active and the inactive humus in the soil. Much of the black waxy material coating the soil grains is soluble in 4 per cent ammonia water, provided the soil has previously been well washed with hydrochloric acid. The black extract thus obtained is evaporated to dryness, and weighed. The black, shiny mass remaining is called Grandeau's *Matiere Noire*. The term humus is often limited to mean this black extract. Hilgard has determined the amount of this material, sometimes called humic acid, in a large number of soils, and reports the following results:

Table XXI Humus in soils ofdifferent climatic regions.

	Per cent humic acid	Per cent nitrogen in humic acid
Soils of arid regions....................	0.2-0.3	15.2
Soils of irrigated regions...............	0.36-2.0	8.4
Soils of humid regions..................	1.0-10.0	4.2

Some investigators maintain that all organic matter must reach this black waxy stage before it becomes active in the soil. When we consider the large quantities of vegetable matter annually returned to many soils it seems unlikely that this is the case, and that instead, the chemically active vegetable matter is the material on its way to the formation of this comparatively small store of inert waxy substance. Climatic conditions, the kind of vegetable matter, and the reaction of the soil will determine in a large measure the proportion of the annually returned vegetable matter that is active in the soil.

Since the attempts to distinguish between the kinds of humus are so imperfect, the determination of the total organic matter in the soil becomes of value. Even here, chemists are unable to furnish us an ideal method. The best that they have been able to do is to burn the soil by direct heating or by digesting with some strong oxidizing agent, and then determine the amount of carbon dioxid produced. The weight of the carbon dioxid is multiplied by an arbitrary factor in order to convert the results to percentage of organic matter. For general comparative purposes, soil may be burned in open dishes and the loss on ignition determined. This method is open to serious objections, as the results obtained are always too high. When a clay soil is burned, the water is driven out of the aluminum silicates forming the clay, and since this method determines the organic matter by difference, such water would be counted as organic matter.

299. Composition of Humus. If this partly decayed organic soil substance is subjected to a chemical analysis, the elements carbon, hydrogen, oxygen, and nitrogen are found along with small amounts of potassium, phosphorus, and other mineral elements. The amount of nitrogen in humus is determined to a considerable degree by the climatic conditions under which the original organic matter decomposed. If the composition of humus is compared with the composition of fresh organic substances, you will discover that the making of humus has resulted in the concentration of carbon and nitrogen and the decrease of oxygen and hydrogen.

300. Rate of Decomposition of Vegetable Matter. We may have vegetable matter decomposed so rapidly in the air, if ignited, that we call the process combustion or burning. Decomposition processes, similar and just as sure in their results, are occurring in the soil, but this slow oxidation, although causing the actual destruction of tons and tons of organic substance, often escapes our notice. The rate of decomposition in the soil leading to the making of humus, as well as to its final destruction, is influenced by the following factors: (1) Access of air, (2) temperature, (3) amount of vegetation, (4) reaction of the soil. The influence of the several factors has been discussed in sections 81 to 85.

FUNCTIONS OF HUMUS

301. Benefits. Someone has said, "Humus is the life of the soil." Since we can draw no hard and fast line between the part which active humus plays and the part which the more inactive matter plays, we may well sum up, as does Bulletin 135 of the Vermont experiment station, the benefits of all soil humus in the following brief statements: Humus serves first as a nitrogen supply; second, as a mineral plant food supply; third, as a storehouse for water; fourth, as a source of warmth; fifth, as an improver of the physical condition; and sixth, as an aid to bacterial and other micro-organic growth in the soil.

302. Humus and Nitrogen. We have previously pointed out that the process of humus-making from organic matter means an accumulation of nitrogen. The method by which this nitrogen becomes available to plants has been discussed in Chapter IV. It is fortunate indeed that nitrogen accumulates in the soil largely in the organic form. When organic matter is quickly nitrified, all the soil nitrogen is changed to nitrates, which may be quickly leached from the soil.

303. Mineral Plant Food in Humus. 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 form inert structureless humus, yields up its ash content readily. It is this rapid availability of the ash content of the plant residues that helps to maintain the revolving fund discussed in Chapter III. Some of the material thus quickly set free may be lost to succeeding crops by leaching. When the phosphorus and potassium of decaying vegetable matter form a part of the waxy humus compound, it is probable that these mineral elements become available very slowly, because of the difficulty of oxidizing this true humus.

It is held by some investigators that the humus in the soil may act as an acid, combining with mineral elements 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 that it is impossible to make definite statements concerning the action of the so-called humus acids.

The oxidation of both true humus and of unhumified vegetable matter, sets free carbon dioxid, much of which combines with the soil water to form carbon dioxid, a very powerful solvent of soil minerals. From the plant food aspect, therefore, organic matter benefits the soil in two ways: By supplying plant food resulting from its own decay, and by unlocking food elements in rock mineral by means of the contact with carbon dioxid and organic acids.

304. Humus and Water-Holding Capacity. The black waxy coating of soil grains becomes somewhat gelatinous when wet, and, like all such matter, has the power of absorbing large quantities of water. 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 stands foremost in this respect among the soil constituents." Lyon and Fippin quote the following data from Storer, in illustrating the water-holding capacity of different forms of organic matter:

PERCENTAGE OF WATER RETAINED BY

	Per cent
1. Humic acid extract from peat	1200
2. Non-acid humus prepared from peat	645
3. Ordinary vegetable mold	190
4. Peat	201-309
5. Garden loam (54% clay and 7% humus)	96
6. Dark Illinois prairie soil	57
7. Muck soil (weighing 30 lbs. per cubic foot)	75

305. Humus and Soil Temperature. In the first place, humus is a black material, so that an abundance of humus means greater absorption of heat from the sun, black substances being able to absorb more heat than lighter-colored substances. In the second place, the various decay and oxidation processes, incident to the destruction of vegetable matter in the soil, produce heat. You have also noted the same process in the fermentation and heating of a manure heap, although in such a case much more heat is developed in a given time, and higher temperatures reached in a limited amount of material, than in the same amount of soil in the same time. The same amount of heat is developed in the decay of manure when it is spread over an acre of soil, even though the rise in temperature is not so evident.

306. Humus and Texture. Humus coating the soil grains causes them to adhere to one another, so that instead of a soil being made up of an infinite number of separate grains, groups of grains are formed. The development of this crumb structure favors the movement of air and water through the soil, and makes tillage easier. On the Western prairie soil, where tillage used to be comparatively easy on account of the abundant supply of humus to maintain this crumb structure, farmers are now compelled to use more and more power to turn the soil, as the supply of soil-granulating humus is being exhausted.

307. Food for Soil Organisms. Our soils contain a vast population of tiny organisms, such as bacteria and molds. These bacteria and molds depend upon the vegetable matter or animal remains in the soil for their food supply. They perform an enormous amount of work in the preparation of plant food for the higher plant life. The necessary energy for this work is obtained from the oxidation of organic matter. Different organisms attack different kinds of vegetable matter, or the different elements in it, but there is such a complex array of material that each specific organism finds its own suitable food supply.

LOSS OF HUMUS

308. Continuous Growth of Intertilled Crops. We have mentioned the ways in which humus benefits the soil. Let us now inquire into the ways in which humus may be lost, so that we may learn to avoid wasteful methods. The greatest cause of humus decrease is 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 on the same land, there is no increase in the total vegetable matter in the cropped soil as compared to the amount in the adjacent virgin soil, even though large amounts of manure have been annually returned to the cultivated field. Several cases show an actual decrease in the organic matter of such soil.

The Nebraska station has reported analyses on a large number of pairs of loess soils, the cultivated and the adjacent virgin prairie soil forming each pair. The following table gives the average of those soils; each of the cultivated soils were cropped 30 years:

Table XXII. Effect of continuous cropping.

	Cropped soil, per cent	Adjacent virgin prairie, per cent	Loss, per cent
Total organic matter	1.77	2.31	0.54
Humus (ammonia extraction)	3.15	4.53	1.38
Nitrogen	0.56	1.98	1.42

Excessive tillage and cropping may reduce the supply of vegetable matter in the soil from 5 to 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 insure a humus supply, for a rotation of cereal crops is also destructive to humus. The use of commercial fertilizers year after year in the growth of intertilled crops promotes the rapid loss of humus, and unless the soil is sandy, soon creates unfavorable physical conditions. Commercial fertilizers are more economically used in combination with humus and nitrogen-restoring crops.

309. Erosion and Deforestation. Continuous tillage not only causes loss of humus by oxidation, but it also results in the loss of humus by erosion. As the supply of organic matter in the soil is depleted, sheet erosion (flat washing—not in rills) increases, carrying with it the finer parts of the surface soil with its thin coating of humus. The absence of porous, fibrous roots in the soil and of the water-holding humus results in a great loss by the more conspicuous ditch erosion.

Deforestation has removed from many hillsides the protective covering of water-holding vegetable mold. The shade-loving plants which formed the mold die, erosion ensues, causing loss to the hillsides and damage to the fields below. Forest fires, too, have consumed much of the natural vegetative mold.

MAINTENANCE OF HUMUS

310. How Maintained. Since humus may be lost so readily, it is necessary to know what practices will aid us in maintaining and increasing the supply. The current farm practices tending to keep up the humus supply are: (1) Maintenance of pastures and meadows for rather long periods of time, (2) green manuring, (3) use of farm manures, and (4) crop rotation.

311. Pastures and Meadows. The growing of such crops as the grasses, especially Kentucky blue grass, timothy, and red top, fills the soil full of tiny roots. The weight of organic matter in the roots and stubble of an acre of timothy and red top sod, down to a depth of 3 feet, has been found to be 8223 pounds, the first 6 inches of the soil containing 7606 pounds of root and stubble. In the material obtained from the first 6 inches of soil, 84 pounds of nitrogen were found, and 6 pounds in the remaining 30 inches. Virgin prairie soils often contain 8 to 10 per cent of total organic matter, largely derived from the fibrous roots of the grasses. Soils kept in pasture or meadow 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 mineral fertilizers. This supplementary top dressing is often practiced in England, a country noted for the fertility of her pastures. The annual removal of hay, with no return to the soil, will tend toward loss of humus, although, of course, at a much slower rate than in tilled soils.

The value of pasture in improving soil is well shown in the results from a crop rotation experiment at the Illinois station. Circular 96 gives the yields of corn obtained in 1904 for the different rotations.

ROTATION	YIELD OF CORN IN 1904
Corn, oats—28 years	36 bu. per acre
Corn, oats, clover—28 years	59 bu. per acre
Pasture—18 years; corn, oats, clover, —10 years	74 bu. per acre

The third rotation scheme gives a yield more than double that of the rotation of corn and oats, and 50 per cent better than the second rotation.

312. Green Manure Versus Farm Manure. In Circular 120 of the Illinois experiment station, C. G. Hopkins states that the humus in Illinois soils must be maintained by plowing under manure or clover and crop residues. In referring to green manuring and farm manure, he makes the following significant statement: "Average animals digest, and thus destroy, 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 manure is returned to the land without loss by fermentation." On extensive areas of soils where humus and nitrogen are the principal limiting factors, we cannot afford to destroy so much organic matter, nor to transform large quantities of the nitrogen of the organic matter into easily-lost urea, a condition that is apt to arise if all organic matter produced is fed. In addition to this fact, we are all aware that it is entirely impossible to establish at once the necessary pastures and meadows to produce the necessary feed for the stocking of large areas of worn clay lands and poor sandy lands so greatly in need of humus. Green manuring must be expected to aid in bringing up the soils to a condition where they may be fitted for another system of farming.

313. Crops for Green Manuring. Both legumes and non-legumes are grown for green-manuring purposes. The first class are the most important. Two classes of legumes are available; namely, the annuals and those living longer than one year, such as mammoth and medium red clovers and alfalfa. Among the annual legumes suitable for use are cow peas, soy beans, velvet beans, the vetches, the lupines, and the serradellas. The lupines and serradellas have been very successfully used in building up humus and nitrogen on large areas of poor sandy soils in Germany, but these crops have received little attention in this country. Spring vetch, or tare, is excellent for green manuring purposes. In the North Central states it should be seeded without a nurse crop about the middle of May, at the rate of 1 to 1½ bushels per acre. Sand, winter, and hairy vetches may be sown later in the season. They should be seeded rather deep, the depth depending upon the season. Experiments on sandy soils in Wisconsin indicate that for those soils, at least, inoculation is unnecessary in the case of vetches.

Cow peas and soy beans are extensively grown in the South, both for forage and green manuring purposes. They can be profitably grown in the North Central states for green manuring, if they are allowed a growing period of at least two months. Cow peas are particularly well adapted for this purpose on sandy soils. Practically all of the annual legumes thus far enumerated will thrive on acid soils, but the two most important humus-collecting and nitrogen restoring legumes adapted to northern United States, namely, red clover and alfalfa, do not thrive on acid soils. The soil acidity must be neutralized by some form of lime where these crops are chosen for green manuring purposes.

314. Management of Green-Manuring Crops. All crops require mineral plant food. Legumes add only nitrogen. Neither legumes or non-legumes can be expected to do their best in humus-building unless supplied with the necessary calcium, phosphorus, potassium, etc. The soils most in need of humus, the sands and worn clay loams, are apt to be deficient in these essential mineral elements. The clover plant that does not get enough phosphorus cannot be expected to garner much nitrogen from the air. On poor sandy soils, both potassium and phosphorus are necessary for the best growth of a green-manuring crop.

Care should be exercised in the handling of the green-manuring crop after it is grown. If too heavy a growth of green stuff is turned under, it is liable to cause acid fermentation. If turned under on light soils so that there is a poor contact between the soil and subsoil, capillary connection may be destroyed in seasons of drought, thus defeating the very end sought, namely, increasing the ability of the soil to supply water to the plant. Green-manuring crops that demand large quantities of water for their growth, and that live over winter and resume growth in the spring, should be plowed under before they have an opportunity to rob the crop designed for that particular field, of the water stored in the soil. Where rye is grown for this purpose, a mistake is often made in not turning it under soon enough.

315. Farm Manures. Farm manure consists largely of vegetable matter, and as such, aids in restoring humus. It is in an easily oxidizable condition, so that only a small portion accumulates as true humus. Farm manure is so thoroughly inoculated with decay organisms that it decays very rapidly, and at the same time promotes the decay of other organic matter in the soil. This seems to be especially true where excessive amounts of manure are used on tilled crops without rotation. Manure may be used more economically if spread over larger areas than is the common practice in the growth of intensive crops. When manure is used to restore humus, it should be hauled to the fields as soon as possible. We have already noted that stored manure rapidly loses its organic matter.

316. Crop Rotations. Crop rotations may be planned so as to materially assist in maintaining or even increasing the supply of humus in a soil. A crop rotation which consists merely of corn and oats, or of a rotation of the 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 the intelligent use of farm manures—is calculated to maintain or even increase the supply of humus. The best combination of these practices will have to be worked out by the individual farmer on his own soil and under the specific conditions operative on his farm. The legumes must always occupy a prominent place in any economical crop rotation.

CHAPTER XVI

RELATION OF CROPS TO CLIMATE AND SOILS

There is nothing more essential to the success of the farmer than adequate knowledge of the conditions necessary for the best growth of the various crops. Some of these conditions cannot be modified by man, and plants must be adapted to them, while others can be influenced by proper methods of cultivation.

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

317. Relation of Character of Plant to Character of Soil. There is a great diversity 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 they require from the soil. Some plants are therefore 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 coarser texture, in order that they may easily force their way through the soil. Others, less coarse, such as alfalfa and corn, can grow in soils of medium texture, while soils of very fine 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 often makes nearly one-half its growth in a month. Enough available plant food material must be on hand or made ready during that time to allow this rapid growth. Some plants, like alfalfa and brome grass, on account of the great length of their roots, are able to draw water from depths of soil beyond the reach of other plants.

Red clover and alfalfa 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 calcium than most crops (See table in Sec. 18). For this reason, these legumes thrive unusually well on the loess soils of the Missouri and Mississippi valleys, and on the glacial till of the Northern states where this till 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 reach the partially undecomposed limestone.

The winter-killing of plants is often dependent on the character and condition of the soil. Clover is more apt to be killed in poorly-drained soils and in those of fine texture than in well-drained and coarser-textured soils, on account of the heaving produced by the freezing of the water in the soil.

318. Relation of Crop to Climate. The distribution and amount of rainfall in a given region is another determining factor in the selection of crops. 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.

For convenience we may divide general farm crops into three classes: (1) tilled crops, (2) cereals, and (3) grasses and clover.

TILLED CROPS

319. General Likeness of Tilled Crops. All those crops which are planted in rows to admit of tillage, such as corn, potatoes, tobacco, cotton, and the root crops generally, have certain features in common. The chief likeness is in coarseness of root system and size of stalk. The nature of the root causes them to be adapted to somewhat open-textured soils, through which the coarser roots may ramify, while the size of stalk and leaves permits them to be planted far enough apart to allow intertillage because the plants finally grow so large as to completely cover the ground with foliage. The foliage is so extensive that it covers the ground during the later growth of the crops, while still leaving space for tillage during the earlier growth. The intertilled crops of any section 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.

320. 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 downward at an angle which varies greatly with the character of the soil. The secondary roots, starting from the first and second nodes above ground, grow down to the soil as braces and develop horizontally comparatively near the surface. In a deep loam soil, at six weeks from planting, when the plant is about a foot and a half high, the roots often meet between the rows 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.

The soil to which corn is best adapted is a deep, fertile loam, having a large water-holding capacity, with a surface of such character that it becomes warm early. Corn is the most vigorously growing plant commonly raised, and takes the greatest amount of plant food material from the soil, particularly nitrogen and potassium. This, together with the lateness of starting, permits the use of stable manure, green manure, clover sod, or other organic forms of fertilizer, such as dried blood, which are easily transformed into available material for the growth of the crop. Clover, while adding large quantities of nitrogen to the soil, takes away large amounts of potassium and phosphorus. Any deficiency must be made good, either by stable manure or by commercial fertilizers, to secure the best growth of the corn on ground not containing a sufficient supply of these essential elements in an available condition.

Where the available potassium and phosphorus in the soil are sufficient for both clover and corn, the benefit of the clover sod to the corn is very great. The Canadian experiment station reports 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.

321. Effect of Stable Manure on Corn. The benefits of stable manure are 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 52.3 pounds on July 29, while the same number of hills on the unmanured portion weighed but 29 pounds. Later in the season the difference was not so great, although, of course, the manured portion produced a heavier crop than the unmanured, the yield being 8440 pounds of dry matter per acre on the manured and 5965 on the unmanured. Professor Latta, of the Indiana experiment station, found that a single application of 50 tons of fresh horse manure maintained a yield averaging 10.4 bushels per acre above that of unmanured land for eleven years. He also found that an application of artificial fertilizers containing more nitrogen, phosphorus, and potassium than the crop took from the soil, gave a yield of only four-fifths that of cow manure. Humus and sandy soils often require potassium for the growth of corn, while clay soils are frequently benefited by phosphorus.

322. Preparation of Soils for Corn. Deep plowing is especially important in the preparation of clay soils for corn, and as much of it as possible should be done in the fall. A thorough working with the disk harrow in the spring, followed by a spike-tooth harrow, or a planker when it is necessary to break clods, will then leave the ground in good condition for planting. The disking 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 with marked success in the Southwestern states has no advantage over the usual method followed in the corn belt.

When favorable weather permits the corn to be planted earlier than usual, 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 adjusts 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, wider planting than in the North is desirable.

323. 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 as soon as the corn is up two inches is usually necessary. Cultivation should follow every rain to destroy the crust produced, care being taken to so time the cultivation as to develop the best tilth, all possible work being done when the soil is in the proper condition as regards moisture. This cultivation should, as far as possible, be shallow enough to avoid cutting the roots which come close to the surface. In a humid or semi-humid climate, a mulch of 3 inches is as effective as one of greater depth, while the loss to the corn by the cutting of the upper roots, which feed 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 3 to 5 bushels per acre, besides requiring more labor than shallow cultivation. In a wet season, deeper cultivation may be necessary to cover weeds. In a semiarid climate, tillage should be somewhat deeper.

324. Potatoes. The most desirable soil conditions for potatoes are very similar to those for corn. It is especially important that the soil be loose and not liable to bake. 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 as a result of the baking of the ground was found in one case to be over 10 per cent of the crop. Clay loam soils containing sufficient humus to prevent baking and to render them open textured for the favorable development of tubers, will ordinarily give larger yields of potatoes than more sandy soils, but the quality is not so good and more labor is involved in cultivation and harvesting.

Thorough preparation of the ground is necessary. Deep fall plowing followed by shallow spring plowing or disking, 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 generally preferable to the ridging system, 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. Manure, when used, should be well rotted. Nothing is better than turning under a good growth of clover. On sandy soils the addition of some potassium fertilizer with the clover is often profitable. Sulfate of potassium is said to produce a better quality than potassium chloride. On acid marsh soil, phosphorus as well as potassium fertilizers, are needed. Do not use lime, because it tends to the development of scab.

325. 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 feeds very heavily on nitrogen, and especially on potassium. 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.

326. 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, too, 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 potassium. Many soils which have the proper texture and situation are lacking in sufficient potassium for the best tobacco production and should be fertilized with potassium fertilizers, sulfate 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.

327. 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 phosphorus from fields so treated. Recent results obtained at the Wisconsin station[1] 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 1300 pounds of phosphorus per acre surface eight inches, above that removed by the tobacco and other crops. On the average, five times as much phosphorus 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. In the growth of an intensive crop like tobacco, the farmer can well afford to re-enforce at least part of his soils with the necessary commercial fertilizers.

328. Sugar Beets. The sugar beet is best adapted to the northern part of the United States, 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 averages three or four per cent higher in beets grown in the latitude of 40° than in those grown in latitude 38.° The great amount of sun-

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[1] Research Bulletin No. 2, Wisconsin experiment station.

shine of arid regions increases still more the percentage 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 deeper cultivation may be practiced, although a depth of 3 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.

329. Cotton. The cotton crop of America is about three-quarters of the world's crop, and has a valuation of about $750,000,000. It can be grown only in countries having a long growing period of at least six months from the last spring frost to the first one in the fall. In the South it is planted between March 15 and May 1.

This plant is adapted to a considerable variety of soil, but, as in the case of most crops, the yield is greatly dependent on the fertility. The lint, which is the part used for cloth manufacturing, contains very little fertility, but the seed produced with it on a good crop requires about the same amount of essential elements as does a good crop of wheat. The black, fertile soils of Texas produce from one to two bales, of 500 pounds each, while the less fertile soils of the Southeastern states yield from one-half to one bale. The seed produced weighs twice as much as the lint.

Ground for cotton should be prepared early by plowing and disking. The seed is sown in very thin drills from 3½ to 5 feet apart, depending upon the fertility of the soil. The plants are later thinned to from 15 to 24 inches apart. Since nitrogen and phosphorus are the chief elements removed in the seed, they are the chief elements needed in fertilizer. The cotton seed itself has been in the past the most commonly used nitrogen fertilizer, but its high price today is making other forms of nitrogen, especially sodium nitrate, more economical; however, the sale of the cotton seed is an additional revenue and makes possible the purchase of commercial fertilizers. The stalks also contain some elements of fertility in addition to their organic matter, and where practicable, they should be cut up and plowed under.

Cultivation of cotton should follow the same general lines as that of corn, the objects being the same; namely, promoting nitrification, killing weeds, and conserving moisture.

CEREALS AND FLAX

330. General Characteristics. 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 intertilled 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 which has thus been able to accumulate nitrates. As a rule they require a relatively large amount of available phosphorus.

331. 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 40 pounds, while a bushel of Southern-grown oats frequently weighs only 20 pounds. The oat is a strong feeder and is 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, 2 bushels per acre often being better than a larger amount.

332. 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 later in the season for other crops. A more fertile soil is required for its best development.

333. Wheat. Wheat makes its best growth on deep clay loam soils containing considerable humus. The large yields secured in the Western states are probably due to the large amounts of humus in the virgin soils. While large yields are produced in the regions of moist climate, experiment has shown that wheat grown in drier regions is richer in protein.

334. 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.

335. Flax. Flax is particularly adapted to the open prairie loam soils that are 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 fungous 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 more than do other grains, is shown by the fact that crops do as well following flax as following most of the grains.

GRASSES

336. Soils for 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 necessary to select varieties of grass 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.

337. 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 to have sufficient available fertility and moisture. In moist climates 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 disking it, then harrowing it during the following four weeks at such times as will produce the best effect on texture, and then sowing the grass in the early autumn.

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 stubble for the protection of the grass.

Timothy makes its best growth on clay loam, but also does well on marsh soils 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.

CLOVER AND ALFALFA

338. Soil Treatment for Clover. Medium red clover and alfalfa are especially valuable both for use as hay and for adding nitrogen to the soil. They are 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 as stated in Secs. 129-131.

While clover and alfalfa have the power of using nitrogen from the air, they require 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 in available form. Better results 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 1½ to 2 bushels of grain, or else to cut it early for hay, thus leaving more moisture for the clover. Oats are rarely used as a nurse crop for alfalfa. Many successful stands of alfalfa have been secured by late seeding (late in May or early in June) without a nurse crop, on well-fertilized soils. In the case of late seeding, the soil should be fitted early in the spring and then kept free from weeds and have its moisture conserved by frequent cultivations.

Alfalfa has a great advantage over red clover and the annual legumes, in being a perennial, in permitting three or more cuttings in a season, and in its very deep root system, which enables it to continue growth by drawing on deeper supplies of water than more shallow-rooted crops can. While the nitrogen for its growth may all be gathered from the air, when no nitrates exist in the soil, the large amounts of phosphorus and calcium used in heavy yields must not be forgotten.

CHAPTER XVII

SOILS OF THE UNITED STATES.

339. Classification of Soils. Soils may be classified in several different ways for different purposes. We have already seen that with reference to their origin they may be classified into five groups: (1) Windblown or loessial; (2) residual—those formed by direct weathering of rock in place; (3) glacial; (4) alluvial; (5) colluvial, or those formed by sidehill wash and sliding. The general character of the soils of these modes of origin has been discussed in Chapter II. Soils may also be classified on the basis of physical composition, or texture. The most commonly recognized classes on the basis of texture are as follows:

1. Course sand.
2. Fine sand.
3. Sandy loam.
4. Fine sandy loam.
5. Loam.
6. Silt loam.
7. Clay loam.
8. Clay.

Soils are seldom classified purely on a chemical basis, it being generally true that chemical differences go with other differences, such as those in mode of origin and texture. Two features only of the chemical composition of soils must be noted; first, the amount of essential plant food; and second, the presence of possible injurious substances, especially the accumulation of soluble or poisonous salts, as in the case of alkali soils.

With reference to their adaptability to different classes of crops, soils may be divided into three classes.

First, those which, on account of their sandy texture and consequent low water-holding capacity, become warm early in the spring and permit being worked readily even when wet. These soils are especially adapted to early vegetable crops and are hence commonly called "truck" soils.

Second, soils which, on account of their very fine texture and large content of clay, have a high water-holding capacity, and are therefore especially adapted to grasses and to some of the cereals. The fine root systems of such crops can penetrate these "grass" soils and take advantage of their fertility and large water content.

Third, soils of intermediate texture, which by reason of a good water-holding capacity and only moderate amounts of clay, so that they can be kept in good tilth, are adapted to a wide range of crops and may be called "general agricultural" soils.

340. Relation of Climate and Soils. Our attention has been frequently called to the fact that there is a close relation between the climate and the soils in their influence on the growth of crops. As a reservoir for water, the soil regulates the supply to the plant. The chemical composition of the soil is in many respects dependent upon the climate under which it is produced. The climate and soil taken together constitute the environment of the plant. Any attempt to classify soils in a broad way as related to the production of agricultural crops, must include the climate. Temperature is the most important climatic factor in determining the chief crops which can be grown in any country. We are all familiar with the terms "cotton belt," "corn belt," etc. Such terms are applied more to the climate than to the soil. In attempting to classify the soils of the United States in a broad way, therefore, we must first subdivide and consider each climatic factor and its influence on the character of the soils. The chief agricultural regions characterized by a more or less uniform climate are as follows:

First, the coastal plains extending in a broad belt from New Jersey south, including Florida and stretching around the Gulf of Mexico.

Second, Piedmont Plateau, lying between the coastal plain area and the Appalachian Mountains.

Third, the Mississippi Valley soils.

Fourth, the Appalachian Mountain region.

Fifth, Northeast glaciated region.

Sixth, the Black Prairie region.

Seventh, the semiarid or dry-farming region.

Eighth, the arid region.

There are, of course, some other small regions of more or less definiteness.

341. **The Coastal Plain region** includes a broad area along the Atlantic Coast and the Gulf of Mexico from New York to Texas. This region is one in which large adjacent bodies of water modify the climate and produce heavy rainfall, ranging from 45 to 60 inches. The soils are, for the most part, of recent origin. For this reason, the soils of this section are, to a large extent, of sands, sandy and fine sandy loams. Soils of these classes probably constitute three-fourths of the entire area. They are therefore naturally adapted to vegetable crops, to which their southern location further adapts them. Soils of this region from New Jersey to Florida and Alabama supply the enormous quantity of vegetables used in the large cities of the Central and Northern states, from January to June. They are, therefore, farmed in a rather intensive way. Large amounts of artificial fertilizers are

required to supply the continual drain caused by the shipment of such crops. Fortunately, the climate of this region permits the growth of two or more crops during a season, so that it is entirely practicable to grow a crop for green-manuring purposes during the fall and early winter, which can be plowed under and so maintain the humus content of the soil. The heavier soils of this area are used for rice, some cotton, and a small amount of wheat and corn.

342. The Piedmont area covers a broad belt from Alabama on the south to New Jersey on the north, lying between the Coastal Plain and the Appalachian Mountains and having an elevation of from 300 to 1000 feet. The soils of this region are largely derived from weathering from crystalline rocks, such as granite, gneiss and schist, though some shales are included. The soils are heavier than those of the Coastal Plain, and are largely sandy loams, loams, and clays. The agriculture of the region is of a general character, including the growing of small grains, corn and hay; and in the South, tobacco and cotton are also grown. This region is well adapted to the tree fruits, especially apples and peaches. On account of the fact that the subsoils of this region are, as a rule, heavier than the surface soils, and on account of the torrential nature of the rainfall in connection with considerable elevation, erosion is one of the greatest difficulties with which the farmer has to contend. The maintenance of organic matter by the use of green-manuring crops, by prevention of erosion by the replacement of the elements sold in products marketed, and by the use of the proper commercial fertilizers, are the essential principles necessary to the maintenance of fertility.

343. The soils of the Mississippi Valley, from the delta to the mouth of the Ohio River, form a broad belt from 20 to 50 miles in width, and are of an alluvial nature, being brought down from the highlands of the north and by floods of the Mississippi and its tributaries. Since finer grained material is more readily transported in suspension than coarser material, the soils of this region are, as a class, very much finer grained than those of any other general region. Clays, silt loams, and loams greatly predominate. The heavy rainfall, the close texture of the soil, and the general low level of the land are conditions favorable to the high degree of fertility which these soils as a whole possess, though locally they are often strikingly deficient in some of the essential elements, especially phosphorus. The character of the soil and of the climate of this region adapts it to such crops as corn, cotton, sugar cane, and, on the better drained areas, to wheat and alfalfa.

344. The Appalachian Mountain region, extending from Pennsylvania to northern Alabama, is a broad belt of mountainous country, including a great variety of rocks and residual soils derived from them. A relatively small portion of the area is under cultivation, much being too rough for agricultural use and is therefore left in forest. Western Kentucky, Tennessee, southern Missouri, and northern Arkansas form a tableland of moderate elevation, largely underlaid by limestone rocks, from which residual soils have been derived. Such soils are of fine texture, varying from silt loams to clay loams, and of a good degree of fertility. Locally they are very stony, from the large amount of chert contained in the limestone.

As is usually the case with limestone soils, these soils have a good supply of organic matter.

345. The area of the last glaciation covered the portion of the United States now including central and northern Minnesota and part of Wisconsin, part of Michigan, northeastern Illinois, northern Indiana, northern Ohio, small portions of Pennsylvania, all of New York, and the New England States. This region is one of considerable uniformity in climate, though the regions immediately bordering on the larger bodies of water, especially the Atlantic Ocean, have the extremes of both summer and winter materially modified. The underlying rocks of this region are largely granite and other crystalline rocks in New England and eastern New York, while west of central New York the rocks are largely limestone with a smaller amount of sandstone and crystalline rocks.

The soils owe their character to the influence of glaciation on the previously existing residual soils. On crystalline rocks the soils are of a loam character, differing but little from residual soil on such rocks. In the regions of limestone, such glacial soils contain large amounts of finely ground limestone mixed with whatever residual soil existed before glaciation. Such soils, therefore, differ radically in their large amount of lime from the soils of other regions. In regard to texture, they are largely loams, silt loams, and clay loams. In the sandstone regions, which form considerable areas in Michigan, Wisconsin, and Minnesota, glacial soils, of course, differ but little from residual soils, since practically the only effect of glaciation was that of breaking down the sandstone and giving it a somewhat more uniform topography. Glaciation in this region was so recent that the topography is still essentially that produced by the ice, including ground moraines, drumlins, veneered hills, and terminal moraines. Small lakes and marshes are scattered over practically the entire region, and marsh soils, either of muck or peat, formed in such poorly drained regions, constitute an important class. The glaciation of this region has resulted in the formation of a great variety of soils.

Practically this entire region was more or less heavily timbered before settlement took place, and for this reason the soils are, as a rule, low in organic matter. We have seen that humus is largely produced by the decomposition of the fine roots of grasses. The leaves and stems of tree vegetation produce some leaf mould on the surface, but this decomposes so rapidly that no considerable amount collects. Leaf mould, too, is always left as a layer on the surface instead of becoming incorporated with the earthy portion of the soil itself.

As a rule the heavier classes of soils of this region have a high degree of fertility, and are especially well supplied with phosphorus and potassium in addition to the large amounts of lime carbonate. The climate of this region, together with the general character of the soils, leads to the development of a general agriculture, including, especially the raising of small grains, and dairying, the greatest dairy states of the Union, Wisconsin and New York, being located in this region. The influence of climate is particularly marked in the manufacture of cheese, which requires a comparatively cool temperature.

346. The area of black prairie lands lies south and west of the region of the last glaciation and forms a large territory, including eastern North and South Dakota, Kansas, Nebraska, a large part of Iowa, Illinois, southwestern Minnesota, southwestern Wisconsin, and southern Indiana. This region is characterized by a remarkable uniformity in soils and has a level to a gently undulating topography. The luxuriant growth of grasses on these nearly treeless prairies led to the development of an unusually large supply of humus, so that the soils are almost universally of a deep black color. The rainfall of this region varies from 25 inches in the northern and western portion, to 40 in the southern and eastern. This rainfall comes very largely during the summer months, especially in June and July. The altitude of the region is comparatively low, varying from 500 to 1500 feet. This combination of altitude, soil, and rainfall makes this region one of the most fertile regions of the world, and especially fit it for the growth of crops which draw heavily on the fertility of the soil. This section has become the greatest corn-producing section of the world, on account of the favorable combination of the factors essential to its growth. The large amount of nitrogen originally in the soil; the good distribution of rainfall at the time corn is making its most rapid growth; the warm nights, due to the high humidity and low altitude—all combine to favor the growth of this wonderful crop. The northern part of the region, which is somewhat too cold for the best growth of corn, is well adapted to small grains, and the southern portion is equally well adapted to cotton, alfalfa, and wheat, in addition to corn. In the more humid portions of the prairie district, which also happens to be the portion which has been under cultivation the longest, there is a marked tendency for the soils to become acid on account of the leaching by rains and the removal of lime by crops. In the western portion, where the rainfall is less, lime carbonate usually exists in large amounts, and there is as yet but little tendency toward the development of acidity. The surface soil of this region, as previously stated, is of a black prairie character, while the subsoil is for the most part a deep silt loam and is largely of loessial, or wind origin. A considerable portion of the area was covered by the earlier glaciations, such as the Illinoian, Iowan, and Kansan, but for the most part these glacial deposits were covered later by the loess which now forms the most common subsoil.

As is usually the case in subsoils of this character, those of this region are usually well supplied with lime carbonate and have a high content of potassium and a moderately high percentage of phosphorus. The supply of the essential inorganic matter is, on the whole, large, and the unusually large amount of organic matter serves to keep a good supply of these elements in a form available to crops.

Under continous cropping, with removal of crops from the land, the supply of phosphorus is apt to become exhausted first. In other words, phosphorus is most commonly the limiting element, the large amounts of nitrogen, calcium, and potassium overbalancing the moderate amount of phosphorus. In some sections where the supply of humus is not so great, the available nitrogen has been depleted and the growth of leguminous crops is essential for its renewal.

CHAPTER XVIII

SANDY SOILS AND THEIR MANAGEMENT

347. Types of Sandy Soils. The term "sandy soils" may be used to cover a considerable range of variation in texture, including everything 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, and (3) black sandy loams.

COARSE SANDY SOILS

348. Management of Coarse Sandy Soils. Coarse sandy 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. Moreover, they are extremely low in potassium and even in phosphorus. 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. There are so many drawbacks to the cultivation of very sandy soils that it is only under peculiar conditions with respect to location and market and the growth of certain crops, that their use for agricultural purposes is profitable.

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.

349. Protection from Wind. It frequently happens that wind storms, especially in the spring and early summer, blow these sands with such force as to cut crops entirely to the ground. Destruction by wind can be lessened by leaving strips of jack pine and other native vegetation between comparatively narrow strips of cultivated lands. Such windbreaks 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 which cover the ground early 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.

350. 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 some other crops are grown. The nitrogen left by the legumes is largely consumed by the first crop following, so that short rotations are necessary.

Fig. 48. On coarse sandy soils a much better catch of clover or alfalfa can usually be secured by seeding alone without a nurse crop, as shown in this illustration.

Except under unusual conditions of origin, such as in 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. 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.

351. Addition of Essential Mineral Elements. The addition of potassium and phosphorus may be in the form of farm manure or commercial fertilizers. Manure used on such lands should be well rotted in order to avoid the drying effect of material used in bedding. Special care is necessary in this composting to prevent the loss of the soluble material, as indicated in Sec. 201. The commercial fertilizers, muriate and sulfate of potash, or wood ashes, where available, should be used as indicated in Sec. 160. Phosphorus 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.

352. 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.

353. 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 sandy soils can be worked, potatoes, strawberries, and other truck crops can be profitably grown when sufficient care is taken to plant them after a good green-manuring crop or on a good clover sod. The organic matter thus supplied will materially improve the water-holding capacity for at least one year.

Fig. 49. Showing the effect of irrigation on the yield of potatoes on light sandy soil at Stevens Point, Wisconsin. The large pile at the left is of marketable potatoes grown on an irrigated plot, while the pile at the right is of the marketable potatoes grown on an unirrigated plot; the two small piles are the unmarketable potatoes.

SANDY LOAMS

354. Management of Sandy Loams. Sandy loam soils vary all the way from distinct sandy soils to soils of a finer texture. The lighter ones have the same general characteristics as 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

355. Management of Black Sandy Loams. Large areas of black sandy loam soils 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 when this black humus is of an acid character and contains relatively little mineral matter, and which, moreover, oxidizes slowly even when present in considerable amounts. When the humus is naturally neutral or when its acidity is neutralized by lime carbonate, its oxidation after cultivation will usually yield a fair supply of nitrogen to growing crops, but such soils will still be deficient in both potassium and phosphorus, and require either farm manure or commercial fertilizers to supply this deficiency. This class of soils, while better adapted than the coarse sandy soils to such crops as corn, potatoes, and others requiring large amounts of water, are not so well adapted for growing vegetables as are the fine sandy loams previously mentioned.

CHAPTER XIX

MANAGEMENT OF IMPORTANT TYPES OF CLAY SOILS

356. General Character of Clay Soils. Clay soils vary in texture from light clay 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 potassium, but the supply of phosphorus 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

357. 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 region and the heavy clays of the Red River Valley may be mentioned as illustrations; but the most extensive areas of clay soils exist in the South as described in Sec. 343.

358. Drainage of Clay Soils: 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. By the laying out of fields in narrow plow lands, the dead furrows of which are deepened and connected with end ditches, great improvement in surface drainage may be effected. These dead furrows should be kept in the same place permanently, or at least two years out of three.

Underdrainage by tile constitutes a permanent improvement of the greatest possible value. It greatly lessens the care 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 will pass down quite readily through the checks and cracks, so that these are retained and the physical condition improved from year to year. It has been demonstrated repeatedly by practical experience that the heaviest of these clays can be successfully tile drained, at least in the Northern states.

359. Tilth of Heavy Clay Lands. Heavy clay lands when plowed in the fall and allowed to lie in the rough furrow will improve greatly in texture, provided sufficient care is taken not to cultivate them when so wet that puddling would result. Proper treatment will improve tenacious clays, so that, while at the beginning of their cultivation working of them costs at least double the labor necessary 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. The use of coarse manure is also beneficial in this respect.

It has been the practice in older countries to apply lime to clays for the purpose of improving their tilth. This effect is undoubtedly produced, but lime 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.

360. Fertilizer Requirements. As above stated, these soils are apt to be deficient in nitrogen and phosphorus. Nitrogen should be supplied by the growth of clover or other legume, and the phosphorus can be most cheaply supplied in the form of floats, though where little organic matter is present and no manure available, acid phosphate or bone meal should be used.

Peat, which is frequently available in the vicinity of both clay and sandy soils, contains, in a partly 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 effective in adding nitrogen to such soils.

361. Crops for Clay Soils. The large water-holding capacity of clays 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, although this soil is not especially adapted to such crops.

EXHAUSTED CLAY LOAM SOILS

362. 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 attention paid to the maintaining of 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 Secs. 127-134, 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 dairy or other classes of live stock, manure should be available, which, when supplemented with floats or rock phosphate, as indicated in Sec. 207, will add the necessary phosphorus. The use of green-manuring crops and of pasture in the 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

363. Management to Lessen Erosion. Large tracts of clay soils along the bluffs of our river valleys and their tributaries are so steep that they constitute a distinct type of agricultural lands. The cultivation of such lands in tilled crops greatly increases the tendency to erosion, the greatest difficulty encountered in their management. Such lands are therefore best fitted for grazing purposes. In the selection of farms in rough regions, care should be taken to have the farm include some sufficiently level land to permit of considerable cultivation, as well as the rough land which must be used as pasture. One crop of corn may be grown about 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. Further methods of preventing erosion have been given in Chapter XIII.

CHAPTER XX

MANAGEMENT OF MARSH SOILS

364. Characteristics of Marsh Soils. Marsh soils have been formed by the drying up and filling in of lakes and marshes. They contain an excess of organic matter and a deficiency of the mineral elements. These soils may have either a clay or a sand subsoil, and vary greatly in depth. Marsh soils are either acid or neutral.

ACID MARSH SOILS

365. Origin. 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.

Fig. 50. A good stand of timothy and alsike clover on a drained peat bog in northern Wisconsin. Such land needs the mineral fertilizers containing phosphorus and potassium only.

They include practically all of the marshes of central and northern Wisconsin, large areas of Minnesota, Michigan, and other states. These soils are usually largely formed of sphagnum moss, producing a peat 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 12 to 15 pounds as compared to 70 pounds for a cubic foot of an ordinary clay loam soil.

366. Nitrogen and Acidity of Peat Soils. The excess of nitrogen in peat soils makes it unnecessary to grow legumes for the purpose of increasing the nitrogen content. 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 required would make the expense prohibitive. It occasionally happens, however, that peat 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 been met with by the writers to a very slight extent in this country.

367. Phosphorus and Potassium. Acid marsh soils, in common with acid soils generally, are deficient in available phosphorus. 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 400 to 500 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 potassium also, and this may be supplied in the form of wood ashes, of which 30 to 40 bushels per acre is a good treatment; or muriate or sulfate of potassium may be used, of which 100 to 150 pounds to the acre every year are sufficient.

368. Crops for Acid Marsh Soils. The low marsh lands in the colder sections of the country are more subject to frosts than uplands, 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 treatment with phosphorus and potassium fertilizers just mentioned, 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 these marshes.

NEUTRAL MARSH SOILS

369. 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 are not acid. The subsoil is commonly clay. For this reason these soils ordinarily nitrify more rapidly than the acid marsh soils, and seldom show need of phosphorus fertilizers. They

Fig. 51. Showing the effect of a potash fertilizer on marsh soil. On non-acid marsh soils this fertilizer alone is often all that is necessary to make the difference between no crop and a heavy crop.

are, however, often deficient in potassium. 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 a lack of potassium, and so the addition of a potassium fertilizer alone will enable this soil to produce heavy yields. From 100 to 150 pounds of sulfate or muriate of potassium 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 potassium, so that the need for special potassium treatment disappears. Because these soils are deep and black they should not be regarded as inexhaustible. Under long continued cultivation, a general fertilizer, such as farm manure, becomes as necessary on these soils as on other soils.

CHAPTER XXI

DRY FARMING

370. General Influence of Rainfall. As nearly as can be determined from the records of the Weather Bureau on the rainfall of the United States, nearly one-half of our entire country, not including Alaska, has less than 20 inches of rainfall on the average, and 63 per cent has less than 30 inches. All of the eastern and southern, or older sections of the country, have 30 inches or over, of rainfall, and while short periods of drought are not infrequent, as a rule lack of moisture is not the limiting factor in crop production. On the other hand, when the annual rainfall is under 20 inches, it is usually the supply of moisture which determines the yield of crops, and even with a rainfall between 20 and 30 inches wherever the soil is in good condition of fertility, the lack of moisture is apt to be seriously felt. Moreover, as seen in our study of the origin of the soil and the relation of fertility to rainfall, the soils of dry countries are almost universally of a high degree of fertility, on account of the fact that the soluble salts which are available to crops have not been leached out, as has been the case in more humid countries. For these reasons, it is evident that the study of the water supply of crops and the management of the soil so as to make as large a portion of it as possible available to the plants, is a matter of the very greatest importance. The term "dry farming" is applied to agriculture in all sections where the moisture supply of growing crops is the problem of greatest importance.

Experience of practical farmers, extending over 40 to 50 years, and carefully-conducted experiments of 15 to 20 years' duration, indicate that profitable agriculture is entirely possible in any section having suitable soil when the annual rainfall is as great as 12 to 14 inches in the northern part of the United States, and 16 to 18 inches in the southern part.

The possibilities of agriculture where the rainfall is very low depend upon several important factors, among which may be mentioned the amount of water required by plants in their growth, the character of the precipitation, the water-holding capacity of the soil, the possibilities of preventing loss by evaporation, the conservation of rainfall, and the selection of those crops that are best adapted to such conditions.

371. Water Requirements of Plants. As we saw in Chapter I, all plants require seemingly large amounts of water during their growth. Experiments made in the humid countries of the eastern part of the United States and Europe indicate that from 250 to 600 pounds of water are evaporated in the growth of one pound of dry matter. The experiments of Widstoe in Utah and of others in the West indicate that a still larger amount is required in drier countries. Assuming that in the case of wheat 750 pounds of water are used in the growth of one pound of grain, a bushel would require 45,000 pounds, and if equal amounts of straw and grain are produced, the water requirement would be twice as great. While these figures seem large, if expressed in the form of inches of rainfall it will be found on calculation that a rainfall of one inch over an acre would be sufficient to produce 2½ bushels of wheat and an equal weight of straw, or a rainfall of 10 inches, if entirely used by the plant, would be sufficient for 25 bushels. The great problem of agriculture evidently is that of the conservation of the water received by the soils.

372. Distribution of Rainfall. The distribution of the rainfall during the year varies greatly in different parts of the country. On the Pacific Coast, the rainfall occurs chiefly in the winter months, while the summers are very dry. Over a large section just east of the Sierra Nevada region and including eastern Washington, Nevada, and Utah, there are comparatively heavy rains in April and May. Arizona, farther south in this same belt, has its heaviest rainfall in July and August. The northern Rocky Mountain district, Wyoming and Montana, receives its chief rainfall from April to June; while the states of the great plain country, including the Dakotas, Nebraska, Kansas, and Oklahoma, have their maximum rainfall a little later, from May till the middle of July.

373. Other Climatic Factors. Not only is the total rainfall throughout this great Western area low, but other climatic conditions lead to intense evaporation. The relative humidity (the ratio of the moisture actually held by the atmosphere to that which it can hold) is low as compared to that in more humid countries, so that evaporation is greatly increased. Moreover, the higher latitude and consequent lower barometer, the greater amount of sunshine, and the greater amount of wind, all tend to the same result. The evaporation from a free water surface in that section varies from 3 to as high as 15 times the rainfall, and this of course makes the conservation of the moisture in the soil all the more difficult.

374. Character of Soil. When the conservation of moisture in the soil becomes the all-important problem, the character of the soil must be studied from this point of view. Where soils are too sandy and water penetrates too deeply, comparatively little water can be held near enough to the surface to be of use to crops. On the other hand, a large portion of heavy showers runs off the surface of clay soils before having time to penetrate them. Soils of intermediate texture are therefore best adapted to dry farming. Organic matter, as we have seen, has great water-holding power, and as much as possible should be added to the soil, though the conditions in dry countries make it very difficult to collect humus in soils.

Another matter of importance is the uniformity of texture to a considerable depth, or rather the absence of layers of coarse sand or gravel, which would have the effect of draining off moisture from the surface soils and of preventing the capillary rise of water from below. In the West, soils having such layers of sand or gravel are commonly called *faulty* soils.

375. Conservation of Moisture. The proper management of the soil in dry farming requires, first, cultivation which will put it in condition to absorb as large an amount of the rainfall during the wet season as possible; and second, to prevent its escaping by evaporation during the dry and growing season. Deep fall-plowing, leaving the ground in a rough condition so that the melting snow and early spring rains will find their way downward at once rather than run off over the smooth surface, is advisable. The development of a dry mulch through which capillary moisture can rise only with the greatest difficulty, is the next step. For this purpose thorough disking as early as possible in the spring is practiced. If crops are to be sown, pulverizing tools must be used. Since evaporation is greatest when the soil is moist, it is necessary that cultivation to re-establish this mulch should follow quickly after each fall of rain. When crops are on the ground they should be cultivated to develop the mulch just as far as possible. Crops permitting intertillage have the advantage over the small grains, since they permit tillage practically throughout the growing season. Nevertheless, small grains can be harrowed until they are 6 or 8 inches high without serious injury. For this purpose a spike-toothed harrow with teeth set back and weighted when necessary to break the crust, should be used.

376. Deep and Thin Seeding. Since the seed must be in contact with moisture in order to germinate, it is necessary to plant it much deeper in a dry country than in a more humid one. Small grains should be drilled to a depth of 3 or 4 inches, or double that practiced in humid sections. It is also important that the seeding be thin, so that only as many plants develop as can be supplied with proper moisture for growth to maturity. One-half of the amount of seed used per acre in humid sections is usually found sufficient in countries where dry farming is practiced, and sometimes even less is desirable.

377. Summer-fallowing. On account of the fact that it is often possible to conserve a large amount of moisture in the soil throughout the dry season by thorough surface cultivation, a system of fallowing has been developed. In this system a field is carefully cultivated throughout one season without any crop whatever, the crop being grown the following year. In this way a large portion of the rainfall of two years is made available for a single crop. Wherever the rainfall is so small that it becomes a more valuable factor in crop production than simply the area of land, this system must receive attention. The cultivation of the soil during the fallow season involves some expense, but there is no expense for seed or harvest and there is a larger net profit in the growing of a good crop on a small area than of a lesser crop on a larger area.

378. Crops Available in Dry Farming. Two important factors must be considered in selecting crops for growth in a dry-farming district. First, as far as possible, they should be such as will make an early growth during the period of greatest rainfall and before the period of greatest evaporation has arrived; and second, they should be able to make most efficient use of moisture. Small grains, especially wheat, are the greatest crop of dry-farming countries, and these countries will in all probability produce the greatest proportion of wheat during coming generations. Suitable varieties of wheat have been developed through many generations in the old countries of low rainfall. Turkey wheat has in this way become especially suited to our needs. Rye is well adapted to such conditions, making its growth even earlier than wheat. Less attention has been given to the production of varieties of oats and barley, although these can be grown successfully. On account of the dry weather, barley is usually very bright and of good market quality.

All investigators agree that maize, or corn, is one of the most economical plants in its use of water. Moreover, it permits the intertillage so necessary for the conservation of moisture. Wherever temperature conditions are favorable, the growth of the varieties of corn suited to dry sections will be profitable. Milo maize is another plant even better adapted to withstand drought and to economize the supply of moisture. This has already become an important crop in many Southwestern states, yielding from 35 to 45 bushels of grain. Alfalfa, while like most other legumes requiring relatively large amounts of moisture, has certain features fitting it well for dry farming. Its very long taproot permits it to reach moisture at low depths of soil. The seeding should be very thin, so that only as many plants develop as can be well supported.

379. Results of Dry Farming. Although dry-farming methods have been practiced in several sections of our own country for from 40 to 50 years and in other countries for hundreds of years, there is still some uncertainty as to just how successful it will finally prove to be. The results of modern methods carefully followed in several sections of the West are certainly encouraging. Probably 2,000,000 acres of land in the Columbia River Basin are now in dry farms, and large quantities of wheat are being grown in sections which had for the last 2 or 3 years as low as 10 or 12 inches of rain. In the Great Basin area, including Utah, successful dry farming has been practiced for from 40 to 50 years in which wheat, corn, and other crops are grown. At the Canadian experiment station located at Indian Head, an average of 32.4 bushels of wheat per acre has been grown where the system of alternate summer fallowing and cropping has been practiced, and of 20.5 bushels where continuous cropping has been practiced. This station has had an average of 13 inches of rain annually during a period of 19 years.

LABORATORY EXPERIMENTS AND DEMONSTRATIONS

CHAPTER I

EXERCISE 1.

Object: To prove that seeds absorb moisture in germinating.

Material: Two beakers, seeds (beans, peas, or corn), and a germinating pan.

Method: Place 50 grams of seeds in each beaker. Cover the seeds in one beaker with water, and let stand over night. Note results. Place the soaked seeds in a germinating pan and set in a warm place. Note results.

EXERCISE 2.

Object: To prove that the absorption of water by the seed enables the seed to perform work.

Material: Stoppered bottle, seeds, copper wire.

Method: Fill the glass bottle with dry seeds, add water until the pore space is filled. Wire stopper on securely. Set the bottle away under a box or jar. Note results.

EXERCISE 3.

Object: To ascertain the effect of temperature on the germination of seeds.

Material: Two beakers, seeds, cold water, warm water, two 100 c. c. graduated cylinders, wire screen.

Method: Weigh out two 50-gram portions of seeds, placing one portion in a beaker containing 100 c. c. of cold water, and the other in a beaker containing 100 c. c. of warm water. At the end of one hour drain off the water from each beaker into the two cylinders, using the screen to hold the seeds. Note the number of cubic centimeters of water that have been absorbed. It is suggested that the student observe the rate of germination of seeds planted in a jar of soil, kept in a cool place, and compare with rate where the jar of soil is kept in a warm place.

EXERCISE 4.

Object: To ascertain the effect of soluble salts on the absorption of water by seeds.

Material: Seeds, saturated solution of common salt, pure water, two beakers, two 100 c. c. graduated cylinders.

Method: Follow method outlined in Exercise 3.

EXERCISE 5.

Object: To show the bad effect of an excessive application of soluble fertilizer salts on soils in which the seeds have just been planted.

Material: Three gallon-jars of poor soil, sodium nitrate (Chile saltpeter).

Method: Apply ½ gram of sodium nitrate to jar No. 1, 10 grams of sodium nitrate to jar No. 2, leaving jar No. 3 untreated. Mix the fertilizer thoroughly with the soil. Plant the same number of seeds in each jar. Water each jar, maintaining in each case favorable moisture and temperature conditions. Note results. Should soluble fertilizers be used in large quantities at any one time? An acre of ordinary soil to the depth of 8 inches weighs 2,000,000 pounds. Estimate the above rates of application on the basis of an acre application.

EXERCISE 6.

Object: To prove that oxygen is necessary for the germination of seeds.

Material: Stoppered bottle, freshly-boiled water, seeds.

Method: Place a small quantity of seeds in a bottle and fill completely with boiled water that has just been cooled. Stopper the bottle tightly. Note results. It is suggested that the student plant seeds in soils that are kept flooded with water, comparing results with those obtained where seeds receive a normal supply of water.

EXERCISE 7.

Object: To observe the effect of the depth of planting upon the germination of seeds.

Material: Large open-mouth bottle, or deep glass battery jar, sandy soil, seeds of corn, peas, and clover.

Method: Place a two-inch layer of moist soil in the bottom of the bottle jar or bottle. Plant the seeds near walls of the jar in order that their germination and growth may be observed. Now cover with two inches more of soil, and again plant seeds. Repeat. Plant the top layer of seeds about one inch deep. Keep the soil moist and warm. Do the large or small seeds germinate more readily in the deeper layers? Note results. Where fields are available, the above exercise may be given as a field exercise, planting corn and clover at different depths.

EXERCISE 8.

Object: To prove that the elements nitrogen, potassium, and phosphorus are necessary for the growth of plants—sand culture method.

Material: 5 1-gallon butter jars or battery jars, Ottawa silica sand, culture solutions, pure water, seeds.

Method: Preparation of culture solutions (the solutions used are those suggested in the Hopkins-Pettit Manual). Teachers should prepare the following solutions and place them in carefully-labeled bottles. Care should be taken to avoid contaminating one solution with another. A 25 c. c. graduated cylinder makes a convenient vessel for dispensing the solutions.

SOLUTION 1—containing nitrogen. Dissolve 80 grams of ammonium nitrate in 2500 c. c. of distilled water. Use 10 c. c. per pot.

SOLUTION 2—containing phosphorus. Dissolve 25 grams of monocalcium phosphate or 26 grams of disodium phosphate in 2500 c. c. of pure water. Use 10 c. c. per pot.

SOLUTION 3—containing potassium. Dissolve 50 grams potassium sulfate in 2500 c. c. of pure water. Use 10 c. c. per pot.

SOLUTION 4—containing magnesium. Dissolve 20 grams of magnesium sulfate in 2500 c. c. of pure water. Use 10 c. c. per pot.

Solution 5—containing iron. Dissolve 0.1 ferric chlorid in 250 c. c. of pure water. Use 1 c. c. per pot.

Only *pure* chemicals should be used in the preparation of these solutions.

Preparation of Pots. In order that the butter jars may have drainage, a small hole should be chipped through the bottom of the jar. Cover the hole with glass wool, or small pieces of clean gravel, or broken porcelain. Unless the sand used is very pure it should be washed thoroughly with dilute sulfuric acid (1 part of sulfuric acid in 10 parts of pure water). Wash out the acid with pure water until the washings no longer give an acid reaction with litmus paper. In order to insure that the sand contains no free acid, mix 10 grams of pure calcium carbonate with each jar. If the sand is not washed with acid, at least a gram of calcium carbonate should be added.

Arrange the five jars as follows:

No. 1. No plant food.
No. 2. Lacking nitrogen.
No. 3. Lacking phosphorus.
No. 4. Lacking potassium.
No. 5. Complete plant food ration.

Apply the culture solutions with about 1 liter of pure water. Make fresh applications of plant food every two weeks. Maintain the best moisture conditions by supplying pure water from time to time as needed. At the end of about 6 or 8 weeks, harvest the crop from each jar, dry, and compare the dry weights produced under the different methods of culture. Corn, barley, or rape may be easily grown in this manner. The jars should be placed in good light and protected as far as possible from dust.

EXERCISE 9.

Object: To prove that the elements nitrogen, potassium, and phosphorus are necessary for the growth of plants—water culture method.

Material: Detmer-Moor culture solutions, pint mason jars with flat corks to fit, black paper, cork borer, seeds.

Method: Preparation of solutions.

COMPLETE CULTURE SOLUTION:

600 c. c. distilled water,
7 grams potassium nitrate,
1.5 grams magnesium sulfate,
1.5 grams sodium chlorid,
1.5 neutral potassium phosphate,
Calcium sulfate in excess (add enough so that a small quantity will remain in suspension when the solution is shaken).

SOLUTION WITHOUT POTASSIUM:

600 c. c. distilled water,
7 grams calcium nitrate,
1.5 grams magnesium sulfate,
1.5 grams neutral sodium phosphate.

Before using the two above solutions, dilute with distilled water in the proportion of 1 part solution to 4.8 parts water.

SOLUTION WITHOUT NITROGEN:

May be prepared by substituting potassium sulfate for the potassium nitrate in the complete culture solution. Dilute the solution before use, as usual.

SOLUTION WITHOUT PHOSPHORUS:

1000 c. c. distilled water,
0.5 grams potassium nitrate,
0.5 grams calcium nitrate,
0.5 grams magnesium nitrate,
0.5 grams neutral potassium sulfate.
Do not dilute this solution before using.

Add a few drops of ferric chlorid solution to each culture solution prepared, that is, to each pint jar when the diluted culture solutions are prepared.

Germinate corn, barley, or wheat in clean sawdust or sand, letting them grow until, in the case of the corn, the root is about an inch and a half long or slightly longer, and the shoot is nearly an inch long. To prepare the culture bottles for the reception of the plant, fit them with perforated cork stoppers. The hole cut in the stopper should be of such size as to admit of the growth of a small corn stalk. The germinated corn seedling may be easily fastened to the cork by thrusting a pin through the softened seed. Smaller seeds may be held in place with a bit of cotton or asbestos. Grow one corn plant to a pint jar, or three or four grain plants. As soon as the germinated seedlings are removed from the sawdust, they should be washed clean with pure water, and immediately transferred to the culture bottles. The culture bottles should be filled with the solutions to within about ¼ of an inch of the cork. Wrap each bottle with black paper to exclude the light. In order that the roots may receive sufficient oxygen, each culture bottle should be fitted with a glass tube running to the bottom of the jar and having a right-angle bend at the top of the jar. Air should be bubbled through the solutions every four or five days. Instead of fitting the plants into corks, perforated disks of hardened paraffine may be floated on the surface of the solutions. The culture solutions should be put in a well-lighted place, but the solutions themselves should be protected from excessive heat. If necessary, the jars may be sunk in a box of moist sand. If the part of the plant passing through the cork is kept dry and carefully protected with clean cotton, there will be little trouble from an attack of molds.

EXERCISE 10.

Object: To determine the amount of water used by plants in a given time.

Material: Corn plants growing in good soil in 1-gallon butter jars, heavy paper, paraffin.

Method: As soon as the corn plants have reached a height of about 2 feet, cut a paper disk of such size as to exactly fit the top of the jar, fitting it down on to the soil. Place a small pasteboard ring around the corn plant. Now flood the tar paper with melted paraffin, being careful not to injure the plant with the warm paraffin. It is well to pack a little cotton inside the pasteboard ring that has been put around the corn plant. Now weigh the entire plant on a balance that is sensitive to at least a gram. Set in the light and again weigh the plant at intervals of half an hour to an hour, determining the rate of loss of water.

CHAPTER II

EXERCISE 11.

Object: To note the properties of the common minerals.

Material: Small pieces of crystals of quartz, feldspar, (orthoclase), horneblende, mica (both biotite and muscovite), calcite, gypsum, a jack knife, and dilute hydrochloric acid.

Method: COLOR: Which of the above mineral specimens are light colored? Consult sections 45 to 51 for the chemical composition of these minerals.

HARDNESS: Which of the specimens can you scratch with your finger-nail? With the knife? Which are harder than steel?

CLEAVAGE: Which of the specimens split readily in definite directions? Suppose some of these minerals occur in rocks that are exposed to the weather—what effect will this property of cleavage have upon the crumbling of the rock?

ACTION OF ACID: Apply dilute hydrochloric acid to each of the specimens, noting which are attacked and which are not attacked. What is the important acid in nature causing solution of the minerals in the rocks? Does it act rapidly or slowly?

EXERCISE 12.

Object: To study the properties of the important rocks.

Material: Small hand specimens of Igneous rocks: (1) granite (preferably a coarse-grained granite), (2) basalt, (3) schist; Sedimentary rocks: (4) conglomerate, (5) sandstone, (6) shale, (7) limestone; Metamorphic rocks: (8) gneiss, (9) quartzite, (10) slate, (11) marble, and (12) Residual soil from granite.

Method: Select specimens 1 to 7, inclusive. Referring to Exercise 11, what minerals can you readily distinguish in the granite? Can you distinguish definite minerals in the basalt? How are the mineral crystals arranged in the schist? In the granite? What is the principal difference between specimens 4, 5 and 6? What evidences of formation under water does the limestone show? What is the action of acid on specimens 4, 5, 6, and 7? How may a soil be formed from a sandstone or a shale? How will it differ in composition from the original rock? How does a well-weathered limestone soil differ from limestone?

Examine the residual soil from granite, using a small hand lens if available. What mineral occurring in the original granite is still found in the soil? Can you detect much feldspar in the residual granite soil? Examine specimens 1 and 3. What paths for the entrance of water do' these rocks offer? What happens when a water-soaked rock freezes? The minerals in granite, schist, etc., expand at different rates when heated. What effect will this property have upon the breaking up of the rocks? What mineral is the source of the clay in the residual granite soil?

Select specimens 8-11. In what respects do the following resemble each other? Differ from each other? Granite and gneiss? Sandstone and quartzite? Shale and slate? Limestone and marble? Will soils formed from metamorphic rocks differ greatly from soils derived from the original igneous or sedimentary rocks?

EXERCISE 13.

Object: To note the effect of weathering on rocks.

Material: Fresh limestone (powdered), partly weathered, or rotten limestone, residual limestone soil; dilute hydrochloric acid.

Method: Weigh out 25 gram portions of each of the above pulverized limestones, and of the soil. Place in beakers and add 100 c. c. of dilute hydrochloric acid, and allow to stand for one hour. Filter off the insoluble material on filter papers of known weight, wash with water, dry in oven, or over radiator, and weigh. Calculate the per cent of insoluble matter in each case and explain the results. What material in the limestone forms most of the residual soil?

CHAPTER III

EXERCISE 14.

Object: To compare the fertility of soils and their corresponding subsoils.

Material: Two 2-gallon butter jars, a soil, and its corresponding subsoil taken at a depth where there is a change of color, seeds.

Method: Plant corn or rape in the above soils and note the difference in growth. Is there necessarily any difference in the total amount of plant food present in the soil and the subsoil? Is the plant food in the subsoil in an available condition? Does the subsoil contain much of "the revolving fund of fertility?"

CHAPTER IV

EXERCISE 15.[1]

Object: To estimate the nitrogen supply in soils.

Method: From figures in the tables given in Sec. 110 estimate the number of four-year rotations of corn, oats, wheat, and clover, producing average crops, it would require to entirely exhaust the nitrogen of the soils, whose nitrogen content is given in Sec. 110, provided it should all become available. Assume that the clover is fed or plowed under so that a two-ton crop will return about 75 pounds of nitrogen to the soil. Compare, for example, the light-colored Wisconsin sand with the corn-belt soil of Illinois. How much more rapidly would the soil be exhausted if clover were omitted from the rotation and another year of wheat substituted?

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[1] Adapted in part from Hall.

EXERCISE 16.

Object: To trace the changes occurring in the nitrogen compounds in the soil.

Material: Graduate, 300 c. c. flasks, cotton wool, fresh field or garden soil, carbonate of lime, peptone, potassium phosphate, magnesium sulfate, sodium chloride, iron chloride, Nessler's solution, Trommsdorf's reagent, diphenylamine, dilute sulfuric acid, porcelain dish.

Method: Dissolve in a liter of water

2 grams of peptone
0.2 " " potassium phosphate
0.1 " " magnesium sulfate
0.1 " " common salt (sodium chloride)

and add a few drops of iron chloride solution. Place 100 c. c. portions of this solution in 300 c. c. flasks (or bottles that will stand heating) and plug the necks with cotton-wool. Sterilize these portions by placing the flasks in a steamer for an hour at the temperature of boiling water. In order to insure sterilization it is better to steam the flask again at the end of 24 hours. Now treat four of these flasks as follows:

No. 1.—Add nothing.

No. 2.—Add 1 gram of fresh moist field or garden soil.

No. 3.—Add 1 gram fresh soil and ½ gram of carbonate of lime (ground limestone).

No. 4.—Same as No. 3, but boil the contents of the flask vigorously on a sand bath for half an hour after adding the soil and lime carbonate. Repeat this boiling every day for three days to insure sterilization.

Now set the four flasks away in a warm, dark place, and examine at the end of about a week. The solution in No. 2 and especially in No. 3 will have a strong, putrid odor and will be cloudy from the large numbers of bacteria that have developed; the process of putrefaction is in full sway. There should be no change in the odor or appearance of flasks Nos. 1 and 4.

If the flasks are again set away in the dark for two or three weeks, the bad odors should disappear and be succeeded by a faint odor of ammonia. If a few drops from each flask (a small loop in the end of a piece of aluminum wire furnishes a convenient means of securing a drop) are placed in drops of Nessler's solution, the presence of ammonia may be recognized by the yellow or brownish-red coloration developed. Nessler's solution is easily prepared by any druggist, or may be cheaply purchased from a chemical supply house.

If the flasks are again set away for a few weeks, the ammonia will completely disappear. The time required for this to happen may be determined by testing the solutions with Nessler's reagent every three or four days. As the ammonia begins to disappear, the solution should be tested for nitrites with Trommsdorf's reagent. To test for nitrites, place 3 drops of Trommsdorf's reagent on a white porcelain dish. Add 1 drop of diluted sulfuric acid (1 part sulfuric acid and 3 parts of distilled water). Add a drop of the solution to be tested to the drop of the test solution. The presence of a blue color indicates nitrites.

Test the solutions for nitrites every three or four days until a blue reaction is no longer obtained. The solutions may now be tested for nitrates as follows: Place three drops of concentrated sulfuric acid on a white porcelain dish. Add a tiny crystal of diphenylamine. Now add a drop of the solution to be tested. If a blue color develops, nitrates are indicated. *Do not use this diphenylamine test until the nitrites have disappeared.*

The Trommsdorf reagent may be purchased very cheaply (Merck's, N. Y., ¼ lb. bottle for 35 cents), or may be prepared as follows: Rub up four grams of starch in water. Add slowly with constant stirring to a boiling solution of 20 grams of zinc chloride in 100 c. c. of distilled water. Heat until the starch is dissolved as much as possible and the solution is nearly clear. Then dilute with water, add 2 grams of zinc iodide, dilute to one liter, and filter. Keep in glass-stoppered bottles in the dark. Since this solution can be purchased very cheaply from any chemical firm, its preparation is not advised. An expenditure of about one dollar will provide all of the chemicals and apparatus necessary for this exercise. Because of the wonderful lesson that it teaches concerning the preparation of plant food by soil bacteria, teachers are urged to demonstrate this to their classes. This exercise may conveniently be expanded so as to note the behavior of different soils. Particular attention should be paid to the effect of the presence of lime carbonate.

EXERCISE 17.

Object: To study the solubility of the common nitrogen fertilizers.

Material: Samples of sodium nitrate (Chile saltpeter), ammonium sulfate, and blood meal; small funnels and filter paper.

Method: Place equal weights of each of the above fertilizers on filter papers that have been fitted to the funnels. (Pulverize to nearly equal fineness before testing.) Leach each sample with equal amounts of water. Which samples dissolve readily? Which sample is comparatively insoluble in water?

EXERCISE 18.

Object: To demonstrate the nitrogen-fixing power of legumes.

Material: 3 one-gallon jars, pure white sand, distilled water, alfalfa seed, mercury bichloride solution, nutrient solutions as in Exercise 8.

Method: Fill three common one-gallon butter jars with pure white sand. The silica sand supplied by the Ottawa Silica Company, of Ottawa, Ill., is a very pure as well as very cheap sand and is well suited for plant-culture experiments. Obtain a supply of pure distilled water. Now sterilize the sand in each of these jars by steaming about three hours on two successive days or by baking for several hours in an oven.

Select some bright alfalfa seeds that show no cracks in their seed coats. Immerse about 75 seeds in a solution of mercury bichloride (1 part mercury bichloride and 500 parts of water) for just 20 minutes. (*Caution*—Mercury bichloride is very poisonous.) Now immediately rinse the seeds thoroughly with the pure water. Sow 25 seeds in each jar. Apply to jar No. 1 a nutrient solution from which nitrogen has been omitted, and to jar No. 2 a complete nutrient solution including nitrogen. Treat jar No. 3 as follows: After sowing the seed and before covering with sand, apply to each seed two or three c. c. of an infusion of soil from a field where either alfalfa or sweet clover thrives. The soil infusion may be made by shaking up a good double handful of soil with a quart of water and letting stand about 24 hours; use the cloudy liquid that remains. After thus inoculating jar No. 3, cover the seeds and apply a nutrient solution which does not contain nitrogen. Handle the jars as little as possible after they are prepared so that 1 and 2 will not become inoculated. Set the jars in good light, but away from the dust. A small hole should be chipped in the bottom of each jar in order to afford drainage. About 1 quart of water to a gallon of Ottawa sand maintains nearly optimum water supply.

EXERCISE 19.

Object: To become familiar with the appearances and properties of the different forms of lime used on soils.

Material: Dilute hydrochloric acid (1 part concentrated acid plus 5 parts water), clear limewater, test tube fitted with stopper and delivery tube, and suitable dishes or test tubes for making the required tests, samples of limestone rock, sea shells or clam shells, ground limestone, fresh quick lime, air slaked lime, marl, rock phosphate, and calcium sulfate (gypsum, or land plaster).

Method: PART A. Apply dilute hydrochloric acid to each of the above named materials. Note the bubbling that occurs in some cases. Place a small quantity of the material in the test tube having a delivery tube fitted to it and run some of the gas into clear limewater. The white precipitate proves that the gas is carbon dioxid. Do all of the above substances evolve CO^2?

PART B. Note the appearance of fresh quick lime. Slack a lump of this lime, about the size of a hen's egg. Add the water, a little at a time, until the lump falls apart into a powder. Compare the volume of the fresh lime and of the slaked lime. Add a spoonful of this water-slaked lime to a cup of water and insert a strip of red litmus paper. What is the effect of limewater on red litmus? Apply a spoonful of slaked lime to a cupful of acid soil, mix well, and let stand several hours, at the end of which period test again for acidity. Repeat this part of the experiment, using ground limestone instead of slaked lime, letting the soil and limestone remain in contact for several weeks before testing for acidity.

EXERCISE 20.

Object: To ascertain the fineness of grinding of a sample of ground limestone.

Material: Several samples of ground limestone and an 80-mesh sieve.

Method: Follow method described in Exercise 23.

CHAPTER V

EXERCISE 21.

Object: To study the solubility of the common potassium fertilizers.

Material: Samples of kainit, muriate of potash (potassium chloride) and sulfate of potash (potassium sulfate), wood ashes.

Method: Follow method outlined under Exercise 17. Refer to Sec. 160, and learn the percentage of potassium in each of the above-named fertilizers. Why are leached ashes a poor source of potassium? What is the per cent of potassium in orthoclase feldspar? Why is ground feldspar of little value as a fertilizer?

EXERCISE 22.

Object: To study the solubility of phosphate fertilizers.

Material: Samples of acid phosphate, steamed bone meal (or raw bone meal), and rock phosphate (floats), funnels, and filter paper.

Method: Follow method outlined under Exercise 17.

EXERCISE 23.

Object: To ascertain the fineness of grinding of raw rock phosphate.

Material: Samples of raw rock phosphate from several different sources; 100-mesh sieve.

Method: Weigh out 50 gram portions of each of the samples obtained. Sift through a hundred-mesh sieve, weighing the portion that passes, or that which is held. Determine percentage passed? Held? What is the importance of fineness of grinding?

CHAPTER VI

EXERCISE 24.

Object: To study the method of sampling soils.

Material: Soil auger or King soil tube; cloth or paper sacks, or tin cans.

Method: By means of the soil auger or tube obtain samples of typical soils on the home farm or in your community. Take five cores from each field, calling the first eight inches the surface sample, the second 8 inches the subsurface sample and the third 8 inches the subsoil sample. Examine the character of the deeper subsoil to the depth of at least 4 feet. The fresh field samples thus obtained may be used in some of the following exercises.

EXERCISE 25.

Object: To practice the preparation of soil samples.

Material: Fresh soil samples obtained in the previous exercise, mortar and pestle or wooden roller, twenty-mesh sieve, mixing cloth, and tin can or glass jar for storing sample.

Method: Air dry the fresh samples. Pulverize the dried samples in the mortar, or with the wooden roller, sift through the twenty-mesh sieve, rejecting the gravel that will not pass the sieve. Mix the sifted sample thoroughly by rolling back and forth on the mixing cloth. Store the sample in cans for future use.

EXERCISE 26.

Object: To test soils for acidity.

Material: Acid and non-acid sandy soils, clay loam soils, and peat soils from stock samples, and samples of soil from each student's home farm, sensitive blue litmus paper, clean dishes, and a number of clean sticks for mixing wet soils.

Method: Place about a handful of one of the above soils in a clean dish, moisten with enough pure water to make slightly sticky, mix well with a clean stick, and separate into two portions. Now place a piece of blue litmus paper on one portion of the soil, and cover with the other portion. Allow the soil and litmus to remain in contact for 5 minutes, and then remove the paper. An entire reddening of the part of the paper in contact with the soil, or the appearance of red spots indicates acidity. Test each sample in the same manner.

CHAPTER VII

EXERCISE 27.

Object: To determine the fertility requirements of some soil known to be infertile.

Method: Follow the directions outlined in Sec. 185. What fertilizer treatment would you recommend for the soil? Give amounts and cost per acre of the fertilizers that you would apply.

EXERCISE 28.

Object: To determine the per cent of water-soluble salts in an "alkali" soil.

Material: Alkali soil, quart Mason jar, funnel, filter paper, pure water, sand bath. The "alkali" soil is an example of the kind of soil that may develop in a region of very little rainfall.

Method: Place 50 grams of an oven-dry alkali soil in a quart Mason jar. Add 500 c. c. of pure water. Cover tightly. Shake vigorously for three minutes and let stand; most of the soil settles. Filter the solution through filter paper until clear. Evaporate 250 c. c. of the filtrate in a weighed dish, adding portions of the 250 c. c. as the solution evaporates. Finally dry the residue remaining after evaporation in a hot air oven at 105° C. for one hour. Cool and weigh. Express the amount of soluble salts as per cent of the oven-dry weight.

CHAPTER IX

EXERCISE 29.

Object: To make a mechanical analysis of a soil.

Material: An 8-ounce sterilizer bottle or a small bottle of similar size and shape, cork or rubber stoppers to fit, a 5/10 millimeter round hole sieve that may be placed on a large glass or tin funnel, soft water, rubber-tipped glass stirring rod, three 250 c. c. beakers, four 600 c. c. beakers numbered 1, 2, 3, and 4, 5, 6, 7, respectively.

The smaller beakers should be of such size that two of them filled up to a certain height (5 centimeters) contain together enough to fill those of larger size to about the same height. Water columns of uniform length should be used throughout the operation. A chemist's wash bottle or "Spritz" bottle should be provided.

Method: Weigh out a 10-gram sample of soil, place in drying oven, dry to constant weight, weigh and record dry weight of the same. Place the dried sample of soil in the bottle, add about 60 c. c. of water and 2 c. c. of strong ammonia water, stopper and shake vigorously for 3 minutes at a time at intervals of a half hour for about 6 hours (if a mechanical shaking device is available it is much better to place the soil bottle in this and shake for a period of at least 24 hours).

REMOVING THE COARSE SAND. By means of the wash bottle, wash soil on to the 5/10 millimeter round hole sieve, held in a large funnel, collecting the wash water in beaker No. 1. Wash until only coarse sand is held on the sieve. If more than enough water to fill beaker No. 1 to the 5 centimeter mark is used, an extra beaker may be used and the liquid collected in it used for filling beaker No. 1 up to the mark as directed in the next paragraph.

REMOVING THE MEDIUM SAND. Beaker No. 1 is filled to the 5 centimeter mark. With the rubber-tipped glass stirring rod, stir crosswise of the beaker to bring all particles into suspension without causing a rotary motion. Record time when stirring ceases and hold the rod in the liquid for a few seconds to check movements which may exist there. Remove the rod and at the end of *one minute* pour the water quickly, but steadily, into No. 2. At the end of the next minute pour the liquid from No. 2 into No. 3 and return sediment to No. 1. Fill No. 1 up to the mark (use either the wash water obtained from washing the sand on the screen, or pure water), stir and allow to stand for one minute and then pour the liquid into No. 2, which is now empty. The sediment in beaker No. 1 is *medium sand.* It should be washed into a small evaporating dish, dried and weighed.

REMOVING THE FINE SAND. Stir the material in No. 2 and 3 and allow to stand for *5 minutes*, when the liquid from both is poured into No. 4 (the 600 c. c. beaker), where it is allowed to stand for 5 minutes and then poured into No. 5. In the meantime fill No. 2 and No. 3 up to the mark, stir, and allow to stand for 5 minutes, and pour both into No. 6. Collect the sediment in Nos. 2, 3, and 4, wash out into a small evaporating dish, evaporate to dryness, dry in the oven, and weigh as *fine sand.*

REMOVING VERY FINE SAND AND COARSE SILT. Stir the liquid in No. 6 and No. 5, and at the end of a 20-minute sedimentation period, pour the liquid from No. 6 into No. 7 and from No. 5 into No. 4. Fill No. 5 and No. 6 up to the mark and allow the four beakers to stand 20 minutes, when the muddy liquid from them all is rejected. Collect the sediment in Nos. 4, 5, 6, and 7, dry and weigh as before.

DETERMINING THE WEIGHT OF FINE SILT AND CLAY. The fine silt and clay are the materials still held in suspension after 20 minutes of settling and have been rejected in the process just described. The difference between the dry weight of the soil with which you started and the sum of the weights of the first four separates will give you the weight of the fine silt and clay.

It is suggested that some of the students in the class make mechanical analyses of sandy soils and that others use silt loam or clay loam soils.

EXERCISE 30.

Object: To show the effect of puddling on the structure of soils.

Material: Two small boxes or tin pans that will each hold about a pint of soil, dry clay soil.

Method: To pan No. 1 add water until the soil is slightly moist, but do not stir or work the soil in any way. To pan No. 2 add enough water to make the clay sticky, mix thoroughly with a stick, now place both pans in the sun to dry and note results.

EXERCISE 31.

Object: To show the effect of freezing and thawing upon soil structure.

Material: Clay soil and mixing board.

Method: Take a big hand full of clay, wet it, mix it well, and mould it into a ball with the hands. Prepare a second ball of clay in the same manner, adding the same quantity of water to an equal weight of clay. Expose the second ball of clay to alternate freezing and thawing about 10 times, but keep the first ball in a frozen condition. At the end of a week or ten days allow both balls of clay to thaw out. Compare their structures.

EXERCISE 32.

Object: To show the effect of film water in holding soil grains together.

Material: Common plasterers' sand, water, clay.

Method: In a shallow pan, place about half an inch of water, pour a heap of sand in the center of the pan. Note the capillary rise of water. Do the sand grains roll down the sides of the cone of sand as easily when they are moist as when they are dry? Repeat the exercise, using a heap of finely-powdered clay instead of the sand. In which soil does the film water seem to exercise the greatest holding power?

EXERCISE 33.

Object: To make a comparative study of some important soil types. This exercise may be confined to the soils listed below or may be used in a study of the typical soils of the locality.

Material: Gallon jar samples of a sandy soil, clay loam soil, heavy clay soil, and some humus soils (peat or muck), four 6-inch test tubes about half an inch in diameter fitted with stoppers, glass plate, hand lens, blue litmus paper, cups or small boxes for taking samples, cups or small boxes of soil for the individual students.

Method: 1. Note color of each of the samples when dry; when moist.

2. Spread small samples of each of the soils on the glass plate and examine with the hand lens. In which of the soils are the grains well coated with humus? Can you detect undecomposed fragments of minerals? What is the most common mineral easily detected in the coarser textured soils? Note the arrangement of the soil grains in groups.

3. Rub up small quantities of the samples in your hands. Which have a gritty feeling? Which a velvety feeling? What is the effect of the fine and of the coarse soil particles on the movement of air and water through the soil?
4. Wet equal parts of the different soils with equal amounts of water. Stir them well and compare as to stickiness. What factors seem to cause the stickiness of a soil?
5. Test the reaction of each sample with blue litmus paper.
6. Place equal weights (about 10 grams) of each of the soils in the respective test tubes, add water until the test tubes are half full. Shake the four tubes vigorously, and allow the soil to settle. Compare the rate of settling. Which soils contain the higher proportion of fine grains? Of coarse grains?

CHAPTER X

EXERCISE 34.

Object: To observe the factors influencing the rate of the capillary rise of water in soils.

Material: Six 30-inch glass tubes about an inch in diameter, rack for holding the same, cheese cloth, pan for water, 30-inch rule; prepared samples of 20-, 40-, 60-, and 80-mesh sand, set of sieves, clay loam soil, coarse peat or chopped straw. 20-mesh sand is sand that has passed a 20-mesh sieve, and is held on a 40-mesh sieve after all finer particles have been sifted out. 40-mesh sand is sand that has passed a 40-mesh sieve and is held on a 60-mesh sieve after the finer particles have been sifted out. 60-mesh is sand passing a 60-mesh sieve and held on an 80-mesh sieve. 80-mesh is sand passing an 80-mesh sieve and held on a 100-mesh sieve.

Method: Cover one end of each of the glass tubes with cheese cloth, tying the cloth securely over about one-half of the lower end of the tube. From the prepared samples of sand and clay loam soils, fill the glass tubes, compacting, after adding 6 inches of soil or sand, by letting drop twice through the distance of two inches on to a book. Fill two tubes with clay loam soil, placing an inch layer of coarse peat or chopped straw about 6 inches from the bottom in one of the clay loam tubes. Now place the tubes in the rack with covered ends in a dry pan. Add water to the pan. Note the time, and begin immediately to record the rise in each tube as indicated in the following:

Kind of soil	Height of moisture at end of					
	5 min.	15 min.	30 min.	1 hr.	2 hrs.	24 hrs.
20-mesh sand.						
40-mesh sand.						
60-mesh sand.						
80-mesh sand.						
Clay loam.						
Clay loam with layer of peat. . . .						

EXERCISE 35.

Object: To determine the total moisture in field soils.

Material: Soil auger, covered tin boxes, a balance that is sensitive to a gram, a drying oven.

Method: The following exercise should be performed in the late spring or early fall when crops are growing on the soil. If the exercise is performed in the spring, soil samples from different fields on a soil of uniform texture may be taken as follows:

1. Sod land.
2. Field plowed early in the spring.

3. Field plowed early in the spring and kept tilled.
4. Land bearing a vigorous growth of some crop.

Take samples with the soil auger down to a depth of at least 3 feet, sampling the following depths separately: 0" to 8", 8" to 16", 16" to 24", and 24" to 36". If an extension auger is available the student should examine the soil down to greater depths so as to determine, if possible, the location of the temporary water table. Take composite samples of about 3 cores from each plot. Cover the sample boxes as the samples are obtained, bring them to the laboratory, weigh, place the covers on the bottoms of the cans, and dry in the oven to constant weight.

Expressing the Moisture Content of Soils. The amount of water in a soil in any given time may be expressed as percentage of the dry weight, as percentage of the moist weight, as cubic inches per cubic foot, etc.

In determining the ability of soils to hold water it is usual to express the amount of water that they contain at any one time as a percentage of the dry weight.

EXERCISE 36.

Object: To determine the water-holding capacity of soils.

Material: 5 brass cylinders with perforated bottoms (cylinders 1 foot long and 2 inches in diameter), a 3-gallon jar or tank of water, and samples of the following soils that have been pulverized and sifted through a 20-mesh sieve:

(1) Very sandy soil,
(2) A mixture of 4 parts very sandy soil and 1 part peat,
(3) Light-colored clay loam,
(4) Black clay loam,
(5) Clay.

(Instead of the brass cylinders tin cans with the bottoms perforated with small holes may be used—a 1-pound baking powder can is a convenient size and shape), disks of cheese cloth to fit bottoms of cylinders, or cans, and a balance sensitive to 1 gram and capable of weighing several thousand grams.

Method: Fit a cloth disk in the bottom of each cylinder, or can, weigh and record the weights in a neat tabular form. Fill the cylinders, or cans, with the above soils to within one-half inch of the top, compacting each cylinder, or can, by dropping them through a distance of 2 inches on to a book. Compact all equally. Weigh, place in tank of water of such depth that the water on the outside of the cylinders, or cans, rises to the same height as the soil in them. If tin cans are used, coarse screen should be put in the bottom of the tank so as to permit ready movement of water into the bottoms of the cylinders.

Let stand until free moisture appears on the surface of the soil, noting the time required for the water to reach the surface of each of the soils. Remove from the tank, catching all drip water in a tin cup and weigh immediately. Estimate the maximum amount of water in the soil when all the pore space is filled, basing your percentages on the dry weight of the soil. Now place the cylinders or cans on a draining board under an inverted stone jar and allow to stand at least one week or until no more water drains away. Estimate the amount of water held against gravity, that is, the maximum amount of capillary water retained by the different soils. Express percentages as above.

It is suggested that the above exercise be repeated, filling the cylinders without compacting them so as to determine the effect of increasing the pore space on the water-holding capacity of soils.

EXERCISE 37.

Object: To show the rate of percolation of water through fine textured and coarse textured soils.

Material: A very fine sand, a coarse sand, 2 funnels, or percolators (an ordinary long-necked bottle that has had its bottom cut off makes a good percolator) and 2 two-quart bottles, racks or clamps for holding the apparatus in place.

Method: Place the samples of each of the sands in the respective percolators, filling them to a height of about 6 inches. Invert over each funnel a bottleful of water, arranging the bottles so that an equal head of water will be maintained over the top of the sand in each percolator. As soon as the water is running steadily through the sands, place beakers under each percolator and note the time. At the end of a given time remove the beakers and measure the quantity of water in a 100 c. c. graduate. Calculate the rate of flow of water in cubic centimeters per second. What is the influence of the size of the soil grains on the amount of percolating water? Is leaching a more important problem on coarse grained or fine grained soil?

EXERCISE 38.

Object: To compare the availability of water to plants in sandy soil, clay loam soil, and humus soil.

Material: 3 1-gallon butter jars filled with the respective soils, soil boxes for moisture determinations, and drying oven.

Method: Plant corn in each of the above jars and allow to grow until it is about a foot high, keeping the soils well cultivated and well watered. Now stop watering the plants and note the number of days that elapse before the plants in each jar begin to wilt. As soon as the corn is well wilted in each jar, turn out the soil on to a large paper, mix thoroughly and weigh out 200-gram samples for moisture determinations. Treat all soils in the same manner as soon as the plants wilt. Compare the amount of water still left in the different soils.

CHAPTER XI

EXERCISE 39.

Object: To note the effect of color, drainage, and slope on soil temperature.

Material: 6 wooden boxes about 1 foot square and 4 inches deep, sandy loam soil, lamp black, slaked lime or some other white powder, and soil thermometers. The soil thermometers should be graduated on the Fahrenheit scale to about 130 degrees. About 6 to 8 inches of the mercury column above the bulb should be ungraduated so that there is enough room to thrust the thermometer into the soil and still read the temperature.

Method: EFFECT OF COLOR. Fill two of the boxes with the soil and compact similarly by dropping from a height of 2 inches. Cover one box of soil with a thin layer of lamp black and the other with a layer of slaked lime or other white powder. Insert the bulb of a soil thermometer to a depth of 1½ inches into each box and expose the boxes to the rays of the sun. Take readings of the thermometers every 10 minutes for 2 hours. Tabulate results.

EFFECT OF SLOPE. Fill two more boxes with soil as above, omitting the black and white materials. Expose the boxes to the sun so that one makes an angle of 10 degrees toward the sun and the other an angle of 10 degrees away from the sun. Take readings as above.

EFFECT OF DRAINAGE. Fill two wooden boxes as above, one of which is lined with tin so that it is waterproof. Add water to the soil in the box not lined until the water begins to drain away. Add the same quantity of water to the other box. Let stand until the water in the unlined box has largely drained away, and then take temperature readings as above.

CHAPTER XV

EXERCISE 40.

Object: To determine the relative amounts of organic matter in typical soils.

Material: Four small porcelain evaporating dishes or crucibles (the cheaper iron crucibles may be used), burners, poor sandy soil, black clay loam soil, light colored clay loam soil, and a peat or muck soil, drying oven.

Method: Weigh out 5 grams of each of the above air-dried soils into the dishes or crucibles provided. If a sensitive balance is not available, use larger quantities of soil. Dry the samples in the drying oven at about 105° C., in order to remove the hygroscopic moisture. After drying, cool, weigh and express the loss of water as a percentage of the oven-dry weight. You have determined the hygroscopic capacity of the several soils. Now burn the samples until all black color has disappeared. Cool and weigh. Express the loss of volatile matter as percentage of the oven-dry weight.

EXERCISE 41.

Object: To show the effect of an alkaline solution on soil organic matter, that is, to make a humus extract.

Material: 1 per cent hydrochloric acid (8 c. c. concentrated hydrochloric acid, specific gravity 1.20, and 392 c. c. of water), 4 per cent ammonia solution (80 c. c. concentrated ammonia hydroxide, specific gravitv .90, and 420 c. c. water), large funnel, filter paper, beakers, filter stand, two small pieces of glass—plate or window glass, and a hand lens.

Method: PART A. Place 20 grams of a clay loam soil on the filter paper in the funnel and wash the soil well with the 1 per cent acid solution. The washings may be tested for calcium by making a mechanical filtering and testing the filtrate with ammonium oxalate. A white precipitate indicates calcium. After the soil has been washed with acid, wash free of acid with pure water. Now extract the soil with 4 per cent ammonia solution, washing until the washings come through nearly colorless. The dark colored extract obtained is the "humus solution."

PART B. Place a tiny amount of the extracted soil on one piece of glass and a similar amount of unextracted soil on the other piece of glass. Spread them out thinly and examine with the hand lens. noting differences. Does ammonia extraction obtain all of the organic matter in a soil?

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