SOILS AND FERTILIZERS

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SOILS AND FERTILIZERS

BY

HARRY SNYDER, B.S.

PROFESSOR OF AGRICULTURAL CHEMISTRY AND SOILS
UNIVERSITY OF MINNESOTA

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PREFACE TO THIRD EDITION

This work is the outgrowth of instruction given at the University of Minnesota to young men who intend to become farmers and who desire information that will be of assistance to them in their profession. At first mimeographed notes were prepared, which were later published under the title "The Chemistry of Soils and Fertilizers." This was revised, enlarged, and published as "Soils and Fertilizers." With the extension of various lines of investigation relating to soils, a second revision and enlargement of the book has become necessary. It is the aim to present in condensed form the principles of the various sciences, particularly chemistry, which have a bearing upon the economic production of crops and the conservation of the soil's fertility. The work as now presented includes all the topics and the laboratory experiments relating to soils, as outlined by the Committee on Methods of Teaching Agriculture, of the Association of Agricultural Colleges and Experiment Stations.

HARRY SNYDER.

University of Minnesota,
College of Agriculture,
St. Anthony Park, Minnesota,
March 1, 1908.

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SOILS AND FERTILIZERS

INTRODUCTION

Prior to 1800 but little was known of the sources and importance of plant food. Manures had been used from the earliest times, and their value was recognized, although the fundamental principles underlying their use were not understood. It was believed they acted in some mysterious way. The alchemists had advanced various views regarding them; one was that the so-called "spirits" left the decaying manure and entered the plant, producing more vigorous growth. As evidence, the worthless character of leached manure was cited. It was thought the spirits had left such manure. The terms 'spirits of hartshorn,' 'spirits of niter,' 'spirits of turpentine,' and many others reflect these ideas regarding the composition of matter.

The alchemists held that one substance, as copper, could be changed to another substance, as gold. Plants were supposed to be water transmuted in some mysterious way directly into plant tissue. Van Helmont, in the seventeenth century, attempted to prove this. "He took a large earthen vessel and filled it with 200 pounds of dried earth. In it he planted a willow weighing 5 pounds, which he duly watered with rain and distilled water. After five years he pulled up the willow and it now weighed 169 pounds and 3 ounces."[1] He concluded that 164 pounds of roots, bark, leaves, and branches had been produced by direct transmutation of the water.

It is evident from the preceding example that anything like an adequate idea of the growth and composition of plant bodies could not be gained until the composition of air and water was established.

The discovery of oxygen by Priestley in 1774, of the composition of water by Cavendish in 1781, and of the rôle which carbon dioxide plays in plant and animal life by De Saussure and others in 1800, formed the nucleus of our present knowledge regarding the sources of matter stored up in plants. It was between 1760 and 1800 that alchemy lost its grip because of advances in knowledge and the way was opened for the development of modern chemistry.

De Saussure's "Recherches sur la Végétation," published in 1804, was the first systematic work showing the sources of the compounds stored up in plant bodies. He demonstrated, quantitatively, that the increase in the amount of carbon, hydrogen, and oxygen, when plants were exposed to sunlight, was at the expense of the carbon dioxide of the air, and of the water of the soil. He also maintained that the mineral elements derived from the soil were essential for plant growth, and gave the results of the analyses of many plant ashes. He believed that the nitrogen of the soil was the main source of the nitrogen found in plants. These views have since been verified by many investigators, and are substantially those held at the present time regarding the fundamental principles of plant growth. They were not, however, accepted as conclusive at the time, and it was not until nearly a half-century later, when Boussingault, Liebig, and others repeated the investigations of De Saussure, that they were finally accepted by chemists and botanists.

From the time of De Saussure to 1835, scientific experiments relating to plant growth were not actively prosecuted, but the facts which had accumulated were studied, and attempts were made to apply the results to actual practice. Among the first to see the relation between chemistry and agriculture was Sir Humphry Davy. In 1813 he published his "Essentials of Agricultural Chemistry," which treated of the composition of air, soil, manures, and plants, and of the influence of light and heat upon plant growth. About this period, Thaer published an important work entitled "Principes Raisonnes d'Agriculture." He believed humus determined the fertility of the soil, that plants obtained their food mainly from humus, and that the carbon compounds of plants were produced from the organic carbon compounds of the soil. This gave rise to the so-called humus theory, which was later shown to be an inadequate idea regarding the source of plant food, and for a time it prevented the actual value of humus as a factor of soil fertility from being recognized. The writings of Thaer were of a most practical nature, and they did much to stimulate later investigations.

About 1830 there was renewed interest in scientific investigations relating to agriculture. At this time Boussingault, a French investigator, became actively engaged in agricultural research. He was the first to have a chemical laboratory upon a farm and to make practical investigations in connection with agriculture. This marks the establishment of the first agricultural experiment station. Boussingault's work upon the assimilation of the free nitrogen of the air is reviewed in Chapter IV. His study of the rotation of crops was a valuable contribution to agricultural science. He discovered many important facts relating to the chemical characteristics of foods, and was the first to make a comparison as to the amount of nitrogen in different kinds of foods and to determine their value on the basis of the nitrogen content. His study of the production of saltpeter did much to prepare the way for later work on nitrification. The investigations of Boussingault covered a variety of subjects relating to plant growth. He repeated and verified much of the earlier work of De Saussure, and also secured many additional facts regarding the chemistry of growth. As to the source of nitrogen in crops, he states: "The soil furnishes the crops with mineral alkaline substances, provides them with nitrogen, by ammonia and by nitrates, which are formed in the soil at the expense of the nitrogenous matter contained in diluvium, which is the basis of vegetable earth; compounds in which nitrogen exists in stable combination, only becoming fertilizing by the effect of time." As to the absorption of the gaseous nitrogen of the air by vegetable earth, he says: "I am not acquainted with a single irreproachable observation that establishes it; not only does the earth not absorb gaseous nitrogen, but it gives it off."[2]

The investigations of DeSaussure and Boussingault, and the writings of Davy, Thaer, Sprengel, and Schübler prepared the way for the work and writings of Liebig. In 1840 he published "Organic Chemistry in its Applications to Agriculture and Physiology." Liebig's agricultural investigations were preceded by many valuable discoveries in organic chemistry, which he applied directly in his interpretations of agricultural problems. His writings were of a forceful character and were extremely argumentative. They provoked, as he intended, vigorous discussions upon agricultural problems. He assailed the humus theory of Thaer, and showed that humus was not an adequate source of the plant's carbon. In the first edition of his work he noted that farms from which certain products were sold became less productive, because of the loss of nitrogen. In a second edition he considered that the combined nitrogen of the air was sufficient for crop production. He overestimated the amount of ammonia in the air, and underestimated the value of the nitrogen in soils and manures.

A study of the composition of ash of plants led him to propose the mineral theory of plant nutrition. De Saussure had shown that plants contain certain mineral elements, but he did not emphasize their importance as plant food. Liebig's writings on the composition of plant ash, and his emphasizing the importance of supplying crops with mineral food, led to the commercial preparation of manures, which in later years developed into the commercial fertilizer industry. The work of Liebig was not conducted in connection with field experiments. It had, however, a most stimulating influence upon investigations in agricultural chemistry, and to him we owe, in a great degree, the summarizing of previous disconnected work and the mapping out of valuable lines for future investigations.

Liebig's enthusiasm for agricultural investigations may be judged from the following extract: "I shall be happy if I succeed in attracting the attention of men of science to subjects which so well merit to engage their talents and energies. *Perfect agriculture is the true foundation of trade and industry; it is the foundation of the riches of states.* But a rational system of agriculture cannot be formed without the application of scientific principles, for such a system must be based on an exact acquaintance with the means of nutrition of vegetables, and with the influence of soils, and actions of manures upon them. This knowledge we must seek from chemistry, which teaches the mode of investigating the composition and of the study of the character of the different substances from which plants derive their nourishment." [3]

Soon after Liebig's first work appeared, the investigations at Rothamsted by Sir J. B. Lawes were undertaken. The most extensive systematic work in both field experiments and laboratory investigations ever conducted has been carried on by Lawes and Gilbert at Rothamsted, Eng. Dr. Gilbert had previously been a pupil of Liebig, and his becoming associated with Sir J. B. Lawes marks the establishment of the second experiment station. Many of the Rothamsted experiments have been continued since 1844, and results of the greatest value to agriculture have been obtained. The investigations on the non-assimilation of atmospheric nitrogen by crops, published in 1861, were accepted as conclusive evidence upon this much-vexed question. Their work on manures, nitrification, the nitrogen supply of crops, and the increase and decrease of the nitrogen of the soil when different crops are produced, has had a most important bearing upon maintaining the fertility of soils.

" The general plan of the field experiments has been to grow some of the most important crops of rotation, each separately, for many years in succession on the same land, without manure, with farmyard manure, and with a great variety of chemical manures, the same kind of manure being, as a rule, applied year after year on the same plot. Experiments with different manures on the mixed herbage of permanent grass land, on the effects of fallow, and on the actual course of rotation without manure, and with different manures have likewise been made."[4]

In addition to Davy, Thaer, De Saussure, Boussingault, Liebig, and Lawes and Gilbert, a great many others have contributed to our knowledge of the properties of soils. The work of Pasteur, while it did not directly relate to soils, indirectly had great influence upon soil investigations. His researches upon fermentation made it possible for Schlösing to prove that nitrification is the result of the workings of living organisms. These have since been isolated and studied by Warington and Winogradsky.

The importance of the physical condition of the soil and its relation to crop production was recognized by agriculturists at about the same time that the sources of plant food were being investigated. Jethro Tull published in 1829 a work entitled "The Horse-Hoeing Husbandry," which emphasized the importance of thorough cultivation of the soil. That increase in the yield of crops, destruction of weeds, reduction of rust and blight of wheat, and general improvement of the soil, are all results of improved tillage is clearly set forth in Tull's work. Tull was inclined to believe that tillage could take the place of manure. "All sorts of dung and compost contain some matter which, when mixed with the soil, ferments therein; and by such ferment dissolves, crumbles, and divides the earth very much. This is the chief and almost only use of dung."

While underestimating the value of manure, he has shown the importance of thorough tillage of the soil more clearly than had ever been done before. "The Horse-Hoeing Husbandry" by Jethro Tull is worthy of careful study by all agricultural students.

During recent years the agricultural experiment stations of this and other countries have made soils a prominent feature of their work. Some of the results obtained are noted in the following chapters. Our knowledge regarding the chemistry, physics, geology, and bacteriology of soils is still far from complete, but many facts have been discovered which are of the greatest value to the practical farmer. The literature relating to soils and fertilizers has become very extensive, and in the classification of agricultural subjects for study, the soil forms one of the main divisions of agronomy.

In soil investigations it has frequently happened, owing to imperfect interpretation of results and to the presence of many modifying influences, that the conclusions of one investigator appear to be directly contradictory to those of another. This is well illustrated in the investigations relating to the assimilation of free atmospheric nitrogen, where seemingly opposite conclusions now form a complete theory.

A scientific study of soils is valuable from an educational point of view, as well as because the practical knowledge obtained can be utilized in the production of crops. In the cultivation of soils, complicated physical, bacteriological, and chemical changes occur, many of which are only imperfectly understood. The fundamental principles of soil fertility are, however, reasonably well established, and it is now possible to intelligently conserve the fertility of soils and to produce maximum yields of crops. Since the soil wealth is the greatest and the most important form of wealth of a nation, intelligent effort should be made for its conservation and development.

CHAPTER I

PHYSICAL PROPERTIES OF SOILS

1. Soil. — Soil is that portion of the earth's crust in which plants may grow. It is composed of pulverized and disintegrated rock mixed with animal and vegetable matter. The rock particles are of different kinds and sizes, and are in various stages of decomposition. If two soils are produced from the same kind of rock and differ only in the size of the particles, the difference is merely a physical one. If, however, one soil is formed largely from sandstone, while the other is formed from granite, and the soil particles are not the same in size, the difference is both physical and chemical. Soils are derived from different kinds of rock fragments, which are composed of minerals having a different combination of elements and different percentage composition, and hence it is they differ both physically and chemically. It is difficult to consider the physical properties without also considering the chemical properties. The chemical and physical properties, together, determine largely the agricultural value of a soil.

2. Physical Properties Defined. — The physical properties of a soil are:

1. Weight and volume.
2. Size, form, and arrangement of the soil particles.
3. The relation of the soil to air, water, heat, and cold.
4. Color.
5. Odor and taste.
6. The relation of the soil to electricity.

3. Weight and Volume. — Soils vary in weight with the composition and size of the particles. Fine sandy soils weigh heaviest, while peaty soils are the lightest. But when saturated with water, a cubic foot of peaty soil weighs more than a cubic foot of sandy soil. A given volume of clay soil weighs less than the same volume of sandy soil. The larger the amount of organic matter, the less the weight. Pasture land, for example, weighs less than arable land. A cubic foot of soil from a field which has been well cultivated weighs less than that from a field where the soil has been compacted. Weight is an important property to consider when the total amounts of plant food in two soils are compared. A peaty soil containing 1 per cent of nitrogen and weighing 30 pounds per cubic foot has less total nitrogen than a soil containing 0.40 per cent of nitrogen and weighing 80 pounds.

The weight of soils per cubic foot as determined from apparent density is approximately as follows:[5]

	Pounds
Clay soil	70 to 75
Fine sandy soil	95 to 110
Loam soil	75 to 90
Peaty soil	25 to 40
Average prairie soil	75
Uncultivated prairie soil	65

It is estimated that an acre of soil to the depth of one foot weighs in round numbers from 2,500,000 to 4,200,000 pounds, depending upon the chemical composition, size of soil particles, and state of compaction.

The weight per cubic foot of soils in situ generally exceeds the weight derived from the apparent density of the dry soil; this is because of the tendency of soils in the field to become compacted. While a dry clay soil reduced to a powder may show an apparent weight of 70 pounds per cubic foot, the field weight (air-dry basis) may range from 80 to 98 pounds, depending upon the degree of compactness.

Between the soil particles are non-capillary or pore spaces occupied by air or water. If the soil be considered a homogeneous mass without air spaces, it will have an absolute specific gravity of about 2.6; with the air spaces its apparent specific gravity is about 1.2. That is, in its natural condition a soil weighs about 1.2 times heavier than the same volume of water. The porosity of a soil is determined by dividing the apparent by the real specific gravity.[6] Ordinarily cultivated soils have a pore space range from 30 to 60 per cent of the volume of the soil, depending upon the conditions to which the soil has been subjected.

4. Size of Soil Particles. — The size of soil particles varies from those hardly distinguishable with the microscope to coarse rock fragments and determines the type of a soil as sand, clay, or loam. The term 'fine earth' is used to designate that part of a soil which passes through a sieve with holes 0.5 mm. (0.02 inch) in diameter. Coarse sand particles and rock fragments which fail to pass through the sieve are called skeleton. The amounts of fine earth and skeleton are variable. Arable soils, in general, contain from 5 to 20 per cent of skeleton.

The fine earth is composed of six grades of soil particles. The names and sizes are as follows:

	MILLIMETERS	INCHES
Medium sand	0.5 to 0.25	0.02 to 0.01
Fine sand	0.25 to 0.1	0.01 to 0.004
Very fine sand	0.1 to 0.05	0.004 to 0.002
Silt	0.05 to 0.01	0.002 to 0.0004
Fine silt	0.01 to 0.005	0.0004 to 0.0002
Clay	0.005 and less	0.0002 and less

Soils are mechanical mixtures of various-sized particles. In most soils there is a predominance of one grade, as clay in heavy clay soils, and medium sand in sandy soils. No soil, however, is composed entirely of one grade. The clay particles are exceedingly small; it would take 5000 of the larger ones, if laid in a line with the edges touching, to measure an inch, while it would take but 50 of the medium sand particles to measure an inch.

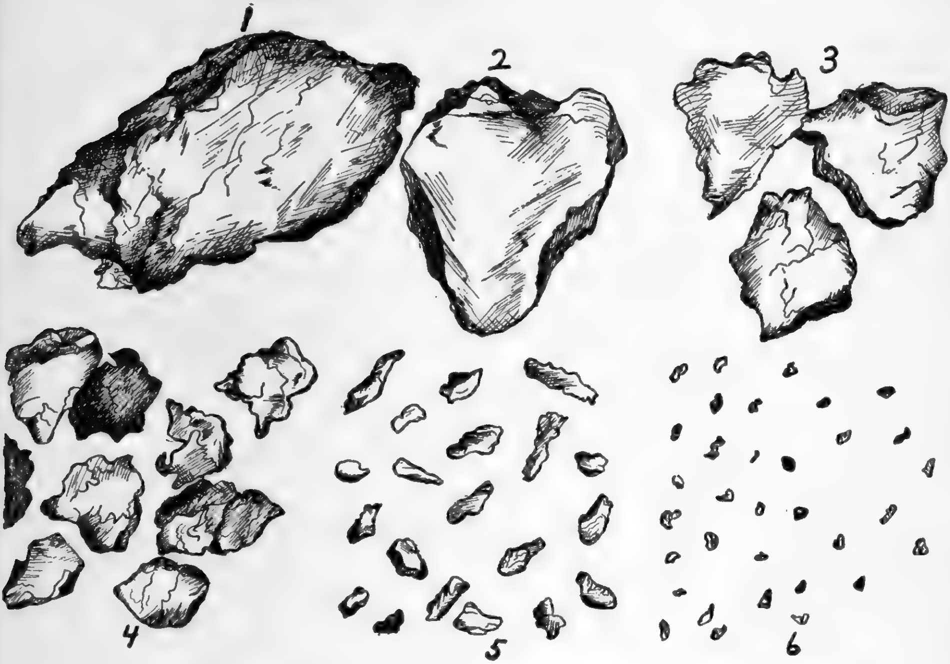

FIG. 1. Medium sand × 150. FIG. 2. Fine sand × 150. FIG. 3. Very fine sand × 150. FIG. 4. Silt × 325. FIG. 5. Fine silt × 325. FIG. 6. Clay × 325.

5. Sand.—Sand is any rock fragment ranging in size between 0.5 and 0.05 mm. in diameter. There are three grades, — fine, medium, and very fine. The chief characteristic of sand is non-cohesion of particles. A soil composed entirely of sand has little, if any, agricultural value. Sandy soils usually contain from 5 to 15 per cent of clay and silt. The relative size of sand, silt, and clay is shown in the illustration. In the coarser grained sand, quartz predominates, while the finer grained is composed mainly of other minerals.

6. Clay. — The term 'clay' used physically denotes those soil particles less than 0.005 mm. (0.0002 inch) in diameter, without regard to chemical composition. It may be silica, feldspar, limestone, mica, kaolin, or any other rock or mineral which has been pulverized until the particles are less than 0.005 mm. in diameter. Chemically, however, the term 'clay' is restricted to one material, as explained in Section 74. The physical properties of clay are well known. It has the power to absorb large amounts of water, and will remain suspended in water for a long time. The roiled appearance of many streams and lakes is due to the presence of suspended clay particles. The amount in agricultural soils may range from 3 to 40 per cent. Clay soils, if worked when too wet, become puddled; then percolation cannot take place, and the accumulated surface water must be removed by the slow process of evaporation. As clays dry, they shrink, become tenacious, and are worked with difficulty. Clay soils owe their properties to the fineness of division of the particles rather than to their chemical composition. Any mineral when finely pulverized has physical properties similar to clay.[7]

7. Silt. — Silt is composed of a great variety of rock fragments. The particles are, in size, between sand and clay. Chemical analysis shows them to be more hydrated than the clay particles. Many of the western prairie subsoils, clay-like in nature, are composed mainly of silt, which imparts characteristics intermediate to sand and clay. While a clay soil is nearly impervious to water, and when wet works with difficulty, a silt soil is more permeable, but is not so open and porous as a sandy soil. When a soil containing large amounts of clay and silt is treated with water, the silt settles slowly, while the clay remains in suspension. The fine deposit in ditches and drains, where the water moves slowly, is mainly silt. Soils composed largely of silt deposited by water and mixed with vegetable matter are among the most fertile.

8. Form of Soil Particles. — Soil particles are extremely varied in form. When examined with the microscope they show the same diversity as is observed among larger stones. In some soils the particles are spherical, while in others they are angular. The shape is determined by the way in which the soil has been formed, and also by the nature of the rock from which it was produced.

The form and arrangement of the particles are important factors to consider in dealing with the water content of soils. In the wheat lands of the Red River Valley of the North, the particles are small and spherical, being formed largely from limestone rock, while the subsoil of the western prairie regions is composed largely of angular silt particles, intermingled with clay, forming a mass containing only a minimum of inter-soil spaces. The silt particles being angular and embedded in the clay, the soil has more the character of clay than of silt. While these two soils are unlike in physical composition, the form and arrangement of the particles give each nearly the same water-holding power. Two soils may have a somewhat similar mechanical composition and yet possess materially different physical properties because of a difference in the form and arrangement of the soil particles. In some soils 10 per cent of clay is of more agricultural value than in other soils. Ten per cent of clay associated with 60 or 70 per cent of silt makes a good grain soil, while 10 per cent of clay associated largely with sand makes a soil poorly suited to grain culture.

The classification of the soil particles into clay, silt, and fine, medium, and coarse sand is purely an arbitrary one. Various authors use these terms in different ways, and when comparing the mechanical composition of soils reported in different works, one may avoid confusion by omitting the names and noting only the sizes of the particles.

9. Number of Particles per Gram of Soil. — It has been estimated that a gram of productive soil contains from 2,000,000,000 to 20,000,000,000 soil particles; soils which contain less than 1,700,000,000 are unproductive. The number of particles in a given volume of soil varies with their size and form. According to Whitney[8] the number of particles per gram of different soil types is as follows:

Early truck	1,955,000,000*
Truck and small fruit	3,955,000,000
Tobacco	6,786,000,000
Wheat	10,228,000,000
Grass and wheat	14,735,000,000
Limestone	19,638,000,000

Assuming the particles are all spheres, it is estimated that in a cubic foot of soil a surface area of from two to three and one half acres is presented to the action of plant roots.

10. Method employed in Separating Soil Particles. — Sieves with circular holes 0.5, 0.25, and 0.1 mm. are employed for the purpose of separating the coarser grades of sand. The sieve *a*, 0.5 mm. size, is connected with the filtering flask *c* by means of the tube *b*, and the flask is connected at point *d* with a suction pump. Ten grams of soil, after soft pestling with boiling water, are placed in the sieve and water is passed through until the washings are clear. All particles larger than 0.5 mm.

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* Figures below sixth place omitted and ciphers substituted.

remain in the sieve, and after drying and igniting, are weighed. The contents of the flask *c*, containing the particles less than 0.5 mm., are now passed through a sieve having holes 0.25 mm. in diameter.

The fine sand and silt are separated by gravity. The fine sand with some silt and clay are readily deposited and the water containing the suspended clay is decanted into a second glass vessel. The residue is treated with more water and allowed to settle, this operation being repeated until the microscope shows the soil particles to be nearly all of one grade. The separation of silt and clay is facilitated by the use of a centrifuge.[9]

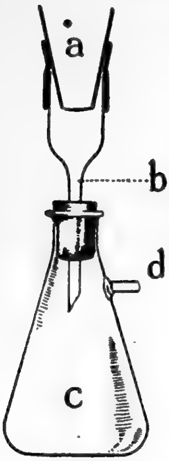


FIG. 7.

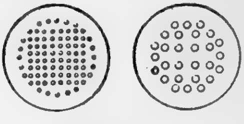
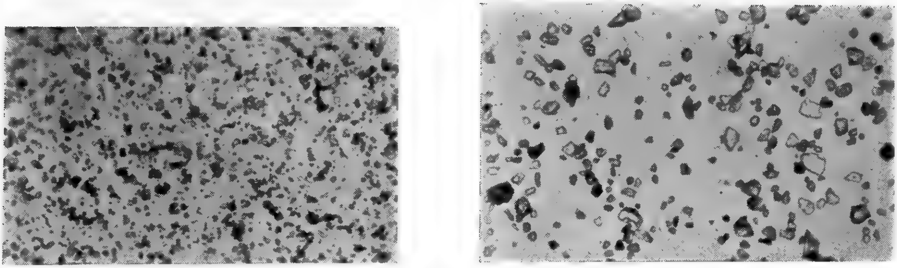


FIG. 8.

It is often difficult to secure even an approximate separation of sand, silt, and clay particles, because the finer particles tenaciously adhere to the larger ones.

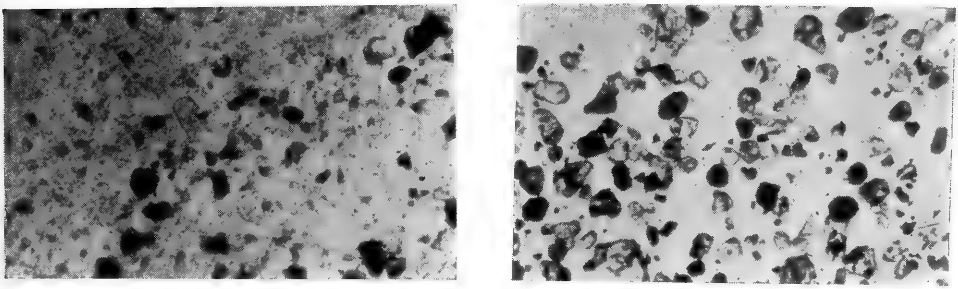
The clay is obtained by evaporating an aliquot portion of the washings or by determining the total per cent of the other grades of particles and the volatile matter and subtracting the sum from 100. This is the modified Osborne sedimentation method.[10]

By means of Hilgard's elutriator[7] a more extended separation of the soil particles is effected. For detailed directions for making mechanical analyses of soils the student is referred to Wiley's "Agricultural Analysis," Vol. I.



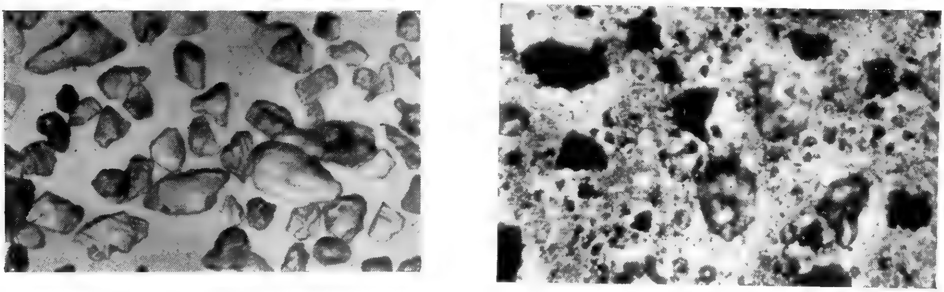
Fine Silt Subsoil × 110.

Silt Subsoil × 110.



Silt and Clay Subsoil × 110

Sandy Soil × 30.



Sandy Subsoil × 30.

Sand, clay, silt, and humus particles blended in soil × 110.

FIG. 9.

SOIL TYPES

11. Crop Growth and Physical Properties. — The preference of certain crops for particular kinds of soil, as wheat for a clay subsoil, potatoes for a sandy soil, and corn for a silt soil, is due mainly to the characteristic of the crop in requiring a definite amount of water, and a certain temperature for growth. These conditions are met by the soil being composed of various grades of particles which enable a certain amount of water to be retained, and the soil to properly respond to heat and cold. In considering soil types, it should be remembered that there are so many conditions influencing crop growth that the crop-producing power cannot always be determined by a mechanical analysis of the soil. The following types have been found to hold true in a large number of cases under average conditions, but they do not represent what

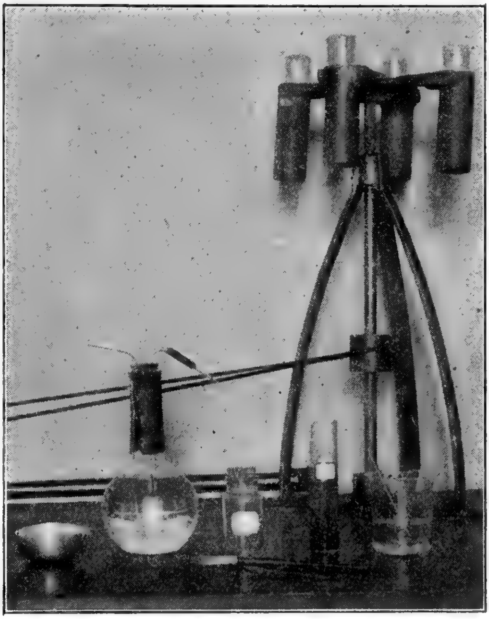


FIG. 10. First Centrifuge used in the Mechanical Analysis of Soils.

might be true under special conditions. For example, a sandy soil of good fertility in which the bottom water is only a few feet from the surface, may produce larger grain crops than a clay soil in which the bottom water is at a greater depth. In judging the character of a soil, the special conditions must always be taken into consideration. In discussing the following soil types, a normal supply of plant food and an average rainfall are assumed in all cases.[11]

12. Potato and Early Truck Soils. — The better types of potato soils are those which contain about 60 per cent of medium and fine sand, 30 per cent of silt, and about 5 per cent of clay. Soils of this nature when supplied with 3 per cent of organic matter will contain from 10 to 20 per cent of water. The best conditions for crop growth exist when the soil contains about 18 per cent of water. In a sandy soil, vegetation may reduce the water to a much lower point than in a clay soil, because the sandy soil gives up its water so readily to growing crops and consequently a larger amount is available, while on a heavy clay, crops show the want of water when the soil contains from 10 to 12 per cent, for the clay holds the water so tenaciously. When potatoes are grown on soils where there is an abnormal amount of water the crop is slow in maturing. For early truck purposes in northern latitudes, sandy loam soils are the most suitable because they warm up so readily, and the absence of an abnormal amount of water results in early maturity. Excellent crops of potatoes are grown on many of the silt soils of the west which have a materially different composition from the type given. A soil may have all of the requisites physically for the production of good potato and truck crops, and still be unproductive on account of unbalanced chemical composition or lack of plant food.

13. General Truck and Fruit Soils. — For fruit growing and general truck purposes the soil should contain more clay and less sand than for early truck farming. Soils containing from 10 to 15 per cent of clay and not more than 50 per cent of sand are best suited for growing small fruits. Such soils will retain from 12 to 20 per cent of water. There is a noticeable difference in the adaptability of different kinds of fruit to different soils. Some thrive on clay land, provided the proper cultivation and treatment are given. There is as much diversity of soil required for producing different fruit crops as for the production of different farm crops. As a rule, however, a silt soil is most capable of being adapted to the various conditions required by fruit crops.

14. Corn Soils. — The strongest types of corn soils are those which contain from 40 to 45 per cent of medium and fine sand and about 15 per cent of clay. Corn lands should contain 15 per cent of available water. Heavy clays require more cultivation and produce corn which matures later than that grown on soil not so close in texture. Many corn soils contain less sand and clay, but more silt than the figures given. If a soil has a high per cent of neutral organic matter, good corn crops may be produced where there is less than 12 per cent of clay. Soils with a high per cent of sand are usually too deficient in available water to produce a good crop of corn. On the other hand, heavy clay soils are slow in warming up and thus are not suited to corn culture. The western prairie soils, which produce most of the corn raised in the United States, are composed largely of silt.

The best types of corn soils have the necessary mechanical composition for the production of good crops of sorghum, cotton, flax, and sugar beets. However, the amount of available plant food required for each of these crops is not the same.

15. Medium Grass and Grain Soils. — For the production of grass and grain a larger amount of water is required than for corn. The yield is determined largely by the amount of water which the soil contains. For an average rainfall of 30 inches, a good grass and grain soil should contain about 15 per cent of clay and 60 per cent of silt. Such a soil ordinarily holds from 18 to 25 per cent of water. Many grass and grain soils have less silt and more clay. A soil composed of about 30 per cent each of fine sand, silt, and clay, is also suitable mechanically, for general grain production. There are a number of different types of grass and grain soils, with different proportional amounts of sand, silt, and clay. Silt soils, however, form the largest part of the grain soils of the United States.

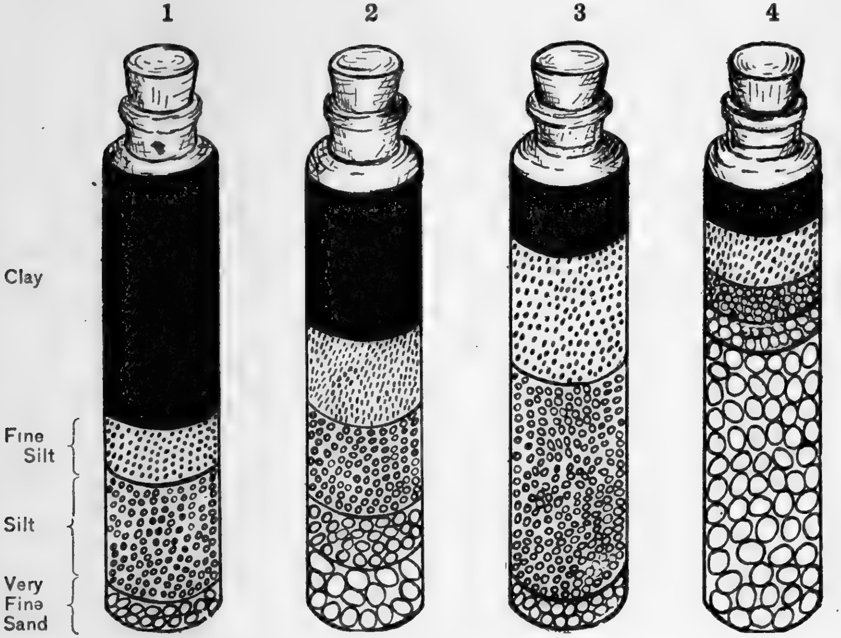


FIG. 11. Soil Types.
1. Heavy wheat soil. 2. Average wheat soil. 3. Medium wheat and grain soil. 4. Corn soil.

16. **Wheat Soils.** — For wheat production, soils of closer texture are required than for other small grains. There are three classes of wheat soils. In the first

(1 in Fig. 11) there are from 30 to 50 per cent of clay particles, mostly disintegrated limestone. The soil of the Red River Valley of the North belongs to this class. The surface soil contains from 7 to 10 per cent of vegetable matter and the subsoil about 25 per cent of limestone in a very fine state of division. For the production of wheat, the subsoil should have a good store of water.

The second type of wheat soil (2 in Fig. 11) has less clay and more silt. Many prairie subsoils which produce good crops of wheat contain about 25 per cent of sand, 50 per cent of silt, and from 18 to 25 per cent of clay. Soils of this class when well stocked with moisture in the spring produce good crops of wheat, but are not able to withstand drought so well as soils of the first class; during wet seasons, however, the yields are larger than on heavier clay soils.

To the third class of wheat soils (3 in Fig. 11) belong those which are composed mainly of silt, containing usually 75 per cent, and from 10 to 15 per cent of clay. The high per cent of fine silt gives the soil clay-like properties. Soils of this class are adapted to a great variety of crops. For the production of wheat it is essential that a good supply of organic matter be maintained in such soils so as to bind together the soil particles. The special peculiarities of the different grain crops as to soil requirements are discussed in connection with the food of crops.

MECHANICAL COMPOSITION OF SOIL TYPES[9]

Kind of Soil		Heavy Wheat	Medium Wheat	Grass and Grain	Corn	Potato, etc.
Name of Particles	Size in Millim.	1	2	3	4	5
Medium sand	0.5 to 0.25	——	3.18	1.20	24.60	59.04
Fine and very fine sand	0.25 to 0.05	6.18	21.43	4.14	21.51	5.60
Silt	0.05 to 0.01	20.25	27.75	44.35	11.08	9.07
Fine silt	0.01 to 0.005	10.35	17.60	30.75	12.81	19.33
Clay	0.005	57.00	25.00	15.45	22.80	4.05
Total volatile		6.22	5.04	4.11	7.20	2.91

1. A heavy wheat soil from the Red River Valley, — the clay consists largely of disintegrated limestone.
2. Medium wheat soil from Western Minnesota.
3. A loam soil adapted to grasses and grains. From Minnesota Experiment Station.
4. A corn soil from Southwestern Minnesota.
5. A potato soil from Eastern Minnesota.

17. Sandy, Clay, and Loam Soils. — Ordinarily in agricultural literature, the term 'sandy,' 'clay,' or 'loam' is used to designate the prevailing character of a soil. Sandy soils usually contain 90 per cent or more of silica or chemically pure sand. The term 'light sandy soil' is sometimes used to indicate that the soil is easily worked, while 'heavy clay' means that the soil offers great resistance to cultivation. Many soils which are clay-like in character are not composed very largely of clay. There are subsoils in the western states which have clay-like characteristics but contain only about 15 per cent of clay, the larger part of the soil being silt. A loam soil is a mixture of sand and clay; if clay predominates, it is a clay loam, while if sand predominates, it is a sandy loam.

RELATION OF THE SOIL TO WATER AND AIR

18. Amount of Water required by Crops. — Experiments show that it takes from 275 to 375 pounds of water to produce a pound of dry matter in a grain crop. In order to produce an acre of average wheat, 350 tons of water are needed. The amount of water required for the production of an acre of various crops is as follows: [12]

	AVERAGE AMOUNT TONS WATER	MINIMUM AMOUNT TONS WATER
Clover	400	310
Potatoes	400	325
Wheat	350	300
Oats	375	300
Peas	375	300
Corn	300	——
Grapes	375	——
Sunflowers[17]	6000	——

The amount of water required for the production of crops in humid and arid regions has not been extensively investigated. Ordinarily crop yield is directly proportional to and dependent upon the water supply.

The rainfall during the time of growth is frequently less than the amount of water required for the production of the crop. One inch of rainfall is equal to about 112 tons of water per acre. An average of two inches per month during the three months of crop growth is equivalent to only 675 tons, a large part of which is lost by surface drainage and by evaporation. Hence it is that the rainfall during an average growing season is less than the amount of water required to produce crops, and consequently the water stored up in the subsoil must be drawn upon to a considerable extent. Inasmuch as the soil's reserve supply of water is such an important factor in crop production, it follows that the capacity of the subsoil for storing up and supplying water as needed is a matter of much importance, particularly since the power of the soil for absorbing and retaining water may be influenced by cultivation and manuring. Before discussing the influence of cultivation upon the soil water, the forms in which water is in the soil should be studied. It is present in three forms: (1) bottom water, (2) capillary water, and (3) hydroscopic water.

19. Bottom Water is that which stands in the soil at a general level, and fills all the spaces between the soil particles. Its distance from the surface can be told in a general way by the depth of surface wells. Bottom water is of service to growing crops when it is at such a depth that it can be brought to the plant roots by capillarity, but when too near the surface, so that the roots are immersed, the conditions are unfavorable for crop growth. When the bottom water can be brought within reach of the roots by capillarity, a crop has an almost inexhaustible supply. In many soils known as old lake bottoms, such a condition exists.

20. Capillary Water. — The water held in the minute spaces above the bottom water is known as the capillary water. The capillary spaces of the soil are the small spaces between the soil particles in which water is held by surface tension, the force acting between the soil and the water being greater than the force of gravity. If a series of glass tubes of different diameters be placed in water, it will be observed that in the smaller tubes water rises much higher than in the larger. The water rises in all of the tubes until a point is reached where the force of gravity is equal to the force of surface tension. In the smaller tubes surface tension is greater than the force of gravity, and the water is drawn up into the tube inversely proportional to its diameter. In the larger tubes the surface tension is less and the water is raised only a short distance. There are present in the

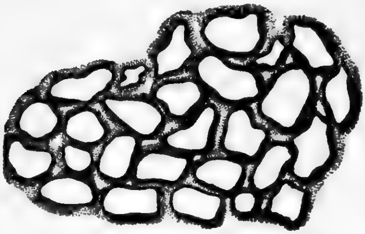


FIG. 12. Water Film surrounding Soil Particles.

soil many spaces which are capable of taking up water in the same way. The height to which water can be raised by capillarity depends upon the size and arrangement of the soil particles, it may be to a height of several feet. Ordinarily, however, the capillary action of water is confined to a few feet. The arrangement of the soil particles influences greatly the capillary power of a soil. Usually from 30 to 60 per cent of the bulk of a soil is air space; by compacting, the air spaces are decreased; by stirring, they are increased. In soils of close texture, as heavy clays, an increase in air spaces results in an increase of capillary spaces and of water-holding capacity, while in other soils, as coarse sandy soils, increasing the air spaces decreases the capillary spaces and the water-holding capacity. The best conditions for crop production exist when the soil contains water to the extent of about 40 per cent of its total capacity for saturation.

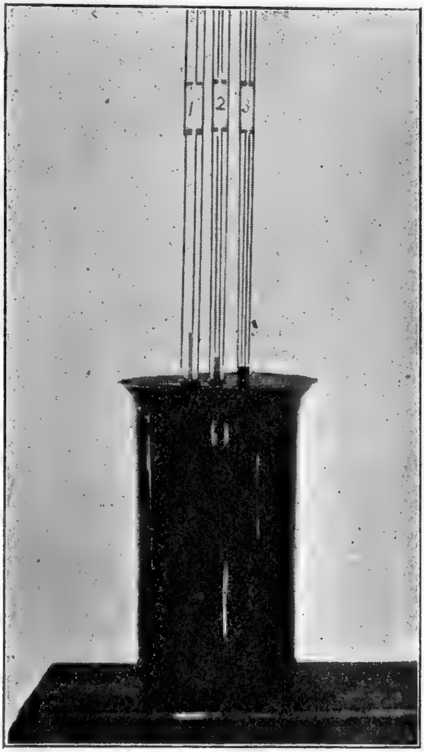


FIG. 13. Showing Rise of Water in Capillary and other Tubes.

21. Hydroscopic Water. — By hydroscopic water is meant the water that is held mechanically in the soil and is not removed by air drying. The air which occupies the non-capillary spaces of the soil is charged with moisture in proportion to the water in the soil. Under normal conditions the soil atmosphere is nearly saturated. When soils have exhausted their capillary water, the water in the soil atmosphere is correspondingly reduced. The available supply in other forms being exhausted, the hydroscopic water cannot contribute to plant growth unless supplemented by heavy fogs.

22. Loss of Water by Percolation. — Whenever a soil becomes saturated, percolation or a downward movement of the water begins. The extent to which losses by percolation may occur depends upon the character of the soil and the amount of rainfall. When soils are covered with vegetation, the losses are less than from barren fields. In all soils which have only a limited number of capillary spaces and a large number of non-capillary spaces, the amount of water which can be held above the bottom water is small. From such soils the losses by percolation are greater than from soils which have a larger number of capillary spaces, and a smaller number of non-capillary spaces. In coarse sandy soils many of the spaces are too large to be capillary.

If all of the water which falls on some soils could be retained and not carried beyond the reach of crops by percolation, there would be an ample supply for agricultural purposes. The texture of the soil may be changed by cultivation and by the use of manures so as to prevent losses by percolation. If the soil is of very fine texture, as a heavy clay, percolation is slow, and before the water has time to sink into the soil, evaporation takes place. With good cultivation, the water is able to penetrate to a depth beyond the immediate influence of evaporation. Compacting an open porous soil by rolling, checks rapid percolation and prevents the water from being carried beyond the reach of plant roots. Thus it will be seen that the treatment necessary to prevent excessive losses by percolation, varies with different soils. In regions of heavy rainfall and mild winters the losses of both water and plant food by percolation are often large.

23. Loss of Water by Evaporation. — The factors which influence evaporation are temperature, humidity, and rate of movement of the air. When the air contains but little moisture and is heated and moving rapidly, the most favorable conditions for evaporation exist. In semi-arid regions the losses of water by evaporation are much greater than by percolation. The dry air comes in contact with the soil, the soil atmosphere gives up its water taken from the soil, and, unless checked by cultivation, the subsoil water is brought to the surface by capillarity and lost. In porous soils a greater freedom of movement of the air is possible, which increases the rate of evaporation. When the surface of the soil is covered with a layer of finely pulverized earth, or with a mulch, excessive losses by evaporation cannot take place, because a material of different texture is interposed between the soil and the air.

24. Loss of Water by Transpiration. — Losses of water may also occur from the leaves of plants by the process known as transpiration. Helriegel observed that during some years 100 pounds more water were required to produce a pound of dry matter than in other years, because of the difference in the amount of water lost in this way. The loss of water by evaporation can be controlled by cultivation, but the loss by transpiration can be only indirectly influenced. Hot, dry winds may cause crops to wilt because the water lost by transpiration exceeds the amount which the plant takes from the soil.

25. Drainage. — Good drainage is essential in order to properly regulate the water supply. An excess of water in the soil is equally as injurious as a scant amount. If the water which falls on the land is allowed to flow over the surface and is not retained in the soil, there is not sufficient reserve water for crop growth. The object of good drainage is to store as much water as possible in the subsoil and prevent surface accumu-

FIG. 14. The "infant Mississippi" below Itasca Lake. The forests at the source of this river should be maintained in order favorably to influence the agricultural conditions of the Mississippi Valley.

lation and loss. Good drainage is accomplished by thorough cultivation, and in regions of heavy rainfall, by tile drainage. Well-drained land is warmer in the spring, has a larger reserve store of water, and is in better condition for crop growth. Many swampy lands are highly productive when properly drained. A high state of productiveness cannot be maintained without suitable provision for drainage. When the pores of the soil are filled with water, air is excluded and the necessary chemical and bacteriological changes which result in rendering plant food available fail to take place. The drainage of wet and low lands forms an important feature of rural engineering.

26. Influence of Forest Regions. — The deforesting of large areas near the sources of rivers has an injurious influence upon the moisture content of adjoining farm lands. By cutting over and leaving barren large tracts, less water is retained in the soil. Also near forests the air has a higher moisture content, due to the water given off by evaporation. Lands adjacent to deforested districts lose water more rapidly by evaporation, because the air is so much drier. In Section 24 it is stated that losses of water by transpiration can be indirectly influenced. This can be accomplished by retaining the forests.

Good drainage is necessary not only for individual farms, but also for an entire community. Good storage capacity in the form of forest lands, for the surplus water which accumulates near the sources of large rivers is also a necessity to agriculture.

The three ways by which crops are deprived of water are, — (1) percolation, (2) evaporation, and (3) transpiration. With proper methods of cultivation losses by percolation and evaporation may be controlled, and losses by transpiration may be reduced.

INFLUENCE OF CULTIVATION UPON THE WATER SUPPLY OF CROPS

27. Capillarity influenced by Cultivation. — The capillarity and moisture content of soils can be influenced by different methods of cultivation, as rolling and subsoiling, deep plowing, and shallow surface cultivation. The treatment which a soil should receive in order to insure the best water supply for crops must vary with the rainfall, the nature of the soil, and the crop to be produced. It frequently happens that the annual rainfall is sufficient to produce good crops, but it is too unevenly distributed, and hence is not all utilized to the best advantage. Losses of water occur through surface drainage, percolation, and excessive evaporation, but if it were properly stored in the subsoil and conserved by cultivation, these losses would be prevented and there would be sufficient for crop production.

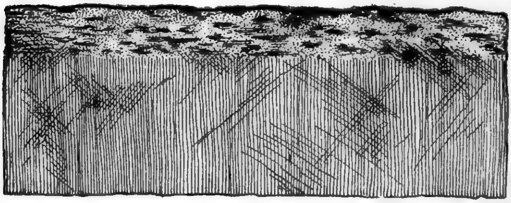


FIG. 15. Soil with Surface Cultivation.

It is possible, to a great extent, to vary the cultivation so as to conserve the moisture of the soil to meet the requirements of crops.

28. Shallow Surface Cultivation. — When shallow surface cultivation is practiced, the capillary spaces near the surface are destroyed and the direct connection of the subsoil water with the upper layer is broken, the ground is covered with finely pulverized earth, and the soil particles have been disturbed so there is not that close contact which enables the water to pass from particle to particle. When evaporation takes place there is a movement of the subsoil water to the surface, but if that is covered with a layer of fine earth, the subsoil water cannot readily pass through such a medium, and evaporation is checked. Hence shallow surface cultivation conserves the soil moisture.

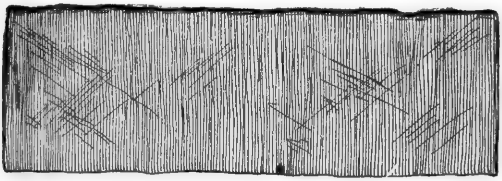


FIG. 16. Soil without Surface Cultivation.

The means by which surface cultivation is accomplished must, of necessity, vary with the nature of the soil. If a harrow is used, the pulverization should be complete, if a disk, the teeth should be set at an angle, and not perpendicularly, so as to prevent, as suggested by King,[13] the formation of hard ridges which hasten evaporation. When the disk is set at an angle, a layer of soil is completely cut off, and the capillary connection with the subsoil is broken. Surface cultivation should be from two to three inches deep, and the finer the condition in which the surface soil is left, the better. Shallow surface cultivation does not mean that the soil should not be previously well prepared by thorough cultivation. It can be practiced in connection with deep plowing, shallow plowing, subsoiling, or rolling; in fact, it can be combined with any method of treating the land, and is an effectual means of conserving soil moisture. The following example shows the extent to which shallow surface cultivation may conserve the soil water:[14]

	PER CENT OF WATER IN CORNFIELD	
	With shallow surface cultivation	Without shallow surface cultivation
Soil, depth 3 to 9 inches	14.12	8.02
Soil, depth 9 to 15 inches	17.21	12.38

29. Cultivation after a Rain. — When evaporation takes place immediately after a rain, not only is there a loss of the water which has fallen, but there may also be a loss of the subsoil water by translocation, if nothing be done to prevent.[13] After a rain, soils should be cultivated as soon as the implements will work well, so as to check evaporation and prevent the formation of a crust. The following example shows the extent to which the subsoil water may be brought to the surface:[14]

	PER CENT OF WATER	
	Surface soil, 1 to 3 inches	Subsoil, 6 to 12 inches
Before the shower	9.77	18.22
After the shower	22.11	16.70

The rainfall was sufficient to have raised the water content of the surface soil to 20.77 per cent. The subsoil showed a loss of 1.52 per cent, while the surface soil showed a gain of 1.34 per cent in addition to the water received from the shower. If evaporation begins before the equilibrium is reëstablished, there is lost, not only the water from the shower, but also the water which has been translocated from the subsoil to the surface. Hence the importance of shallow surface cultivation immediately after a rain.

When the subsoil contains a liberal supply of water, and the surface soil a minimum amount, there is after a shower a movement of the subsoil water to the surface. The soil particles at the surface are surrounded with films of water which thicken at the expense of the subsoil water. Surface tension is the cause of this movement of the water to the surface, and under the conditions stated it is temporarily greater than the force of gravity.

A hard, thin crust should never be allowed to form after a rain, because it hastens losses by evaporation, while a soil mulch formed by surface cultivation has the opposite effect.

30. Rolling. — The use of heavy rollers for compacting the soil is beneficial in a dry season on a soil containing large proportions of sand and silt. Rolling compacts the land and improves the capillary condition, enabling more of the subsoil water to be brought to the surface. Experiments show that when land is rolled the amount of water in the surface soil is increased. This increase is, however, at the expense of the subsoil water.[15] Unless rolled land receives surface cultivation, excessive losses by evaporation, due to improved capillarity, may result. The use of the roller on heavy clay during a wet season results unfavorably. Occasionally, light rolling of clay land is beneficial in pulverizing the clods.

In some localities rolling and subsequent surface cultivation are not admissible on account of drifting of the soil, caused by heavy winds.

31. Subsoiling. — By subsoiling is meant pulverizing the soil below the furrow slice. This is accomplished with the subsoil plow, which simply loosens without bringing the subsoil to the surface. The object of subsoiling is to enable the land to retain, near the surface, more of the rainfall. Heavy clay lands are sometimes improved by occasional subsoiling, but its continued practice is not desirable. For orcharding and fruit growing, it is frequently resorted to, but is not beneficial on soils containing large amounts of sand and silt. Rolling and subsoiling are directly opposite in effect.

Soils which are improved by rolling are not improved by subsoiling. The additional expense involved should be considered when subsoiling is to be resorted to. Experiments have not as yet been sufficiently decisive to indicate all of the conditions most favorable for this practice.

32. Fall Plowing followed by surface cultivation conserves the soil water, by checking evaporation and leaving the land in better condition to retain moisture. If conditions allow, fall plowing can be followed by surface cultivation, but in some localities heavy winds prevent this. It is generally better to give the surface cultivation early the following spring. Clay land should be left in a ridged condition when fall plowed, so as to expose a greater surface area and to allow a better opportunity for the water to sink into the subsoil. Evaporation may take place from unplowed land during the fall, and in the spring the soil contain appreciably less water than plowed land. By fall plowing it is possible to carry over a water balance of 100 tons or more from one year to the next.

33. Spring Plowing. — When land is plowed late in the spring there has been a loss of water by evaporation, and the soil has not been able to store up as much of the rain and snow as if fall plowing had been practiced.[15] Then, too, dry soil is plowed under and moist soil brought to the surface, and if surface cultivation does not follow, this moisture is readily lost by evaporation, good capillary connection of the surface soil and subsoil is not obtained, and the furrow slice soon becomes dry.

	PER CENT OF WATER IN[14]	
	Fall-plowed land	Spring-plowed land
From 2 to 6 inches	24.7	22.4
From 6 to 12 inches	26.6	24.1
From 12 to 18 inches	28.8	26.5
Average difference	2.37 per cent	

Surface cultivation should immediately follow spring plowing.

34. Mulching. — The use of well-rotted manure or straw, spread over the surface as a mulch, prevents evaporation. In forests the leaves form a mulch which is an important factor in maintaining the water supply. In order that a mulch be effectual, it must be compacted, — a loose pile of straw is not a mulch. In reclaiming lands gullied by water, mulching is very beneficial, also a light mulch may be used to encourage the growth of grass on a refractory hillside. Surface cultivation and mulching may be advantageously combined.[14]

	PER CENT OF WATER IN	
	Mulched strawberry patch	Unmulched
Soil 2 to 5 inches	18.12	11.17
Soil 6 to 12 inches	22.18	18.14
Soil 12 to 18 inches	24.31	21.11

35. Depth of Plowing. — The depth to which a soil should be plowed in order to give the best results must, of necessity, vary with the conditions. Deep plowing of sandy land is not advisable, particularly in the spring. On clay land deeper plowing should be the rule. The longer a soil is cultivated, the deeper and more thorough should be the cultivation. While shallow plowing is admissible on new prairie land, deeper cultivation should be practiced when the land has been cropped for a series of years. Also, the depth of plowing should be regulated by the season. In prairie regions, and in the northwestern part of the United States, shallow plowing is more generally practiced than in the eastern states. Deep plowing in the fall gives better results than in the spring. It is not a wise plan to plow to the same depth every year. Professor Roberts says:[16] "If plowing is continued at one depth for several seasons, the pressure of the implement and the trampling of the horses in time solidify the bottom of the furrow, but if the plowing is shallow in the spring and deep in summer and fall, the objectionable hardpan will be largely prevented."

In regions of scant rainfall deep plowing of silt soils should be done only at intervals of three or five years, but with an average rainfall, deep plowing should be the rule on soils of close texture. The depth of plowing should be varied to meet the requirements of the crop and soil and the amount of rainfall.

36. Permeability of Soils.—The rapidity with which water sinks into the soil after a rain depends upon the nature of the soil, and the cultivation which it has received. Shallow surface cultivation leaves the soil in good condition to absorb water. When the surface is hard and dry a large per cent of the water which falls on rolling land is lost by surface drainage. Soils of close texture, which contain but few non-capillary spaces, offer the greatest resistance to the downward movement of water.

A soil is permeable when it is of such a texture that it does not allow the water to accumulate and clog the non-capillary spaces. Cultivation may change the tilth of even a clay soil to such an extent as to render it permeable. Deep plowing increases permeability. In regions of heavy rains, increased permeability is very desirable for good crop production on heavy clays. Sandy and loamy soils have naturally a high degree of permeability, and it is not necessary that it should be increased.

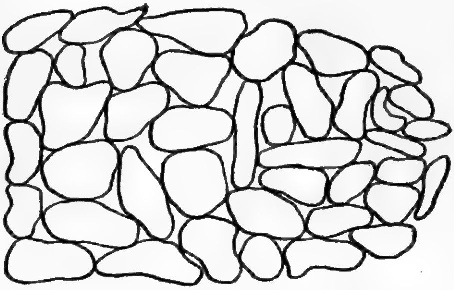


FIG. 17. Sandy Soil without Manure.

37. Fertilizers. — When water contains dissolved salts, it is more susceptible to the influence of surface tension, and is more readily brought to the surface of the soil. In commercial fertilizers soluble salts are present.

However, the beneficial effect of these upon the moisture content of soils is liable to be overestimated, because the fertilizer undergoes fixation when applied, and does not remain in a soluble condition. Fertilizers containing soluble salts exercise a favorable influence upon the moisture content of soils, but the extent of this influence has never been determined under field conditions.

38. Farm Manures. — Farm manures exercise a beneficial effect upon the moisture content of soils. When the manure is worked into a soil, the coarse soil particles and masses bind together, and the non-capillary spaces are made capillary. Free circulation of the air, which increases evaporation, is prevented when a sandy soil is manured. When soils are manured they retain more water, as shown by the following example: [14]

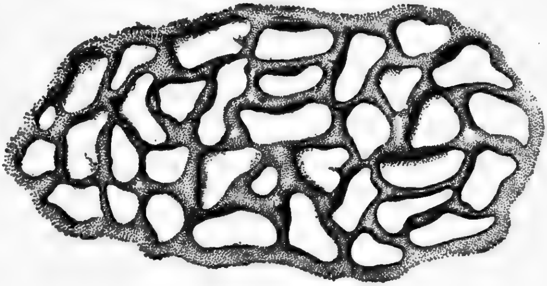


FIG. 18. Sandy Soil with Manure.

	FINE SANDY SOIL. PER CENT	95 PER CENT FINE SANDY SOIL AND 5 PER CENT MANURE. PER CENT
Capacity for holding water	25	42

The manure enables the soil to retain more of the moisture near the surface and prevents losses by percolation. The difference in moisture content between manured and unmanured land is particularly noticeable in a dry season.[14]

	Sandy Soil well Manured. Water	Sandy Soil Unmanured. Water
	Per Cent	Per Cent
Soil 1 to 6 inches	10.50	8.10

Coarse leached manure may have just the opposite effect by producing an open and porous condition of the soil.

RELATION OF SOIL TO HEAT

39. Soil Temperature. — The way in which a soil responds to heat and cold is an important factor in its crop-producing value. A soil temperature of 42° to 50° F. is required for crop growth, and the best conditions do not exist until the soil has reached a temperature of 60° to 70° F. During cold springs in northern latitudes the soil is often so cold as to retard the germination process, and to affect the vitality of seeds, causing a poor stand of grain.

40. Heat required for Evaporation. — It is estimated that the heat required to evaporate a pound of water at 60° F. would raise the temperature of 1000 pounds of water 1° F. When water evaporates, the soil is cooled, and if the heat for evaporation is all furnished by the surrounding soil, it materially lowers the soil's temperature and unfavorably affects crop growth. In the early spring, drying winds may temporarily lower the soil temperature by hastening evaporation. Much heat is unnecessarily lost in evaporating excessive amounts of water which should be removed by good systems of drainage.

41. Temperature of Drained and Undrained Land. — The surface of well-drained land is usually several degrees warmer than that of poorly drained land. Water being a poor conductor of heat, it follows that soils which are saturated are slow to warm up in the spring. At a depth of 2 or 3 feet the difference in temperature between wet and dry soils is not marked. It is to be observed that with proper systems of drainage the surplus water is removed from the surface soil and stored up in the subsoil for future use by the crop, and at the same time the temperature of the surface soil is raised, thus improving the conditions for growth. The relation of drainage to the temperature and proper supply of water for crop growth, receives too little consideration in field practice. When the land is well drained, and receives early cultivation, the conditions are best.

42. Color of Soils and Absorption of Heat. — All dark-colored soils have greater power of absorbing heat than those light in color. Schübler observed a difference in temperature of 8° C. between the same soils, when given a white coating with magnesia and a black coating with lampblack.[17] Black humus soils usually contain so much water that the additional heat is utilized for evaporation, and this results in the soil being cooler than light-colored sandy soil.

43. Specific Heat of Soils. — Soils have a low specific heat; it requires only about one fifth as much to raise a pound of soil 1° as is required to raise a pound of water 1°. When soils are wet, the specific heat is greatly increased, and they respond more slowly to the influence of the sun's rays. Sand has the lowest specific heat of any soil constituent and retains the least water, hence sandy soils warm up more readily than other soils. On the other hand, clay soils, although slower to warm up in the spring, retain their heat longer.

44. Farm Manures and Soil Temperature. — When the animal and vegetable matter of the soil decays, heat is produced. The slow oxidation of manure in the soil yields in the end as much heat as if the dry manure were burned. Whenever combustion or oxidation takes place, heat results.

Manured land is usually 1° or 2° warmer in the spring than unmanured land. It has been estimated that the amount of organic matter which undergoes oxidation in an acre of rich prairie soil produces as much heat annually as the burning of a ton of coal.[9] The additional heat in well-drained and well-manured land is an important factor in stimulating crop growth, particularly in a cold backward spring. The production of heat from manure is utilized in the case of hotbeds where manure in rotting raises the temperature of the soil. When soils are well manured, heat is retained more effectually and crops on such land often escape early frosts.

45. Influence of Exposure upon Soil Temperature. — Land with a southern slope receives the sun's rays longer and at a better angle for absorbing heat than land sloping to the north. In valleys and low places the soil at night cools more rapidly than on higher ground, and hence crops in valleys may be injured by late spring and early autumn frosts, while those on higher and warmer land escape.

46. Influence of Cultivation upon Soil Temperature. — Thorough cultivation resulting in the production of a fine pulverized seed bed enables the soil to absorb a larger amount of heat than if left in a rough lumpy condition. Cultivated land is more porous and allows greater freedom of movement of water into the subsoil. Warm spring rains have a marked effect upon the temperature of cultivated soils by filling the pores with warm water. The influence of temperature upon nitrification is discussed in Chapter IV.

47. Relation of Heat to Crop Growth. — All plant life is directly dependent upon solar heat as the source of energy for the production of plant tissue. The heat of the sun is the main force at the plant's disposal for decomposing water and carbon dioxide and for producing starch, cellulose, and other compounds. The growth of crops is the result of the transformation of solar heat into chemical energy which is stored up in the plant. When the plant is used for fuel or for food, the quantity of heat produced by complete oxidation is equal to the amount required for the formation of the plant's tissue.

48. Color of Soils. — The principal materials which impart color to soils are organic and iron compounds. A union of the decaying organic matter (humus) with the minerals of the soil produces compounds brown or black in color, and consequently soils containing large amounts of humus are dark-colored. When moist, soils are darker than when dry, and soils in which the organic matter has been kept up by the use of manures are darker than unmanured soils.[18] When rich, black, prairie soils lose their organic matter through injudicious methods of cultivation, or when in chemical analysis it is extracted, the soils become light-colored.

The red color of soils is imparted by ferric oxide; the yellow, by smaller amounts of the same material. A greenish tinge is supposed to be due to the presence of ferrous compounds, such soils being so close in texture as to prevent the oxidizing action of the air. Color may serve, to a slight extent, as an index of fertility. Black and yellow soils are, as a rule, the most productive, although occasionally black soils are unproductive because of the presence of acid compounds injurious to vegetation. The main reason why black soils are so generally fertile is because they contain a high per cent of humus and nitrogen.

49. Odor and Taste of Soils. — Soils containing liberal amounts of organic matter have characteristic odors due to the presence of aromatic bodies produced by the decomposition of organic matter. In cultivated soils these have a neutral reaction. The amount of aromatic compounds in soils is very small. Poorly drained peaty soils give off volatile acid compounds when dried.

The taste of soils varies with the chemical composition. Peaty soils usually have a slightly sour taste, due to the presence of organic acids. Alkaline soils have variable tastes according to the prevailing alkaline compound. The taste of a soil frequently reveals a fault, as acidity or alkalinity.

50. Power of Soils to absorb Gases. — All soils possess, to a variable extent, the power of absorbing gases. When decomposing animal or vegetable matter is mixed with soil, the gaseous products given off are absorbed. Absorption is the result of both chemical and physical action. The chemical changes which occur, as the fixation of ammonia, are considered in the chapter on fixation. The organic matter of the soil is the principal agent in the physical absorption of gases; peat has the power of absorbing large amounts. This action is similar to that of a charcoal filter in removing noxious gases from water.

51. Relation of Soils to Electricity. — There is always a certain amount of electricity in both the soil and the air. The part which it takes in plant growth is not well understood. The action of a strong current upon the soil undoubtedly results in a change in chemical composition, but in order to change the composition of the soil so as to render the unavailable plant food available, a current destructive to vegetation would be required. When plants are subjected to too strong a current of electricity, they wilt and have all of the after-effects of frost. A feeble current has either an indifferent or a slightly beneficial effect upon crop growth, but not sufficient to warrant its use in general crop production on account of cost, and it is undoubtedly physiological rather than chemical in its action unless it be in the favorable influence exerted upon nitrification. The electrical conductivity of soils has been taken by Whitney as the basis for the determination of moisture.[19] It is, however, dependent largely upon the nature and amount of dissolved salts.

52. Importance of the Physical Study of Soils. — A study of the physical properties of soils gives much valuable information regarding their probable agricultural value; but while the physical properties should always be taken into consideration, they should not form the sole basis for judging the character of a soil, because two soils from the same locality frequently have the same general physical composition, although entirely different crop-producing power, due to differences in chemical composition and amounts of available plant food. It is not possible from a physical analysis alone to determine the agricultural value of a soil.

Attempts have been made to overestimate the value of the physical properties of soils and to explain nearly all soil phenomena on the basis of soil physics, but important as are the physical properties, it cannot be said they are of more importance than the chemical or bacteriological. In fact, the four sciences, chemistry, physics, geology, and bacteriology, are all closely connected and each contributes its part to our knowledge of soils.

CHAPTER II

GEOLOGICAL FORMATION AND CLASSIFICATION OF SOILS

53. Agricultural Geology. — The geological study of a soil concerns itself with the past history of that soil, the materials out of which it has been produced, together with the agencies which have taken part in its formation and distribution. Geologically, soils are classified according to the period in the earth's history when formed, and also according to the agencies which have distributed them. The principles of soil formation and distribution should be understood, because of their important bearing upon fertility. Agricultural geology forms a separate branch of agricultural science; in this work only a few topics especially relating to soils are treated.

54. Formation of Soils. — Geologists state that the surface of the earth was at one time solid rock. It is held that soils have been formed from rock by the joint action of the various agents: (1) heat and cold, (2) water, (3) gases, (4) micro-organisms and other forms of vegetable and animal life, and (5) wind. One of the best evidences that soil is derived from rock is that there are frequently found pieces which are rotten, and, when crushed, closely resemble the prevailing soil of the field. This is particularly true of clay soils where there are fragments of disintegrated feldspar that when crumbled are similar to the soil in which the feldspar was embedded. The process of soil formation is extremely slow and the various agents have been at work for an almost unlimited period.

Weathering is the joint action upon rocks of the various atmospheric agencies. Some rocks are more susceptible to it than others, and in different localities even the same kind of rock may vary in the rapidity with which it responds to weathering.

55. Action of Heat and Cold. — The cooling of the earth's surface, followed by a contraction in volume, resulted in the formation of fissures which exposed a larger area to the action of other agencies. The unequal cooling of the rocks caused a partial separation of the different minerals of which the rocks were composed, resulting in the formation of smaller rock particles from the larger rock masses. This is well illustrated by the familiar splitting and crumbling of stones when heated. Shaler estimates that a variation of 150° F. will make a difference of 1 inch in the length of a granite ledge 100 feet long. As a result of changes in temperature there is a lessening in cohesion of the rock particles. The action of frost also is favorable to soil formation. The freezing of water in rock crevices results in breaking up the rock masses, forming smaller bodies. The force exerted by water when it freezes is sufficient to rend large rocks.

56. Physical Action of Water. — Water acts upon soils both chemically and physically. It is the most important agent that takes a part in soil formation. The surface of rocks has been worn away by moving water and in many cases deep ravines and cañons have been formed. This is called erosion. The pulverized rock, being carried along by the water and deposited under favorable conditions, forms alluvial soil. This physical

FIG. 19. Boulder split by Frost.
(Minnesota Geological and Natural History Survey.)

action of water is illustrated in the workings of large rivers where the pulverized rock particles are deposited along the river and at its mouth. Large areas of the soil in valleys and river bottoms have been formed in this way, and in most cases these soils are of high fertility. The action of water is not alone confined to forming soils along water courses, but is equally prominent in the formation of soils remote from streams or lakes, as in the case of soils deposited by glaciers.

FIG. 20. Granite Bluff shattered by Frost.
(Minnesota Geological and Natural History Survey.)

57. Glacial Action.— At one time in the earth's history, the ice fields of polar regions covered much larger areas than at present.[20] Changes of climate caused a recession of these, and resulted in the movement of large bodies of ice, carrying along rocks and frozen soil. The movement and pressure of the ice pulverized the rock and produced soil. This action is well illustrated at the present time where mountains rise above the snow line, and the ice and snow melting at the base are replaced by ice and snow from farther up, moving down the side of the mountain and carrying along crushed stones and soil. King estimates that an ice sheet 10 feet in depth exerts a pressure of 570 pounds to the square foot. The frozen mass contains boulders, gravel, and sand which act as a grinding plate upon the rocky surfaces with which it comes in contact.[15] The rubbing of these two surfaces against each other under pressure for centuries has resulted in the production of vast areas of drift soil.

When the glacier receded, stranded ice masses were distributed over the land. These melted slowly and by their grinding action hollowed out places some of which finally became lakes. The numerous lakes at the source of the Mississippi River are supposed to have been formed by glacial action. The terminal of a glacier is called a moraine and is covered with large boulders which have not been disintegrated. The course of a glacier is frequently traced by the markings or scratches of the mass on rock ledges. In glacial soils, the rocks are never angular, but are smooth because of the grind-

FIG. 21. A Lake formed by Glacial Action. There are many thousands of similar lakes in Central and Northern Minnesota. (From Geol. Nat. Hist. Survey, Minn.)

ing action during transportation. The area of glacial soils in the northern portion of the United States is quite large. These soils are, as a rule, fertile because of the pulverization and mixing of a great variety of rock.

58. Chemical Action of Water. — The chemical action of water is an important factor in soil formation. While nearly all rocks are practically insoluble in water there is always some material dissolved, evidenced by the fact that all spring water contains dissolved mineral matter. When charged with carbon dioxide and other gases, water acts as a solvent upon rocks; it converts many oxides, as ferrous oxide, into hydroxides, and produces new compounds more soluble or readily disintegrated, as deposits of clay, which have been formed from feldspar rock by the chemical and physical action of water. Rock decay is often dependent upon chemical change; the addition of water, or hydration of the molecule, particularly of the silicates, is one of the most important chemical changes. When rocks, as feldspar, disintegrate, there is an addition of 12 to 14 per cent of water of hydration to the disintegrated products. This chemical union of water with the rock materials entirely changes their properties and often prepares the way for other chemical changes. Water takes as prominent a part in the decay of rocks as in the decay of vegetable matter. Dissolved minerals produce many chemical changes in both rocks and soils. The chemical action of fertilizers, known as fixation, can take place only when the substances are in solution. In fact, water is necessary for nearly all the chemical reactions in the soil which result in rendering plant food available.

59. Joint Action of Air and Gases.—In the disintegration of materials to form soil, air takes a prominent part. By the aid of oxygen, carbon dioxide, and other gases and vapors in the air, rock disintegration is hastened. The action of oxygen changes the lower oxides to higher forms. All rock contains more or less oxygen in chemical combination. The carbon dioxide of the air under some conditions favors the formation of carbonates. The disintegrating action of air, moisture, and frost is illustrated in the case of building stones which in time crumble and form a powder. Many of the benefits of cultivation are due to aëration of the soil, as air promotes chemical changes of mineral substances and prepares the way for life processes in the soil.

60. Action of Micro-organisms. — Micro-organisms, found on the surface and in the crevices of rocks, are active agents in bringing about rock decay, deriving all of their energy from the chemical changes which they induce between minerals, and obtaining their carbon from the air. Such organisms incorporate organic matter with the rock residues.[21] Certain nitrifying organisms can obtain their nitrogen also from the air, and it is believed that they have largely prepared the way for the production of agricultural plants, by incorporating the initial stores of carbon and nitrogen of the air with the disintegrated rock materials.

61. Action of Vegetation. — Some of the lower forms of plants, as lichens, do not require soil for growth, but are capable of living on the bare surface of rocks, obtaining food from the air, and leaving a certain amount of vegetable matter which undergoes decay and is incorporated with the rock particles, preparing the way for higher orders of plants which take their food from the soil. When this vegetable matter decays, it enters into chemical combination with the pulverized rock, forming humates.[18] The disintegrating action of plant roots and vegetable matter upon rocks has been an important factor in soil formation. The action of vegetable remains in soil production is discussed in Chapter III.

62. Earthworms. — Many soils have been greatly modified by the action of earthworms. The soil in passing through their digestive tract is ground into finer particles and is intimately mixed with the indigestible matter excreted by the worms. In the case of rich loam soils it is estimated that all of the particles have at some time passed through the digestive tract of earthworms. Where they have been active, air and water are admitted into the soil more readily. The action of earthworms in soils has been extensively studied by Darwin.

63. Wind. — Wind also has been an important factor in the production and modification of soils. The denuding effects of heavy wind storms are well known. Large areas of wind-formed soils are found in some countries. Sand dunes are transported by winds, and often their subjugation by soil-binding plants is necessary in order to prevent encroachment upon valuable farm lands and inundation of villages. Soils formed by the action of winds are called æolian soils.

64. Combined Action of the Various Agents. — In the decay of rocks the various agents named — water acting mechanically and chemically, heat and cold, air, micro-organisms, vegetation, earthworms, and wind — have acted jointly, and have produced more rapid disintegration than if each agent had acted separately.

DISTRIBUTION OF SOILS

65. Sedentary and Transported Soils. — The place which a soil occupies is not necessarily where it was formed; that is, a soil may be produced in one locality and transported to another. Soils are either sedentary or transported. Sedentary soils are those which occupy the original position where they were formed. They usually have but little depth before rock surface is reached. The stones in such soils, except where modified by weathering, have sharp angles because they have not been ground by transportation. In the southern part of the United States, east of the Mississippi River, there are large areas of sedentary soils as ferrogenous clays in an advanced state of decay.

Transported soils are those which have been formed in one locality and carried by various agents as glaciers, rivers, or winds to other localities, the angles of the stones in these soils having been ground off during transportation. Transported soils are divided into classes according to the ways in which they have been formed; as drift soils produced by glaciers, alluvial soils by rivers and lakes, æolian soils by winds, and colluvial soils formed of rocks and débris from mountain sides.

FIG. 22. A Boulder-filled Channel.
(Minnesota Geological and Natural History Survey.)

In some localities volcanic soils are found. They are extremely varied in texture and composition; some are very fertile and contain liberal amounts of alkaline salts and phosphates, while others contain so little plant food that they are sterile.

ROCKS AND MINERALS FROM WHICH SOILS ARE FORMED

66. Composition of Rocks. — Rocks are composed of either a single mineral or of a combination of minerals. Most of the common minerals are definite chemical compounds and have a varied range in composition, due to the fact that one element or compound may be partially or entirely replaced by another. Most rocks from which soils have been derived contain minerals, as feldspar, mica, hornblende, and quartz.

67. Quartz. — Quartz is the principal constituent of many rock formations. Pure quartz is silicic anhydride, SiO_2, and a soil formed from pure quartz alone would be sterile. White sand is nearly pure quartz or silica. Silica enters into combination with many elements, forming a large number of minerals. Particles of quartz when cemented with iron compounds form sandstone rock. Sand is derived mainly from the decay of rocks containing quartz.

68. Feldspar is composed of silica, alumina, and potash or soda. Lime may also be present, and replace a part or nearly all of the soda. If the mineral contains soda as the alkaline constituent, it is known as albite, or if mainly potash, it is called potash feldspar or orthoclase.

The members of the feldspar group are insoluble in acids, and before disintegration takes place are not capable of supplying plant food. Potash feldspar contains from 12 to 15 per cent of potash, none of which is of value as plant food until disintegrated. When feldspar undergoes disintegration, it produces *kaolin* or clay. A soil formed from feldspar is usually well stocked with potash. Feldspar containing lime readily yields to the solvent action of water in which there is carbon dioxide.

Orthoclase,	$AlKSi_3O_8$	Potash feldspar
Albite,	$AlNaSi_3O_8$	Sodium feldspar

69. Hornblende. — The hornblende and augite groups are formed by the union of magnesium, calcium, iron, and manganese, with silica. As a rule none of the members of the alkali family are present in hornblende. The augites are double silicates of iron, manganese, calcium, and magnesium. Quite frequently, phosphoric acid is in chemical combination with the iron. The members of this group are readily distinguished by their color, which is black, brown, or brownish green. The hornblendes which contain lime are quite readily decomposed when subjected to weathering and the action of water charged with carbon dioxide. They are mainly insoluble in acids, and do not as a rule form very fertile soils.

70. Mica. — Mica is quite complex in composition, is an abundant mineral, and is composed of silica, iron, alumina, manganese, calcium, magnesium, and potassium. Mica is a polysilicate. The color may be white, brown, black, or bluish green, owing either to the absence of iron, or to its presence in various amounts. The chief physical characteristic of the members of this group is the ease with which they are split into thin layers. It is to be observed that the mica group contains all the elements of both feldspar and hornblende. Mica is quite resistant to chemical change.

Soils formed from thoroughly disintegrated mica are usually fertile, owing to the variety of essential elements present.

71. Granite is composed of quartz, feldspar, and mica. It is a very hard rock and slow to disintegrate. The different shades of granite depend upon the proportion in which the various minerals are present. Inasmuch as it contains so many minerals, it usually follows that granite soil is fertile; although when not completely disintegrated or when disintegrated and leached, it is unproductive. Pure powdered granite before undergoing disintegration furnishes but little plant food. After weathering, the plant food gradually becomes available. Granite varies in both physical and chemical composition, and some disintegrates more readily than others. Gneiss belongs to the granite series, but differs from true granite in containing a large amount of mica. Mica schist contains a larger amount of mica than gneiss.

72. Zeolites. — The zeolites are a large group of secondary or derivative minerals formed from disintegrated rock. They are polysilicates containing alumina and members of the alkali and lime families, and all contain water held in chemical combination. They are partially soluble in dilute hydrochloric acid and belong to that class of compounds which are capable, to a certain extent, of becoming available as plant food. In color, they are white, gray, or red. Zeolites are quite abundant in clay and are an important factor in soil fertility. It is this group of hydrated silicates which takes such an important part in the process of fixation. The zeolites, when disintegrated, particularly by glacial action, form very fertile soils.

73. Apatite or Phosphate Rock. — Apatite is composed mainly of phosphate of lime, $Ca_3(PO_4)_2$, together with small amounts of other compounds, as fluorides and chlorides. It is generally of a green or yellow color and is present in many soils, but is of little value as plant food unless associated with organic matter and soluble alkaline salts.

74. Kaolin is chemically pure clay and is formed by the disintegration of feldspar. When feldspar is decomposed and acted upon by water, the potash is removed and water of hydration is taken up, forming the product kaolin, which is hydrated silicate of alumina, $Al_4(SiO_4)_3 . H_2O$. Impure varieties of clay are colored red and yellow owing to the presence of iron and other impurities. Pure kaolin is white, is insoluble in acids, and is incapable of supplying any nourishment to plants. Clay soils are fertile on account of the other minerals and organic matter mixed with the clay and are usually well stocked with potash because of its incomplete removal from the disintegrated feldspar. It is to be observed that the term 'clay' used chemically means aluminum silicate, while physically it is any substance the particles of which are less than 0.005 mm. in diameter.

75. Limestone.—Limestone is present in many secondary rocks. It is composed of calcium carbonate and is slowly soluble in water containing carbon dioxide. Extensive deposits of calcium carbonate, as limestone, marble, and chalk, occur in nature. It is widely diffused in soils, and is a constituent that imparts fertility. Many soils contain appreciable amounts of disintegrated limestone.

76. Disintegration of Rocks and Minerals. — In addition to the rocks and minerals which have been mentioned, there are many others that contribute to soil formation, as glauconite, a hydrated silicate of iron; alumina and potash; limonite, a hydrated oxide of iron; dolomite, a double carbonate of calcium and magnesium; serpentine, a silicate of magnesium; and gypsum calcium sulphate. All rocks and minerals are subject to disintegration and change in chemical composition and physical properties. The process of soil formation has resulted in numerous chemical and physical changes. These changes are still taking place, and as a result plant food is constantly being made available.

Chemical Composition of Rocks[11]

	Silica SiO_2	Alumina Al_2O_3	Potash K_2O	Soda Na_2O	Lime CaO	Magnesia MgO	Ferric Oxide Fe_2O_3	Water H_2O
Quartz . . .	95–100	—	—	—	—	—	—	—
Feldspar . .	55–67	20–29	0–12	1–10	1–11	—	—	—
Kaolin . . .	46	39	—	—	—	—	—	14
Apatite . .	—	—	—	—	53	—	(P_2O_5 42)	—
Mica	40–45	12–37	5–12	—	—	—	—	1–5
Hornblende	40–55	0–15	—	—	—	—	—	—
Granite . .	60–80	10–15	4–5	—	—	—	2–3	—

77. Value of Geological Study of Soils. — Agricultural geology is a valuable aid in studying soil problems, but like other sciences it is incapable alone of solving all the problems of soil fertility. Means have not yet been devised for accurately determining the extent of rock disintegration and the rapidity with which it has taken place or the degree to which disintegrated minerals have been removed from rocks by leaching and other agencies. It is known that the rate of weathering of soils is influenced by various factors, as origin, texture, composition, humidity and other climatic conditions, presence of decaying organic matter, micro-organisms, mechanical treatment and manipulation of the soil, fertilizers, sunlight and vegetation. Some of these agencies for promoting soil disintegration are under the control of the farmer and are utilized by him in rendering plant food available. A knowledge of the origin of soils, of the minerals of which they are composed, and of the ways in which they have been distributed is of much assistance in determining their agricultural value.

CHAPTER III

THE CHEMICAL COMPOSITION OF SOILS

78. Elements Present in Soils. — Physically considered, a soil is composed of disintegrated rock mixed with animal and vegetable matter; chemically considered, the rock particles consist of a large number of simple and complex compounds, each compound being composed of elements chemically united. Elements unite to form compounds, compounds to form minerals, minerals to form rocks, and disintegrated rock forms soil. When rocks decompose, the disintegration, except in a few cases, is never carried to the extent of liberating the elements, but the process ceases when the minerals have been broken up into compounds. While there are present in the crust of the earth between 65 and 70 elements, only about 15 are found in animal and plant bodies, and of these but 12 are known to be absolutely essential. Only four of the elements which are of most importance are at all liable to be deficient in soils. These four elements are: nitrogen, phosphorus, potassium, and calcium.

79. Classification of the Elements. — The elements found most abundantly in soils are divided into two classes:

Acid-forming Elements		Base-forming Elements	
Oxygen	O	Aluminum	Al
Silicon	Si	Potassium	K
Phosphorus	P	Sodium	Na
Sulphur	S	Calcium	Ca
Chlorine	Cl	Magnesium	Mg
Nitrogen	N	Iron	Fe
Hydrogen	H		
Carbon	C		

Boron, fluorine, manganese, and barium are usually present in small amounts, besides others which may be found in traces, as the rare elements lithium and titanium.

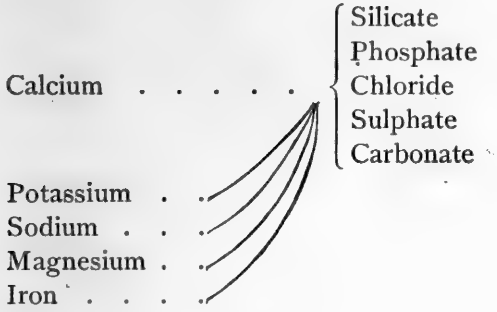
For crop purposes the elements of the soil may be divided into three classes:

1. Essential elements most liable to be deficient; nitrogen, potassium, phosphorus, and calcium.

2. Essential elements usually abundant; iron, magnesium, and sulphur.

3. Unnecessary and accidental elements, usually abundant; as chlorine, silicon, aluminum, and manganese.

80. Combination of Elements. — In dealing with the composition of soils, the percentage amounts of the individual elements are not given, except in the case of nitrogen, but instead, the amounts of the corresponding oxides. The elements do not exist in a free state in soils, but are combined with oxygen and other elements to form compounds. When considered as oxides, the acid and basic constituents may form various compounds as:



The following reactions will explain some of the more elementary combinations:

$$\begin{array}{ll} CaO + SiO_2 = CaSiO_3 & CaO + N_2O_5 = Ca(NO_3)_2 \\ 3CaO + P_2O_5 = Ca_3(PO_4)_2 & K_2O + SO_3 = K_2SO_4 \\ CaO + SO_3 = CaSO_4 & Na_2O + SO_3 = Na_2SO_4 \\ CaO + CO_2 = CaCO_3 & MgO + SO_3 = MgSO_4 \end{array}$$

It is often difficult to determine with accuracy the exact form or combination in which an element is present in the soil. When reported as the oxide, bases may be considered as combined with any of the oxides of the acid-forming elements, as indicated by the reactions, to form salts. Each compound of an element may have a different value as plant food, hence it is important to determine as far as possible the form or solubility of the various elements of plant food.

ACID-FORMING ELEMENTS

81. Silicon. — The element silicon makes up from a quarter to a third of the solid crust of the earth and next to oxygen is the most abundant element found in soils. Silicon never occurs in the soil in the free state. It either combines with oxygen to form silica (SiO_2), or with oxygen and some base-forming element or elements to form silicates. Silica and the various silicates are by far the most abundant compounds present in the soil. Silicon is not one of the elements absolutely necessary for plant growth, and even if it were, all soils are so abundantly supplied that it would not be necessary to use it in fertilizers.

When two or more base-forming elements are united with the silicate radical, a double silicate results. The double silicates are the most common compounds present in soils. There are also a number of forms of silicic acid which greatly increase the number of silicates, and a study of the composition of soils is largely a study of these various silicates.

82. Carbon is an acid-forming element and belongs to the same family as silicon. It is found in the soil as one of the main constituents of the volatile or organic compounds, and also unites with oxygen and the base-forming elements, producing carbonates, as calcium carbonate or limestone. The carbon of the soil takes no direct part in forming the carbon compounds of plants. It is not necessary to apply carbon fertilizers to produce the carbon compounds of plants, because the carbon dioxide of the air is the source for crop production. It is estimated that there are 30 tons of carbon dioxide in the air over every acre of the earth's surface.[22] The carbon in the soil is an indirect element of fertility, because it is usually combined with other elements, as nitrogen and phosphorus, which are absolutely necessary for crop growth.

83. Sulphur occurs in all soils mainly in the form of sulphates, as calcium sulphate, magnesium sulphate, and sodium sulphate. It is an essential element of plant food. There is generally less than 0.10 per cent of sulphuric anhydride in ordinary soils, but the amount required by crops is small and there is usually an abundance.

84. Chlorine is found in all soils, generally in combination with sodium, as sodium chloride. It may be in combination with other bases. Soils which contain more than 0.2 per cent are, as a rule, sterile. Chlorine is present in the soil in soluble forms. It occurs in all plants but is not absolutely necessary for plant growth. Its use in fertilizers is unnecessary, although chlorine with sodium, as common salt, is sometimes used as an indirect fertilizer.

85. Phosphorus, one of the essential elements for plant growth, is combined with both the volatile and non-volatile elements of the soil. Plants cannot make use of it in other forms than the phosphates. Phosphorus is usually present in the soil as calcium phosphate, magnesium phosphate, or aluminum phosphate, and may also be combined with the humus, forming humic phosphates. The form of the phosphates, as available or unavailable, is an important factor in soil fertility. Soils are quite liable to be deficient in phosphates, inasmuch as they are so largely drawn upon by many crops, particularly grain crops, where the phosphates accumulate in the seed, and are sold from the farm. The phosphorus content of soils is usually reported as phosphorus pentoxide (P_2O_5), anhydrous phosphoric acid, commonly called phosphoric acid.

86. Nitrogen. — This element is present in soils in various forms. As a mineral constituent it is combined with oxygen and the base-forming elements as potassium, sodium, and calcium, forming nitrates and nitrites, which, on account of their solubility, are never found in average soils in large amounts. Nitrogen is mainly in organic combination, being associated with carbon, hydrogen, and oxygen as one of the elements forming the organic matter of soils. Nitrogen may also be present in small amounts in the form of ammonia, or of ammonium salts, derived from rain water and from the decay of vegetable and animal matter. While free nitrogen is in the air in large amounts, it can be appropriated as food in this form by only a limited number of plants and by them indirectly. For ordinary agricultural crops, particularly the cereals, nitrogen must be present in the soil as combined nitrogen. This is the most expensive of any of the elements of plant food, and is liable to be deficient. No other element takes such an important part in agriculture or in life processes as does nitrogen.

87. Oxygen. — Oxygen is combined with both the acid- and base-forming elements and is found in nearly all of the compounds of the soil. It has been estimated that about one half of the crust of the earth is composed of oxygen, which in large amounts is combined with silicon, forming silica. That which is held in chemical combination in the soil takes no part in the formation of plant tissue. In addition to being present in the soil, oxygen constitutes eight ninths of the weight of water and about one fifth of the weight of air. It also forms about 50 per cent of the compounds found in plants and animals. Oxygen in the interstices of the soil is an active agent in bringing about many chemical changes, as oxidation of the organic matter, and disintegration of the soil particles.

88. Hydrogen. — This element is never found in a free state in the soil, but is combined with carbon and oxygen in animal and vegetable matter, with oxygen to form water, and in a few cases with some of the base elements to form hydroxides. It is not in the soil in large amounts, and that which forms a part of the tissues of plants and animals comes from the hydrogen in water. Hydrogen in the organic matter of soils takes no part directly in producing the hydrogen compounds of plants. On account of its lightness, hydrogen never makes up a very large proportion, by weight, of the composition of bodies.

BASE-FORMING ELEMENTS

89. **Aluminum** is present in the soil in the largest amount of any of the base elements. It forms probably from 6 to 10 per cent of the solid crust of the earth. As previously stated aluminum is one of the constituents of clay, and is not necessary for plant growth. Physically, however, the aluminum compounds take an important part in soil fertility. Aluminum is usually in combination with silica or with silica and some base-forming element, as iron, potassium, or sodium. The various forms of aluminum silicate are the most numerous compounds found in soils. Alumina is the oxide of aluminum, Al_2O_3, and is the usual form in which this element is reported in soil and rock analyses.

90. **Potassium** is in the soil mainly in the form of silicates, and is one of the elements absolutely necessary for plant growth. The term 'potash' (potassium oxide, K_2O) is usually employed when reference is made to the potassium compounds. The amount and form of

the soil potash have an important bearing upon fertility. Potassium is one of the three elements of plant food usually supplied in fertilizers. The form in which it is in the soil and its economic supply as plant food are important factors in crop production. The amount of potash in soils ranges from 0.02 to 0.8 per cent. In a fertile soil it rarely falls below 0.2 per cent.

91. Calcium is in the soil in a variety of forms, as calcium carbonate, calcium silicate, calcium sulphate, and calcium phosphate. The calcium oxide, CaO, of the soil is generally spoken of as the lime content. Calcium carbonate and sulphate are important factors in imparting fertility. A subsoil with a good supply of lime will stand heavy cropping and remain in excellent chemical and physical condition for crop growth. In a good soil there is usually 0.2 per cent or more of lime, mainly as calcium carbonate.

92. Magnesium is found in all soils and is usually associated with calcium, forming the mineral dolomite, which is a double carbonate of calcium and magnesium. Magnesium may also be present in the soil in the form of magnesium sulphate or magnesium chloride. All crops require a certain amount of magnesia in some form, in order to reach maturity and produce fertile seeds. There is generally in all soils an amount sufficient for crop purposes, hence it is not necessary to consider this element in connection with fertilizers.

The term 'magnesia' (magnesium oxide, MgO) is used when reference is made to the magnesium compounds of the soil.

93. Sodium is in the soil mainly as sodium silicate, and to about the same extent as potassium, which it resembles chemically in many ways. It cannot, however, replace potassium in plant growth. Inasmuch as sodium takes an indifferent part in plant nutrition, it is never used as a fertilizer except in an indirect way.

94. Iron is an element necessary for plant food and is found in all soils to the extent of from 1 to 4 per cent. Crops require only a small amount of iron, hence there is always sufficient for crop purposes. Iron in soils is in the form of oxides, hydroxides, and silicates.

FORMS OF PLANT FOOD

95. Three Classes of Compounds. — For agricultural purposes, the compounds present in soils may be divided into three classes :[9] (1) Compounds soluble in water and dilute organic and mineral acids ; (2) compounds soluble in more concentrated acids ; (3) insoluble compounds decomposed by strong acids and fluxes.

96. Water- and Dilute Acid-soluble Matter of Soils. — This class includes silicates and other compounds of potash, soda, lime, magnesia, phosphorus, etc., which are soluble in the soil water and in very dilute organic and mineral acids, and represents the most soluble and the most active and valuable forms of plant food. There is only a very small amount in these forms. In 100 pounds of arable soil, rarely more than 0.005 pound of any one of the important elements is soluble in the soil water or more than 0.05 pound in dilute organic acids.

FIG. 23. Oat Plant grown in soil extracted with hydrochloric acid.

97. Acid-soluble Matter of Soils. — The plant food of the second class is in a somewhat more insoluble form, and consists of compounds, principally the zeolites, soluble in hydrochloric acid of 23 per cent strength, sp. gr. 1.115. This represents the limit of the solvent action of the roots of plants.[9] In this class are included also all the mineral elements combined with the humus and soluble in dilute alkalies. As a rule, not over 10 to 20 per cent of the total soil is soluble in hydrochloric acid; and the more important elements make up only a small part of this amount. In 200 samples of soil, the potash, nitrogen, lime, magnesia, and phosphoric and sulphuric anhydrides amounted to 3.5 per cent; in many fertile soils the sum of these is less than 1.50 per cent. This means that in every 100 pounds of soil there are only from 1.5 to 3.5 pounds which can take any active part in the support of a crop, while 96 to 98.5 pounds are present simply as so much inert material, and valuable only from a physical point of view. Not all of the potash, for example, soluble in hydrochloric acid is equally valuable. In fact, the acid represents more than the limit of the crop's feeding power, when there is not enough of more soluble forms to aid in the first stages of growth.

98. Acid-insoluble Matter of Soils. — This class includes all of those compounds of the soil which require the joint action of the highest heat and the strongest chemicals in order to decompose them. The insoluble residue obtained after digesting a soil with strong hydrochloric acid contains potash, soda, and limited amounts of magnesia and phosphoric acid, with other elements which are of no immediate value as plant food. When seed was planted in soil extracted with strong hydrochloric acid, it made no growth after the reserve food in the seed had been exhausted. A plant grown in such a soil is shown in the illustration.[84] (Fig. 23.)

The acid-insoluble matter of soils is capable of undergoing disintegration and in time may be changed to the second or zeolitic class of silicates. This process, however, is too slow to be relied upon as an immediate source of plant food.

In the following table are given the percentage amounts of compounds soluble and insoluble in hydrochloric acid for a few typical soils:[9]

	Wheat Soil		Heavy Clay Soil		Grass and Grain Soil	
	Soluble in HCl	Insoluble residue	Soluble in HCl	Insoluble residue	Soluble in HCl	Insoluble residue
Insoluble matter	63.07	——	84.77	——	84.08	——
Potash	0.54	2.18	0.21	3.46	0.30	1.45
Soda	0.45	3.55	0.22	2.95	0.25	0.25
Lime	2.44	0.36	0.48	0.16	0.51	0.35
Magnesia	1.85	0.25	0.34	0.47	0.26	0.46
Iron	4.18	0.78	3.76	0.72	2.56	1.07
Alumina	7.89	5.54	6.26	5.44	2.99	9.72
Phosphoric acid	0.38	——	0.12	0.08	0.23	0.05
Sulphuric acid	0.11	0.24	0.09	0.25	0.08	0.02

The insoluble matter, after digestion with hydrochloric acid, was submitted to fusion analysis, and the figures given under insoluble residue represent the amounts of potash, soda, etc., insoluble in the acid. In the clay soil, 94 per cent of the total potash was in forms insoluble in hydrochloric acid.

99. Soluble and Insoluble Potash and Phosphoric Acid. — From the preceding table it is to be observed that the larger portion of the potash in the soil is insoluble in hydrochloric acid. A soil may contain from 2 to 3 per cent of total potash, and 90 per cent or more may be in such firm chemical combination with aluminum, silicon, and other elements, as to resist the solvent action of plant roots. The larger portion of the phosphoric acid of the soil is soluble in hydrochloric acid. In some soils, however, from 20 to 40 per cent is present as the third class of compounds. When a soil is digested with hydrochloric acid, the insoluble residue is usually a fine gray powder. Some clay soils retain their red color even after treatment with acids, showing that the iron is in part in chemical combination with the more complex silicates.

In order to decompose the insoluble residue obtained from the treatment with hydrochloric acid, fluxes, as sodium carbonate and calcium carbonate, are employed which, at a high temperature, act upon the complex silicates and produce silicates soluble in acids. Plants, however, are unable to obtain food in such complex forms of chemical combination.

100. Action of Organic and Dilute Mineral Acids upon Soils. — Dilute organic acids, as a 1 per cent solution of citric acid, have been proposed as solvents for the determination of easily available plant food. It has been shown in the case of the Rothamsted soils which have produced 50 crops of grain without manure, and which are markedly deficient in available phosphoric

FIG. 24. Wheat Plant grown in soil extracted with dilute citric acid; showing that this solvent does not remove all of the available plant food from a soil.

acid, that a 1 per cent solution of citric acid dissolved only 0.003 per cent of phosphoric acid while the soil contained a total of 0.12 per cent. In the case of an adjoining plot which had received phosphate manures until the soil contained a sufficient amount of available phosphoric acid to produce good crops, there was present 0.03 per cent of phosphoric acid soluble in a 1 per cent citric acid solution.[23]

Dilute organic acids are, to a certain extent, capable of showing deficiency of plant food. A soil which has 0.03 per cent of potash or phosphoric acid soluble in 1 per cent citric acid is, as a rule, well stocked with these elements in available forms. Prairie soils of high fertility yield from 0.03 to 0.05 per cent of both potash and phosphoric acid soluble in dilute organic acids; soils which are deficient in these elements usually contain less than 0.01 per cent.

The action of a single organic acid of specific strength cannot be taken as the measure of fertility for all soils and crops alike, because different plants do not have the same amount or kind of organic acid in the sap. Of the various organic acids, citric possesses the greatest solvent action upon lime, magnesia, and phosphoric acid, while oxalic has the strongest solvent action upon the silicates. Tartaric acid appears to be less active as a solvent than either citric or oxalic acid. The combined use of dilute organic acids, as citric with hydrochloric (sp. gr. 1.115), will generally give an accurate idea of the character of a soil. A fifth-normal solution of hydrochloric, or of nitric acid, has also been proposed[24] for determining the available plant food of soils; a soil that yields less than 25 parts of phosphoric acid per million of soil, as soluble in fifth-normal nitric acid, is deficient in available phosphates.

The use of dilute organic acids renders it possible to detect small amounts of readily soluble phosphoric acid and potash. It has been stated that when a soil has been manured a few years with a phosphate fertilizer and brought into good condition as to available phosphoric acid, a chemical analysis will fail to detect any difference in the soil before and after the treatment with fertilizer. In the case of hydrochloric acid as a solvent, this is true, as an acre of soil to the depth of one foot weighs about 3,500,000 pounds and 500 pounds of a phosphate fertilizer would increase the total amount of phosphoric acid about 0.0002 per cent, which is less than can be accurately determined by analysis. When, however, a dilute organic acid is used, only the more easily soluble phosphoric acid is dissolved, and this readily allows fertilized and unfertilized soils to be distinguished. By the use of dilute organic and mineral acids decided differences have been shown between fertilized and unfertilized soils.

101. Sampling Soils. — A composite sample of the soil of a field is obtained by taking several small samples to a depth of 6 to 12 inches, from different places, and uniting them to form one sample. Samples of subsoil also are taken from the same places. There is usually a sharp line of demarcation between the surface soil and subsoil. It is the aim to secure in each case as representative a sample as possible. All coarse stones and roots are removed and a record is made of the amount of these. The soil is air-dried, the hard lumps are crushed, and the material mixed and passed through a sieve with holes 0.5 mm. in diameter. Only the fine earth is used for the chemical analysis.

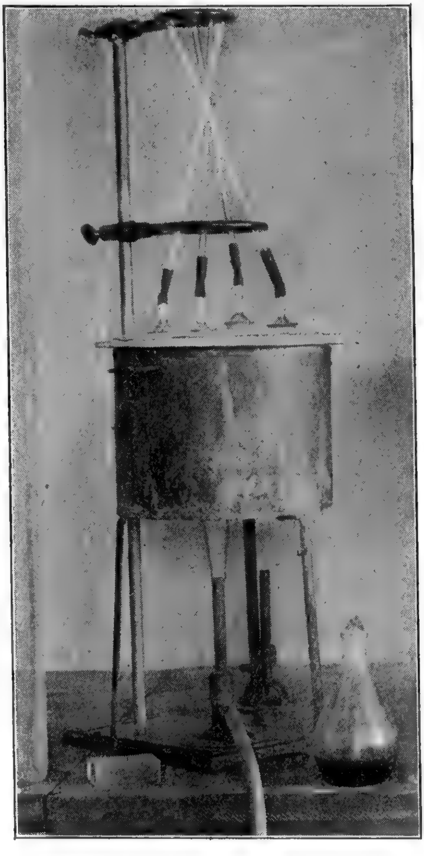


FIG. 25. Soil Flask and Acid Digestion of Soils.

102. Analysis of Acid-soluble Extract of Soils. — Ten grams of soil are weighed into a soil digestion flask, and 10 cc. hydrochloric acid (sp. gr. 1.115) are added for every gram of soil used. The soil digestion flask is then placed in a hot-water bath and the digestion carried on for twelve to thirty-six hours at the temperature of boiling water.[25] After digestion is completed the contents of the flask are transferred to a filter and separated into the insoluble part, and the acid solution which contains the soluble compounds of the various elements. The table on page 89 gives a general idea of the process of soil analysis. One half of the acid solution is used for obtaining the metals as noted on page 89. The second half is divided into two portions, — the first portion to be used for the determination of phosphoric acid, which is precipitated with ammonium molybdate, and the second portion to be used for the determination of sulphuric acid, which is precipitated as barium sulphate. The carbon dioxide is determined in a fresh portion of the original soil, the acid being liberated with hydrochloric acid and the carbon dioxide retained by absorbents and weighed. The nitrogen and humus are determined in separate portions of the original soil. The analysis of soils involves the use of accurate and well-known methods of analytical chemistry, a discussion of which would not be germane to this work.

103. Value of Soil Analysis. — Opinions differ as to the value of soil analysis. It is claimed by some that a chemical analysis of a soil is of no practical value because it fails to give the amount of available plant food. A soil may have, for example, 0.4 per cent of potash soluble in hydrochloric acid and still not contain sufficient available potash to produce a good crop, while another soil may contain 0.2 per cent of potash

ANALYSIS OF SOIL

<table>
<tr><td colspan="5">Soil digested with hydrochloric acid and filtered; an insoluble residue and an acid solution are obtained. One half of filtrate is used as noted below.</td></tr>
<tr><td rowspan="4">Residue. — Either dried, ignited and weighed as insoluble matter, or analyzed by fusion process.</td><td colspan="4">Filtrate, after removing soluble silica, is rendered alkaline with ammonia and a precipitate obtained.</td></tr>
<tr><td rowspan="3">Precipitate contains: iron, alumina, and phosphoric acid. Precipitate ignited and weighed. Dissolved in sulphuric acid and iron determined. The phosphoric acid is determined from a separate portion of the original solution. Sum of iron and phosphoric acid subtracted from total precipitate gives alumina.</td><td colspan="3">Filtrate. — Ammonium oxalate is added and a precipitate is obtained.</td></tr>
<tr><td rowspan="2">Precipitate is calcium oxalate.</td><td colspan="2">Filtrate. — Divide into two parts.</td></tr>
<tr><td>To one part, sodium phosphate and ammonia are added. Precipitate obtained is ammonium magnesium phosphate.</td><td>Potash and soda are determined after all other materials are removed.</td></tr>
</table>

soluble in hydrochloric acid and produce good crops. While these conditions are frequently observed, it does not necessarily follow that the chemical analysis of a soil is of no value, as often the results are not correctly interpreted. Then, too, other solvents than hydrochloric acid are used for determining the more active forms of plant food. Hydrochloric acid is generally used because it represents the limit of the solvent power of plants.[9] The figures obtained by the hydrochloric acid solvent are valuable, as they indicate whenever an element is present in amounts too limited for crop production. Suppose a soil contain 0.02 per cent of acid-soluble potash; this would be too small an amount to produce good crops. On the other hand, the soil might contain 0.5 per cent and yet not have sufficient available potash for crop growth. Hence it is that in interpreting results, the hydrochloric acid solvent may show when a soil is wholly deficient in any one element, as sometimes occurs, but it does not necessarily show a deficiency in the case of a soil rich in acid-soluble potash; this can, however, be approximately indicated, by the use of other solvents, as explained in previous sections. Hydrochloric acid is mainly valuable in determining the general character of the soil, rather than its amount of available plant food.

104. Interpretation of Soil Analysis. — In the analysis of soils their reaction as acid, alkaline, or neutral, should be determined, because plant food exists in a different form in each class of soils. If a soil contain from 0.3 to 0.5 per cent or more of lime and from 0.1 to 0.4 per cent of combined carbon dioxide, and is not strongly alkaline, there is a reasonable content of lime carbonate. If, however, the soil contain only a trace of carbon dioxide, the lime is not present as carbonate, but probably as a silicate, in which case the soil may be deficient in active lime compounds.

In the case of phosphoric acid, a soil which gives an alkaline or neutral reaction, contains 0.15 per cent of phosphorus pentoxide and is well supplied with organic matter and lime, is amply provided with phosphoric acid, and under such conditions the use of phosphate fertilizers is not required, except possibly for special crops. Hilgard states that should the per cent of phosphoric acid be as low as 0.05, there is, in all probability, a deficiency of this element. It frequently happens that in acid soils the phosphoric acid is unavailable until a lime fertilizer is used to neutralize the acid.

Soils containing less than 0.07 per cent of total nitrogen are usually deficient, and one containing as high as 0.15 or 0.2 per cent may fail to respond to crop production, but such a case is generally due to some abnormal condition of the soil, as lack of alkaline compounds which are necessary for nitrification. The appearance of the crop is one of the best indications as to deficiency of nitrogen.

A soil which contains less than 0.10 per cent of potash soluble in hydrochloric acid is quite apt to be deficient in this element. Soils which contain 0.5 per cent or more of lime carbonate will produce good crops on a smaller working supply of potash than soils which are deficient in lime. As a rule the best agricultural soils contain from 0.3 to 0.6 per cent of potash. Sandy soils of good depth may contain less plant food than the figures given, and not be in need of fertilizers.

The best results are obtained from soil analysis when an extended study is made of the soils of a locality. Then a soil of that region which fails to produce good crops can be compared with a productive soil of known composition. An isolated soil analysis, like an isolated analysis of well water, frequently fails in its object because of a lack of proper normal standards for comparison. Where extended series of soil analyses have been made, much valuable information has been obtained.

The term 'volatile matter' of a soil is sometimes incorrectly used for organic matter. The volatile matter includes the organic matter and also the water which is held in chemical combination, as in the hydrated silicates. A soil may have a high per cent of volatile matter and contain very little organic matter. Indeed, all clays contain from 5 to 9 per cent of water of hydration. The per cent of humus, as will be explained in the next chapter, does not represent all of the organic matter.

105. Total and Available Plant Food. — Suppose a soil contain 0.40 per cent of acid-soluble potash and field experiments indicate there is a deficiency of available potash. This may be due to some abnormal condition of the soil, as an insufficient amount of other alkaline compounds, as calcium carbonate, to take the place of the potash which has been withdrawn by the crop, or lost by leaching, in which case the deficiency of available potash can be remedied without purchasing soluble potash fertilizer. Where a soil contains only 0.04 per cent of acid-soluble potash, the purchasing of potash fertilizers is more necessary, but with 0.40 per cent the way is open to render this available for crops. The various ways of rendering acid-insoluble potash and other compounds available for crop production, as by rotation of crops, use of farm manures, use of lime and green manures, or by different methods of cultivation have not been sufficiently studied as yet to offer a solution to all of the problems of rendering inert plant food available.

106. Distribution of Plant Food. — In studying the chemical composition of a soil, the surface soil and subsoil both require consideration. It frequently happens that these have entirely different chemical, as well as physical, properties, and that a soil fault, as lack of potash in the surface soil, is corrected by a high per cent of that element in the subsoil. This is particularly true of some of the prairie soils, where the surface soils generally contain less potash and lime, but more nitrogen and phosphoric acid, than the subsoils. When jointly considered the surface and subsoil have a good supply of available plant food, but if considered separately each would have weak points.

Since plant food is obtained mainly from the silt and clay, the amount present in these grades of particles determines largely the reserve fertility of a soil. A soil in which 70 per cent of the total potash is present in the silt and clay is in better condition for crop production than a similar soil with a like amount of potash which is present mainly in the sand. Because a soil has a given composition, it does not follow that all of the different grades of particles have the same composition. In fact, the different grades of soil particles in one soil may have as varied a composition as is met with among different soils.[26]

The figures under 1 in the table give the composition of the particles, while under 2 are the results calculated on the basis of the total amount of each element in the soil. For example, the clay contains 1.47 per cent of potash, while 50.8 per cent of the total potash of the soil is in the clay particles.

A soil may contain a low per cent of an element, mainly in the finer particles and evenly distributed so the crop is better supplied with food than if more were present in the larger particles, unevenly distributed. The distribution of plant food in the soil has not been so extensively studied as the question of total plant food. The distribution of plant food in both surface soil and subsoil, as well as in the various grades of soil particles, is an important factor of fertility.

	Composition of Soil	Composition of Particles							
		0.5 mm. diameter. 13.67 per cent		0.25 mm. diameter. 12.54 per cent		< 0.25 mm. diameter. 23.56 per cent		Clay 21.64 per cent	
	Per cent	1	2	1	2	1	2	1	2
Insoluble matter	82.83	96.48	15.75	92.23	13.95	83.12	23.76	49.06	13.92
Potash, K_2O	0.63	0.12	1.60	0.29	6.35	0.53	19.05	1.47	50.80
Soda, Na_2O	0.09	0.21	—	0.28	—	0.24	—	—	—
Lime, CaO	0.27	0.09	3.70	0.18	8.10	0.13	11.11	0.09	11.11
Magnesia, MgO	0.45	0.10	2.22	0.26	6.66	0.46	24.44	1.33	64.44
Ferric oxide, Fe_2O_3	5.11	1.03	2.74	2.34	5.67	4.76	21.72	18.76	79.45
Alumina, Al_2O_3	8.09	1.21	2.10	2.64	4.07	4.32	12.85	18.19	49.01
Phosphoric acid, P_2O_5	0.21	0.02	—	0.03	—	0.11	9.52	0.18	19.01
Sulphuric acid, SO_3	0.02	0.03	—	0.03	—	0.02	50.00	0.06	50.00
Volatile matter, CO_2	3.14	0.92	9.23	1.72	7.32	5.61	45.50	9.00	42.30

107. Composition of Typical Soils. — A few examples are given, in tabular form, of the chemical composition of soils from different regions in the United States. On account of variations in the same locality, the figures represent the composition of only limited soil areas. There have been made in the United States a large number of soil analyses which as yet have not been compiled or studied in a systematic way.

108. Alkaline Soils. — When a soil contains enough alkaline salts, as sodium sulphate, sodium or potassium carbonate or chloride, to be destructive to vegetation, it is called an 'alkali' soil. These soils are found in semi-arid regions, and wherever conditions have been such that the alkaline compounds have not been drained from the soil. Occasionally calcium chloride is the destructive material. Sodium sulphate is a milder form. Alkaline carbonates are destructive to vegetation when present to the extent of more than 1 part per 1000 parts of soil. When evaporation takes place, the alkaline compounds are deposited as a coating on the surface of the soil. Of these sodium carbonate is one of the most injurious; it exerts a solvent action upon the humus, forming a black solution which evaporates and leaves the so-called 'black alkali.' Many soils supposed to be strongly alkaline, because a white coating is formed on the surface, simply contain so much lime carbonate that a deposit is formed. Excellent soils have been passed over as 'alkali' soils when in reality they are limestone soils.

COMPOSITION OF TYPICAL SOILS[9]

	SOIL FROM RED RIVER VALLEY[5]		VIRGIN PRAIRIE SOIL[5]			PINE FOREST SOIL		OAK-TIMBERED SOIL		PEATY SOIL	AV. 200 FERTILE SOILS
	Surface Per cent	Subsoil Per cent	Surface 1 to 6 inches Per cent	Subsoil 6 to 12 inches Per cent	Subsoil 30 to 36 inches Per cent	Surface Per cent	Subsoil Per cent	Surface Per cent	Subsoil Per cent	Per cent	Surface Per cent
Insoluble matter	47.64	41.21	72.30	73.95	74.99	94.65	95.58	79.90	79.72	18.47	79.95
Silica (sol. in Na_2CO_3) .	15.43	8.37	6.77	6.58	—	—	—	—	—	—	—
Potash, K_2O	0.54	0.25	0.45	0.40	0.64	0.16	0.15	0.26	0.35	0.32	0.29
Soda, Na_2O	0.45	0.48	0.26	0.42	0.31	0.22	0.27	0.09	0.13	0.20	0.25
Lime, CaO	2.44	7.45	0.69	0.70	3.21	0.47	0.35	0.76	0.23	0.51	2.16
Magnesia, MgO	1.85	4.48	0.38	0.36	0.91	0.24	0.19	0.81	0.19	0.10	0.55
Iron oxide, Fe_2O_3 . . .	4.18	3.48	2.93	3.05	5.79	1.21	1.21	2.43	4.15	2.60	2.68
Alumina, Al_2O_3	7.89	10.72	3.19	4.63	2.91	1.29	1.54	5.02	7.34	1.38	5.20
Phosphoric anhydride, P_2O_5	0.38	0.17	0.35	0.26	0.17	0.13	0.09	0.30	0.11	0.32	0.24
Sulphuric anhydride, SO_3 .	0.11	0.10	0.06	0.04	0.05	0.10	0.05	0.05	0.03	1.06	0.03
Carbonic anhydride, CO_2 .	2.42	14.26	0.55	0.36	2.45	0.04	0.04	0.16	0.06	1.77	1.12
Volatile matter	15.55	6.22	10.90	9.12	8.27	1.51	0.74	8.68	7.02	71.80	7.00
Total	98.88	97.19	98.83	99.87	99.70	100.02	100.21	98.46	99.33	98.53	99.47
Volatile matter containing:											
Humus	5.34	0.89	5.12	—	—	0.47	—	2.48	—	—	3.35
Nitrogen	0.38	0.11	0.38	0.22	0.09	0.04	0.02	0.24	0.08	0.62	0.29

	COTTON SOIL[32] S. C. SEA COAST		BRAZOS RIVER SOIL[33] TEXAS		WASH-INGTON[34]	KENTUCKY SOIL[35]		CALIFORNIA FRUIT SOIL[36]	
	Surface	Subsoil	Surface	Subsoil	Surface soil	Virgin	Culti-vated	Surface	Subsoil
Insoluble matter	93.61	94.46	68.45	77.57	76.49	77.01	81.01	72.72	73.57
Silica (soluble in Na_2CO_3)	1.63	1.89	14.79	0.84	13.66	9.33	—	14.53	6.44
Potash, K_2O	0.05	0.14	1.10	0.44	0.63	0.30	0.32	0.68	1.35
Soda, Na_2O	0.11	0.15	0.23	1.82	0.37	0.39	0.19	0.24	0.25
Lime, CaO	0.03	0.02	5.62	0.18	1.08	0.40	0.32	1.15	0.57
Magnesia, Mgo	0.04	0.04	1.86	3.18	0.72	0.34	0.39	1.30	0.87
Iron oxide, Fe_2O_3 . . .	0.40	0.34	3.21	8.28	4.55	3.30	2.96	9.29	4.93
Alumina, Al_2O_3	1.93	2.52	7.68	0.13	7.52	6.70	5.92	8.29	8.72
Phosphoric anhydride, P_2O_5	0.03	0.01	0.14	—	0.14	0.50	0.38	0.12	0.07
Sulphuric anhydride, SO_3	trace	trace	0.05	—	—	0.17	0.16	0.07	0.04
Carbonic anhydride, CO_2	—	—	3.99	1.71	—	0.10	0.06	—	—
Volatile matter	1.69	1.04	2.50	2.50	3.61	10.59	8.33	6.09	2.91
Humus	0.70	—	—	—	0.99	2.21	2.01	1.09	—
Nitrogen	—	—	—	—	0.10	0.27	0.18	—	—

109. Improving Alkali Soils.[27] — When a large tract of alkali is to be brought under cultivation, the amount and kind of prevailing alkaline compound should be determined by chemical analysis. It frequently happens that improved drainage, coupled with a judicious irrigation system, is all the treatment necessary. If the prevailing alkali is sodium carbonate, a dressing of land plaster may be applied so as to change the alkali from sodium carbonate to sodium sulphate, a less destructive form, the reaction being

$$Na_2CO_3 + CaSO_4 = CaCO_3 + Na_2SO_4.$$

Some shrubs, as greasewood, and weeds, as Russian thistle, take from the soil large amounts of alkaline matter, and it is sometimes advisable to remove a number of such crops so as to reduce the alkali. A slightly beneficial effect is occasionally noticed on small 'alkali' spots where straw has been burned and the ashes used, forming potassium silicate. As a rule, however, ashes are more injurious than beneficial on an 'alkali' soil. Irrigation and thorough drainage, if continued long enough, will effect a permanent cure. Irrigation without drainage causes a worse alkaline condition by bringing to the surface subsoil alkali. All irrigated lands should be provided with suitable drainage systems to prevent accumulation of alkaline salts. The waters from some streams and wells are unsuited for irrigation because they contain too much alkaline matter.

Mildly alkaline soils will usually repay in crop production all the labor which is expended upon them, and when brought under cultivation are frequently very fertile. Some alkaline material in a soil is beneficial; in fact, many soils would be more productive if they contained a small amount. It is the excess of alkali that is destructive to plant life.

When the places are small and located so they can be underdrained at comparatively little expense, this should be done, as it will prove the best and most permanent way of removing the alkali. Good surface drainage should also be provided. Quite frequently a quarter or more of the total alkali in the soil will, in a dry time, be found near and on the surface. In such cases, and if the spots are small, a large amount of the alkali can be removed by scraping the surface and then carting the scrapings away and dumping them where they can do no damage.

When preparing a mildly alkaline spot for a crop, deep plowing should be practiced, so as to open up the soil and remove the excess of alkali from the surface. Where manure, particularly horse manure, can be obtained, these spots should be manured very heavily. The horse manure, when it decomposes, furnishes acid products, which combine with the alkaline salts. The manure also prevents rapid surface evaporation. Oats are about the safest grain crop to seed on an alkali spot because the oat plant is capable of thriving in an alkaline soil where many other grain crops fail.

Alkali soils are usually deficient in available nitrogen. The organism which carries on the work of changing the humus nitrogen to available forms cannot thrive in a strong alkaline solution. In many of these soils, as demonstrated in the laboratory, nitrification cannot take place. After thorough drainage and preparation for a crop, a few loads of good soil from a fertile field sprinkled on alkali spots will do much to encourage nitrification, by introducing the nitrifying organisms.

For a more extended account of the cause of alkali soils, and methods for improving them, the student is referred to Hilgard's "Soils."

110. Acid Soils. — When a soil is deficient in active alkali, and there is an excess of organic material, humic acid is formed from the decay of the animal and vegetable matter. Acid soils are readily detected by the reaction which they give with sensitive litmus paper. In making the test the moistened soil is pressed against blue litmus paper, which changes to red in the presence of free acids. Acid soils are made productive by using lime and other alkaline material to neutralize the humic acid before applying farm and other manures. Acid soils are not suitable for the production of clover and legumes.

Experiments by Wheeler at the Rhode Island Experiment Station indicate that there are large areas of acid soils in the eastern states which are much improved when treated with air-slaked lime.[30] There is great difference in the power of plants to live in acid soils. Some agricultural crops as legumes are particularly sensitive, while many weeds have such strong power of endurance that they thrive in the presence of acids. Weeds frequently reflect the character of a soil as to acidity, in the same way that an alkali soil is indicated by the plants produced. The acid and alkaline compounds of the soil greatly influence the bacterial flora. In the presence of strong acids or alkalis, many of the bacterial changes necessary for the elaboration of plant food fail to take place.

THE ORGANIC COMPOUNDS OF SOILS

111. Sources of the Organic Compounds of Soils. — The organic compounds of soils are composed of the elements carbon, hydrogen, oxygen, and nitrogen. When vegetable and animal material undergoes decay in contact with the soil, compounds, as carbon dioxide, water, ammonia,[28] organic acids, and various derivatives are formed, while some of the organic acids unite with the minerals of the soil to form humates. Micro-organisms take an important part in the decay of animal and vegetable matter and the production of organic compounds. In some soils, the organic compounds of plants, as cellulose, proteids, and carbohydrates, are present, while in others they have undergone partial oxidation. Some authorities claim that a portion of the initial organic matter of soils is the result of the workings of carbon assimilating micro-organisms. The main source of the soil's organic compounds, however, is the accumulated animal and vegetable remains in various stages of decay. The organic matter of soils is a mechanical mixture of a large number of organic compounds, many of which have not yet been studied.

112. Classification of the Organic Compounds. — Various attempts have been made to classify the organic compounds of the soil. An old classification by Mülder[29] was humic, ulmic, crenic, and approcrenic acids. None of these contain more than 4 per cent nitrogen, while organic matter with 8 to 10 per cent and in some cases 18 per cent is quite frequently met with; hence this classification is incomplete as it includes only a part of the organic compounds of the soil. For practical purposes the organic compounds of soils may be divided into three classes: (1) those of low nitrogen content, 1 to 4 per cent of nitrogen; (2) those of medium nitrogen content, 5 to 10 per cent; and (3) those of high nitrogen content, 11 to 20 per cent.

113. Humus. — The term 'humus' is employed to designate the most active of the organic compounds; it is the animal and vegetable matter of the soil in intermediate forms of decomposition. From different soils, it is extremely varied in composition; in one soil it may have been derived mainly from cellulose, while in another from a mixture of cellulose, proteid bodies, and other organic compounds. The term 'humus,' unless qualified, is a very indefinite one. Humus is obtained by extracting the soil with a dilute alkali, as ammonium hydroxide, after treating with a dilute acid to remove the lime which renders the humus insoluble.

114. Humification and Humates. — When the animal and vegetable matter incorporated with soils undergoes decomposition, there is a union of some of the organic compounds with the base-forming elements. The decaying organic matter produces organic products of an acid nature. The organic acids and the base-forming products unite to form humates or organic salts, which are neutral bodies. This process is humification.[18]

Humic acid + calcium carbonate = calcium humate + CO_2.
Humic acid + potassium chloride = potassium humate and soluble chlorides.

That a union occurs between the organic matter and the soil has been demonstrated by mixing with soils known amounts of definite organic compounds and various organic materials, as cow manure, green clover, meat scraps, and sawdust, and allowing humification to go on for a year or more. After humification had taken place, the humus extracted from the soil contained more potash and phosphoric acid, than were present in the humus of the original soil and the humus-forming material, showing a chemical change had taken place between the organic matter and the soil. The power of various organic substances to produce humates is illustrated in the following table: [18, 85]

	Humic Phosphoric Acid	Humic Potash
	Grams	Grams
Cow manure humus:		
In original manure and soil	1.17	1.06
In final humus product (after humification)	1.62	1.27
Gain in humic forms	0.45	0.21
Green clover humus:		
In original soil and clover	3.21	5.26
In final humus product	3.74	4.93
Gain in humic forms	0.53	0.33 (Loss)
Meat scrap humus:		
In original meat scraps and soil	1.07	0.25
In final humus product	1.18	0.36
Gain	0.11	0.11
Sawdust humus:		
In original sawdust and soil	0.85	0.67
In final humus product	0.78	0.70
Oat straw humus:		
In original straw and soil	1.02	2.42
In final humus product	1.03	2.41
Wheat gliadin humus:		
In original gliadin and soil	1.055	0.19
In final humus product	1.220	0.24
Gain	0.165	0.05
Egg albumin humus:		
In original albumin and soil	1.01	0.20
In final humus product	1.11	0.24
Gain	0.10	0.04

115. Comparative Value and Composition of Humates. — The humus produced from a nitrogenous material, as meat scraps, is more valuable than from cellulose bodies, as sawdust, because the former has greater power of combining with the phosphoric acid and potash of the soil. The non-nitrogenous compounds, as cellulose, starch, and sugar, undergo fermentation but seem to possess little, if any, power to form humates. There is also a great difference in soils as to their humus-producing power. Soils deficient in lime or alkaline compounds possess only a feeble power to produce humates. There is too a marked variation in the composition of the humus from different kinds of organic matter. Straw, sawdust, and sugar, materials rich in cellulose and other carbohydrates, yield a humus characteristically rich in carbon and poor in nitrogen. Materials rich in nitrogen, like meat scraps, green clover, and manure, produce a more valuable humus, rich in nitrogen and possessing the power to combine with the potash and phosphoric acid of the soil to form humates.

Composition of Humus produced by

	Cow manure	Green clover	Meat scraps	Wheat flour	Oat straw	Saw-dust	Sugar
Carbon	41.95	54.22	48.77	51.02	54.30	49.28	57.84
Hydrogen	6.26	3.40	4.30	3.82	2.48	3.33	3.04
Nitrogen	6.16	8.24	10.96	5.02	2.50	0.32	0.08
Oxygen	45.63	34.14	35.97	40.14	40.72	47.07	39.04
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00

	Highest	Lowest	Difference
Carbon	57.84	41.95	15.89
Hydrogen	6.26	2.48	3.78
Nitrogen	10.96	0.08	10.88
Oxygen	47.07	34.14	12.93

Variations in composition are noticeable. The humus produced from each material, as green clover, oat straw, or sawdust, is different from that produced from any other material. The humus from green clover is very complex in nature. It contains both nitrogenous and non-nitrogenous compounds, and each class has a different action in humification processes; hence it follows that the green clover humus must be a complex mixture of both nitrogenous and non-nitrogenous bodies.

The nature of the humus, whether nitrogenous or non-nitrogenous, is important. Humus produced from sawdust and humus from meat scraps may be taken as types of non-nitrogenous and nitrogenous humus.

116. Value of Humates as Plant Food. — Various opinions have been held regarding the actual value, as plant food, of this product from partially decayed animal and vegetable matter. Humus was formerly regarded as composed only of carbon, hydrogen, and oxygen, and inasmuch as plants obtain these elements from water and from the carbon dioxide of the air, no value was assigned to it. Later investigators added nitrogen to the list, but stated that the nitrogen, when combined with the humus and before undergoing fermentation, was of no value as plant food.

Recent investigations have proved that the mineral elements combined with the organic matter of soils are of value as plant food,[9] and that crops grown on the black soils of Russia obtain a large part of their mineral food from organic combinations.[84] Culture experiments show that plants like oats and rye may obtain their mineral food entirely from humate sources. Seeds when planted in a mixture of pure sand and neutral humates from fertile soils, produced perfect plants. In order to secure normal conditions, a little lime was added to prevent the formation of humic acid, and the organisms found in fertile fields were introduced. The following results are given of oats which were grown when the only supply of mineral food was in humate forms:

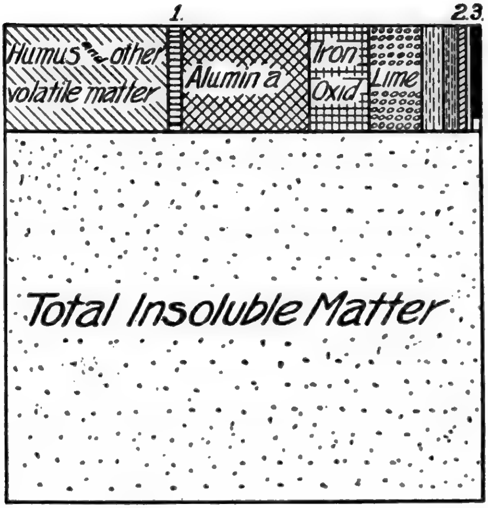


FIG. 26. Graphic Composition of 200 Soils, showing the Proportional Amounts of the Various Soil Constituents.

1. Nitrogen. 2. Potash. 3. Phosphoric acid.

NITROGEN AND ASH ELEMENTS[9]

	IN SIX OAT SEEDS	IN SIX MATURE PLANTS
	Gram	Gram
Nitrogen	0.0040	0.0556
Potash	0 0013	0.0640
Soda	0.0001	0.0079
Lime	0.0002	0.0249
Magnesia	0.0005	0.0110
Iron	——	0.0064
Phosphoric anhydride	0.0016	0.0960
Sulphuric anhydride	0.0001	0.0090
Silicon	0.0026	0.7300

The facts that plants feed on humate compounds, and decaying animal and vegetable matter produce humates from the inert potash and phosphoric acid of the soil, have an important bearing upon crop production in pointing out a way by which inert plant food may be converted into more active and available forms. This also explains that stable manure is valuable partly because it makes the inert plant food of the soil more available.

117. Mineral Matter combined with Humus. — When the humus compounds are separated from a soil, they contain appreciable amounts of phosphorus, potassium, and compounds of other elements which are soluble in the reagents used for obtaining the humus. If the humus materials are precipitated and purified by washing, the impurities are largely removed and the mineral elements which are chemically united with and form a part of the humus can then be determined. Analyses of eight samples of purified humus ash, from productive prairie soils, gave the following average:[9]

	Per Cent
Ash (precipitated humus)	12.24
Composition of ash:	
Silica	61.97
Potash, K_2O	7.20
Soda, Na_2O	8.13
Lime, CaO	0.09
Magnesia, MgO	0.36
Ferric oxide, Fe_2O_3	3.12
Alumina, Al_2O_3	3.48
Phosphoric acid, P_2O_5	12.37
Sulphuric acid, SO_3	0.98
Carbonic acid, CO_2	1.64

118. Amount of Plant Food in Humate Forms. — In a prairie soil containing 3.5 per cent of humus there are present 100,000 pounds of humus per acre. Combined with this humus are from 500 to 1500 pounds each of phosphoric acid and potash. Similar soils which have been under long cultivation without the restoration of any humus, contain from 300 to 500 pounds each of humic potash and phosphoric acid.[9] A decline in crop-producing power has in many cases been brought about by the loss of the plant food combined with the humus.

119. Loss of Humus. — Loss of humus from soils is caused by oxidation and by fires. Any method of cultivation which accelerates oxidation reduces the humus content. In many of the western prairie soils which have been under continuous grain cultivation for thirty years or more, the amount of humus has been reduced one half. Summer fallowing also causes a loss of humus. When land is continually under the plow, and no manures are used, the humus is rapidly oxidized, and there is left in the soil only the organic matter that is slow to decay.

Forest and prairie fires have been very destructive to the organic compounds of the soil. A soil from Hinckley, Minn., before the great forest fire of 1893, showed 1.69 per cent humus and 0.12 per cent nitrogen.[17] After the fire there were present 0.41 per cent humus and 0.03 per cent nitrogen. The forest fire caused a loss of 2500 pounds of nitrogen per acre. In clearing new land, particularly forest land, there is frequently an unnecessary destruction of humus materials. Instead of burning all of the vegetable matter, it would be better economy to leave some in piles for future use as manure. When all of the vegetable matter has been burned, two or three good crops are obtained, but the permanent crop-producing power of the land is reduced because of the loss of nitrogen and humus. When the vegetable matter has been only partially removed, the crops at first may be smaller, but in a few years returns will be greater than if all of the vegetable matter had been burned.

120. Physical Properties of Soils influenced by Humus. — The physical properties of a soil may be entirely changed by the addition or the loss of humus. The influence of humus upon the weight, color, heat, and water-retaining power of soils is discussed in the chapter on the physical properties of soils. Soils reduced in humus content have less power of storing up water and resisting drought. This fact is illustrated in the following table: [31]

PER CENT WATER

	IN SOIL	AFTER 10 HOURS' EXPOSURE IN TRAY, TO SUN
Soil rich in humus (3.75 per cent) . . .	16.48	6.12
Adjoining soil poorer in humus (2.50 per cent)	12.14	3.94

121. Humic Acid. — In the absence of calcium carbonate or other alkaline material, the vegetable matter of soils through processes of decay may form organic acids destructive to the growth of some crops. The composition and physical properties of these organic acids have never been determined, and the indefinite term ‘humic acid’ has been applied to them. Succinic acid has been reported present in peaty soils. Acid soils can be distinguished by their action upon blue litmus paper, and the acidity can be readily corrected by the use of lime or wood ashes. A soil may, however, give an acid reaction and contain a fair amount of lime as a silicate. Studies conducted by the Rhode Island Experiment Station indicate that the areas of acid soils are quite extensive.

122. Soils in Need of Humus. — Sandy and sandy loam soils that have been cultivated for a number of years to corn, potatoes, and small grains without rotation of crops or the use of stable manures are deficient in humus. Clay soils, as a rule, are not in need of humus so much as loam and sandy soils. The mechanical condition of heavy clay is, however, improved by the addition of humus-forming material. The addition of humus to loam and sandy soils is beneficial in preventing drifting, because it binds together the soil particles. There are but few arable soils, under ordinary cultivation, to which it is not safe to add humus-forming mate-

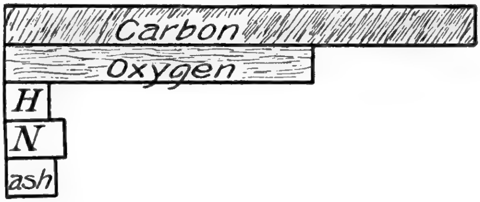


FIG. 27. Humus from Old Soil.

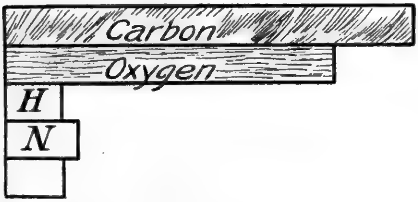


FIG. 28. Humus from New Soil.

rials either alone or jointly with lime. Ordinary prairie soils, for the first ten years after breaking, are usually well supplied. Swampy, peaty, and muck soils contain large amounts; in fact, they are often overstocked and are improved by reducing the humus content. 'Alkali' soils are usually deficient in humus.

123. Active and Inactive Humus. — When soil has been long under cultivation, and no manures have been used, the nitrogen and mineral matters combined with the humus are reduced. The humus from long-cultivated fields contains a higher per cent of carbon than from well-manured or new land; it is also less active because of the carbon which does not readily undergo oxidation.[9]

	HUMUS FROM NEW SOIL	HUMUS FROM OLD SOIL
	Per cent	Per cent
Carbon	44.12	50.10
Hydrogen	6.00	4.80
Oxygen	35.16	33.70
Nitrogen	8.12	6.50
Ash	6.60	4.90
Total humus material	5.30	3.38

124. Influence of Different Methods of Farming upon Humus. — The system of farming has a direct effect upon the humus content and the composition of the soil. Where the crops are systematically rotated, live stock is kept, and the manure judiciously used, the crop-producing power of the land is not lowered, as in the case of the one-crop system. The influence of different systems of farming upon the humus content and other properties of the soil may be observed in the following table: [81]

CHARACTER OF SOIL	Weight per cu. ft. Pounds	Humus Per cent	Nitrogen Per cent	Phosphoric acid combined with humus Per cent	Water-holding capacity Per cent
1. Cultivated thirty-five years; rotation of crops and manure; high state of productiveness	70	3.32	0.30	0.04	48
2. Originally same as 1; continuous grain cropping for thirty-five years; low state of productiveness . . .	72	1.80	0.16	0.01	39
3. Cultivated forty-two years; systematic rotation and manure; good state of productiveness	70	3.46	0.26	0.03	59
4. Originally same as 3; cultivated thirty-five years; no systematic rotation or manure; medium state of productiveness	67	2.45	0.21	0.03	57

CHAPTER IV

NITROGEN OF THE SOIL AND AIR, NITRIFICATION, AND NITROGENOUS MANURES

125. Importance of Nitrogen as Plant Food. — The illustration (Fig. 29) shows an oat plant which received no nitrogen, while compounds containing potassium, phosphorus, calcium, and other essential elements of plant food were liberally supplied. Observe the peculiar and restricted growth and the limited root development. The leaves were yellowish, showing lack of nitrogen for chlorophyll formation.

In the absence of nitrogen a plant makes no appreciable growth. With only a limited supply, growth is begun in a normal way; but as soon as the available nitrogen is used up, the lower and smaller leaves begin gradually to die down from the tips, and all of the plant's energy is centered in one or two leaves. In one experiment when only a small amount of nitrogen was supplied, the plant struggled along in this way for about nine weeks, making a total growth of but six and one half inches.[9] Just at the critical point when the plant was dying of nitrogen starvation, a few milligrams of calcium nitrate were given. In thirty-six hours the plant showed signs of renewed life, the leaves assumed a deeper green, new growth was begun, and finally four seeds were produced. During the time of seed formation more nitrogen was added, but with no beneficial result. All of the essential elements for plant growth were liberally provided, except nitrogen, which was very sparingly supplied, until near the period of seed formation.

When plants have reached a certain period in their development, and have been starved for want of nitrogen, the later application of this element does not produce normal growth, as the energy of the plant appears to have been used up in searching for food. Nitrogen, as well as potash, lime, and phosphoric acid, are all necessary while plants are in the first stages of growth.

In the case of wheat, nitrogen is assimilated more rapidly than are any of the mineral elements. Before the plant heads out, over 85 per cent of the total nitrogen required has been taken from the soil.[37] Corn also absorbs all of its nitrogen from four to five weeks before the crop matures. Flax takes up 75 per cent during the first fifty days of growth.[38]

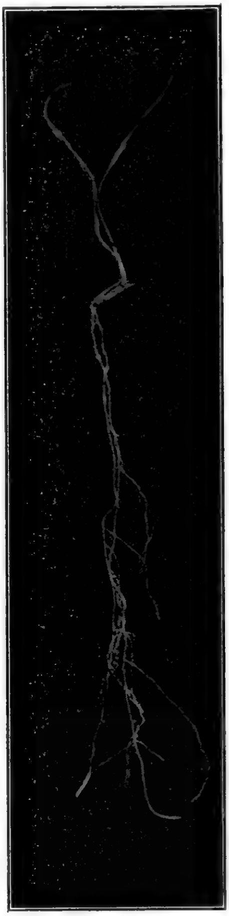


FIG. 29. Oat Plant grown without Nitrogen.

Nitrogen is demanded by all crops; it forms the chief building material for the proteids of plants. In the absence of sufficient nitrogen, the rich green color is not developed; the foliage is of a yellowish tinge. Nitrogen is one of the constituents of chlorophyll, the green coloring matter of plants; hence when there is a lack of nitrogen only a limited amount of chlorophyll can be produced. Plants with large, well-developed leaves of a rich green color are not suffering for this element. Nitrogenous fertilizers have a tendency to produce a luxurious growth of foliage, deep green in color.

ATMOSPHERIC NITROGEN AS A SOURCE OF PLANT FOOD

126. Early Views. — In addition to carbon, hydrogen, and oxygen, which form the organic compounds of plants, it was known as early as the beginning of the present century that plants also contain nitrogen. The sources of carbon, hydrogen, and oxygen for crop purposes were much easier to determine and understand than the sources of nitrogen. Priestley, the discoverer of oxygen, believed that the free nitrogen of the air was a factor in supplying plant food. De Saussure arrived at just the opposite conclusion. Neither of these assumptions was convincing because methods of chemical analysis had not yet been sufficiently perfected to solve the question.[39]

127. Boussingault's Experiments. — Boussingault was the first to make a careful study of the subject. In a prepared soil, free from nitrogen, and containing all of the other elements necessary for plant growth, he grew clover, wheat, and peas, carefully determining the nitrogen in the seed. The plants were allowed free access to the air, being simply protected from dust, and were watered with distilled water. But little growth was made. At the end of two months the plants were submitted to chemical analysis, and the amount of nitrogen present was determined.

The results are given in the following table:[40]

NITROGEN

	IN SEED SOWN GRAM	IN PLANT GRAM	GAIN GRAM
Clover, 2 mos.	0.11	0.12	0.01
Clover, 3 mos.	0.114	0.156	0.042
Wheat, 2 mos.	0.043	0.04	−0.003
Wheat, 3 mos.	0.057	0.06	0.003
Peas, 2 mos.	0.047	0.10	0.053

Boussingault concluded that when plants growing in a sterile soil were exposed to the air, there was with some a slight gain of nitrogen, but that the amount gained from atmospheric sources was not sufficient to feed the plant and allow it to reach full maturity. By many these results were not accepted as conclusive.

Fifteen years later (1853) Boussingault repeated his experiments, but in a different way. The plants were now grown in a large carboy with a limited volume of air so as to cut off all sources of combined nitrogen, as traces of ammonia, nitrates, and nitrites. By means of a second glass vessel (*B*, Fig. 30) the carboy was kept liberally supplied with carbon dioxide, so that plant growth would not be checked for lack of this material. When experiments were carried on in this way, using a fertile soil, the plants reached full maturity; but when a soil free from nitrogen was used, plant growth was soon checked. A general summary of this work is given in the following table:[40]

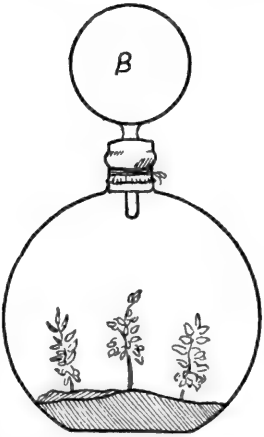


FIG. 30. Plants grown in Carboy.

NITROGEN

	IN SEEDS GRAM	IN PLANT GRAM	LOSS GRAM
Dwarf beans	0.1001	0.0977	−0.0024
Oats	0.0109	0.0097	−0.0012
White lupines	0.2710	0.2669	−0.0041
Garden cress	0.0013	0.0013	——

These experiments show that with a sterilized soil, and all sources of combined atmospheric nitrogen cut off, the free nitrogen of the air takes no part in the food supply of the plant.

In 1854 Boussingault again repeated his experiments on nitrogen assimilation. This time he grew the plants in a glass case so constructed that there was free circulation of air from which all combined nitrogen had been removed. These experiments were similar to his second series, except the plants were not grown in a limited volume of air. The results obtained showed that the free nitrogen of the air, under the conditions of the experiment, took no part in the food supply of the plants. If anything, there was less nitrogen recovered in the dwarfed plants than there was in the seed sown.

128. Ville's Results. — About the same time Ville carried on a series of experiments of like nature, but in a different way, and arrived at just the opposite conclusion. His experiments indicated that plants are capable of making liberal use of the free nitrogen of the air for food purposes. The directly opposite conclusions of Boussingault and Ville led to a great deal of controversy. The French Academy of Science took up the question, and appointed a commission to review the work of Ville. The commission consisted of six prominent scientists. They reported that "M. Ville's conclusions are consistent with his labor and results."[39]

129. Work of Lawes and Gilbert. — A little later Lawes and Gilbert carried on such extensive experiments under a variety of conditions as to remove all doubt regarding the plants' source of nitrogen. Plants were grown in sterilized soils, in prepared pumice stone, and in soils with a limited quantity of nitrogen beyond that contained in the seed. Different kinds of plants were experimented with. The work was carried on with the utmost care and with apparatus so constructed as to eliminate all disturbing factors. The results in the aggregate clearly show that plants, when acting in a sterile medium, are unable to make use of the free nitrogen of the air for the production of organic matter.[39]

130. Atwater's Experiments. — Atwater carried on similar experiments in this country.[41] His results indicate that when seeds germinate they lose a small part of their nitrogen, and when legumes are grown in a sterile soil, but are subsequently exposed to the air, a fixation of nitrogen may occur. He ascribed this gain to micro-organisms or other agencies.

131. Field and Laboratory Tests. — By a five years' rotation of clover and other leguminous plants, Lawes and Gilbert found a soil gained from 200 to 400 pounds of nitrogen per acre, in addition to that removed in the crop, while land which produced wheat continuously, gradually lost nitrogen. The amount in the subsoil remained nearly the same. These facts plainly indicated that crops like clover have the power of gaining nitrogen from unknown sources. The results of prominent German agriculturists led to the same conclusion. It was known that wheat grown after clover gave as good results as when nitrogenous manures were used, but for many years this was unexplained.

Laboratory experiments with sterilized soils do not represent the normal conditions of growing crops, where all of the bacteriological agencies of the soil, the air, and the plant are free to act. Experiments show that these agencies have an important bearing upon plant growth.

In the work of the different investigators prior to 1888, plants were grown mainly in sterilized soils, and under such conditions they were unable to make use of the free nitrogen of the air, except when the soils were subsequently inoculated from the air.

132. Hellriegel's Experiments. — Hellriegel grew leguminous plants in nitrogen-free soils. One set of plants was watered with distilled water, while another had in addition small amounts of leachings from an old loam field. The plants watered with distilled water alone made but little growth, while those watered with the loam leachings reached full maturity and contained something like a hundred times more nitrogen than was in the seed sown. The dark green color also was developed, showing the presence of a normal amount of chlorophyll. The roots of the plants had well-formed swellings or nodules, while those that were watered with distilled water alone had none. The loam leachings contained only a trace of nitrogen.[42]

133. Experiments of Wilfarth. — Experiments by Wilfarth give more exact data regarding the amount of nitrogen taken from the air. Two plots of lupines were grown; one was watered with distilled water, while the other received in addition a small amount of leachings from an old lupine field.

WATERED WITH DISTILLED WATER		WATERED WITH DISTILLED WATER AND SOIL LEACHINGS	
Dry matter Grams	Nitrogen Grams	Dry matter Grams	Nitrogen Grams
0.919	0.015	44.72	1.099
0.800	0.014	45.61	1.153
0.921	0.013	44.48	1.195
1.021	0.013	42.45	1.337

These experiments have been verified by many other investigators until the fact has been established that leguminous plants may, through the agency of micro-organisms, make use of the free nitrogen of the air. When legumes were grown in closed vessels and the air was analyzed, it was found that there was a loss of nitrogen from the air proportional to that gained by the plants.

The work of Hellriegel was not accidental, but the result of careful and systematic investigation. As early as 1863 he observed that clover would develop along the roadway in sand in which there was scarcely a trace of combined nitrogen.

134. Composition of Root Nodules. — The root nodules referred to are particularly rich in nitrogen. In one experiment, the light-colored and active ones contained 5.55 per cent, while those dark-colored and older contained 3.21 per cent, and all the nodules of the root, both active and inactive, contained 4.60 per cent nitrogen. The root itself contained 2.21 per cent.[43]

The root nodules also contain definite and characteristic micro-organisms, and it was the spores of these organisms that were in the soil extract in both Hellriegel's and Wilfarth's experiments. In the sterilized soils they were not present. These organisms found in root nodules are the essential agents which aid in the fixation of the free nitrogen of the air, and in its ultimate use as plant food. The nitrogen assimilated by the micro-organisms in the nodules of the legumes is in part appropriated by the crop, which unaided is incapable of making use of the free nitrogen of the air.

135. Nitrogen in the Root Nodules returned to the Soil. — Ward has shown that when clover roots decay, the organisms and nitrogen present in the nodules are distributed within the soil.[38] Hence, whenever a leguminous crop is raised, nitrogen is added to the soil instead of being taken away, as in the case of a grain crop. The amount of nitrogen returned to the soil by a leguminous crop as clover varies with the growth of the crop. In the roots of a clover crop a year old there are from 20 to 30 pounds of nitrogen per acre, while in the roots and culms of a dense clover sod, two or three years old, there may be 100 pounds or more of nitrogen, not including that which has been added to the soil by the accumulative action of the crop. Peas, beans, lucern, cow peas, and all legumes possess the power of fixing the free nitrogen of the air by means of micro-organisms. The micro-organisms associated with one species, as clover, differ from those associated with another, as lucern. The amount of nitrogen which the various legumes return to the soil is variable.

Hellriegel's results are of the greatest importance to agriculture, because they show how the free nitrogen of the air can be utilized indirectly as food by crops unable to appropriate it for themselves.

THE NITROGEN COMPOUNDS OF THE SOIL

136. Origin of the Soil Nitrogen. — The nitrogen of the soil is derived chiefly from the accumulated remains of animal and vegetable matter. The original source of the soil nitrogen, that is, the nitrogen which furnished food to support the vegetation from which our present stock of soil nitrogen is obtained, was probably the free nitrogen of the air. All of the ways in which the free nitrogen of the air has been made available to plants of higher orders which require combined nitrogen are not known. It is supposed, however, that this has been brought about by the workings of lower forms of plant life, and by micro-organisms. Whatever these agencies, they do not appear to be active in a soil under high cul-

FIG. 31. Clover Roots showing Nodules which contain Nitrogen-assimilating Organisms.

tivation, because the tendency of ordinary cropping is to reduce the supply of soil nitrogen.

137. Organic Nitrogen of the Soil. — In ordinary soils the nitrogen is present mainly in organic forms combined with the carbon, hydrogen, and oxygen as humus, and to a less extent with the mineral elements, forming nitrates and nitrites. The organic forms of nitrogen, it is generally considered, are incapable of supplying plants with nitrogen for food purposes until the process known as nitrification has taken place. The nitrogenous organic compounds in cultivated soils are derived mainly from the undigested protein compounds of manure and from the nitrogenous compounds in crop residues, and are present mainly as insoluble proteids.[85] When decomposition occurs, amides, organic salts, and other allied bodies are without doubt produced as intermediate products before nitrification takes place. The organic nitrogen of the soil may be present in exceedingly inert forms similar to that in leather, as in many peaty soils where there are large amounts of inactive organic compounds rich in nitrogen. In other soils the nitrogen is less complex. The organic nitrogen of the soil may vary in complexity from forms, like the nitrogen of urea, which readily undergo nitrification, to forms like that in peat, which nitrify with difficulty.

138. Amount of Nitrogen in Soils. — The fertility of any soil is dependent, to a great extent, upon the amount and form of its nitrogen. In soils of the highest fertility there is usually present from 0.2 to 0.3 per cent of total nitrogen, equivalent to from 7000 to 10,000 pounds per acre to the depth of one foot. Many soils of good crop-producing power contain as low as 0.12 per cent. There is usually two or three times more nitrogen in the surface soil than in the subsoil. In sandy soils which have been allowed to decline in fertility, there may be less than 0.04 per cent. Of the total nitrogen in soils there is rarely more than 2 per cent at any one time in forms available as plant food.[44] A soil with 5000 pounds of total nitrogen per acre may contain less than 100 pounds of available nitrogen soluble in the soil water, of which only a part is assimilated by the roots of crops. Hence it is that a soil may contain a large amount of total nitrogen, and yet be deficient in available nitrogen.

139. Amount of Nitrogen removed in Crops. — The amount of nitrogen removed in crops ranges from 25 to 100 pounds per acre, depending upon the nature of the crop. It does not necessarily follow that the crop which removes the largest amount of nitrogen leaves the land in the most impoverished condition. Wheat and other grains, while they do not remove so much in the crop, leave the soil more exhausted than if other crops were grown. This, as will be explained, is caused by the loss of nitrogen from the soil in other ways than through the crop.

	Pounds of Nitrogen per Acre removed in Crop[38]
Wheat, 20 bushels	25
Straw, 2000 pounds	10
Total	35
Barley, 40 bushels	28
Straw, 3000 pounds	12
Total	40
Oats, 50 bushels	35
Straw, 3000 pounds	15
Total	50
Flax, 15 bushels	39
Straw, 1800 pounds	15
Total	54
Potatoes, 150 bushels	40
Corn, 65 bushels	40
Stalks, 3000 pounds	35
Total	75

140. Nitrates and Nitrites. — Nitrogen in the form of nitrates and nitrites varies from mere traces to 150 pounds per acre. Soils with large amounts of nitrogenous humus and lime may contain for short periods as high as 300 pounds of nitrates and 15 pounds of nitrites, calculated as sodium salts. Some soils contain more nitrates than are utilized by crops as food, and plants may assimilate more than they can convert into protein.

Wheat, corn, and other crops grown on rich soils may contain both nitrates and nitrites as normal constituents. King reports nitrates in the growing crop in much larger amounts than in the soil water. As the crop matures the nitrate content of the plant declines. Calcium nitrate is the usual form, especially in soils which are sufficiently supplied with calcium carbonate to allow nitrification to progress rapidly. Nitrates and nitrites are the most valuable forms of nitrogen for plant food. Both are produced from the organic nitrogen of the soil. A nitrate is a compound composed of a base element as sodium, potassium, or calcium, combined with nitrogen and oxygen. A nitrite contains less oxygen than a nitrate.

Potassium nitrate, KNO_3, sodium nitrate, $NaNO_3$, and calcium nitrate, $Ca(NO_3)_2$ are the nitrates which are of most importance in agriculture. The nitrites, as potassium nitrite, KNO_2, are present to a less extent than the nitrates. Nitrates and nitrites are found in surface well waters contaminated with animal and vegetable matter. Many well waters possess some material value as a fertilizer on account of the nitrates, nitrites, and decaying animal and vegetable matters which they contain.

141. Ammonium Compounds of the Soil. — The ammonium compounds in a soil are usually less in amount than the nitrates and nitrites. The sources are rain water and the organic matter of the soil. The ammonium compounds are all soluble and readily undergo fixation. See Chapter VI. They cannot accumulate in arable soils, because of nitrification and fixation. Usually they are to be found in surface well waters. In the soil, the ammonium compounds are acted upon by nitrifying organisms, and nitrites and nitrates are formed. Such compounds as ammonium chloride or ammonium carbonate, if present in a soil in excessive amounts, will destroy vegetation in a way similar to the alkaline compounds in alkaline soils, but in small amounts they are beneficial.

142. Nitrogen in Rain Water and Snow. — Ordinarily the nitrogen which is annually returned to the soil in the form of ammonium compounds dissolved in rain water and snow is equivalent to from 2 to 3 pounds per acre. At the Rothamsted Experiment Station the average amount for eight years was 3.37 pounds.[44] When a soil is rich in nitrogen the gain from rain and snow is only a partial restoration of that which has been given off from the soil to the air or lost in the drain waters. The principal forms of the nitrogen in rain water are ammonium carbonate and nitrates and nitrites, present in the air to the extent of about 22 parts per million parts of air.

143. — Ratio of Nitrogen to Carbon in the Organic Matter of Soils. — In some soils the organic matter is more nitrogenous than in others. In those of the arid regions the humus contains from 15 to 20 per cent of nitrogen, while in soils from the humid regions there is from 4 to 6 per cent.[45] In some soils the ratio of nitrogen to carbon is 1 to 6, while in others it may be 1 to 18, or more. That is, in the organic matter of some soils there is 1 part of nitrogen to 6 parts of carbon, while in others the organic matter contains 1 part of nitrogen to 18 parts of carbon. In a soil where there exists a wide ratio between the nitrogen and carbon, it is believed the conditions for supplying crops with available nitrogen are unfavorable.

144. Losses of Nitrogen from Soils. — When a soil rich in nitrogen is cultivated for a number of years exclusively to grain, there is a loss of nitrogen exceeding that removed in the crop, caused by the rapid oxidation of the organic matter of the soil. Experiments show that when a prairie soil of average fertility is cultivated continually to grain, for every 25 pounds of nitrogen removed in the crop there is a loss of about 150 pounds due to the destruction of the organic matter.[18] In general, any system of cropping which keeps the soil continually under the plow results in decreasing the nitrogen. When a soil is rich in nitrogen the greatest losses occur; when poor in nitrogen there is relatively less loss. When a soil rich in nitrogen is given arable culture, oxidation of the organic matter and losses of nitrogen take place rapidly. The longer a soil is cultivated, the slower the oxidation of the humus and relative loss of nitrogen.

Dyer has calculated the income and outgo of nitrogen from manured and unmanured plots at the Rothamsted Station for a period of fifty years. "Of the total 10,000 pounds of nitrogen estimated to have been supplied, then, we find (in round numbers) that 1600 pounds have been recovered in the increased crops and that about 2500 pounds are found in the surface soil, leaving 5900 (or, in round numbers, 6000) pounds to be accounted for otherwise. It is clear, therefore, in spite of the notable surface accumulation, but little of the large quantities of nitrogen supplied in the dung and not returned in crops is to be found in the subsoil. The greater part of it has disappeared either as nitrates in the drainage or perhaps, and probably largely, by fermentative processes yielding free nitrogen."[68]

145. Gain of Nitrogen in Soils. — Lawes and Gilbert found a gain of nitrogen when land was permanently covered with vegetation.[44] Pastures and meadows contain more than cultivated land of similar character.

	AGE OF PASTURE YEARS	NITROGEN PER CENT
Arable land	—	0.14
Barn-field pasture	8	0.151
Apple-tree pasture	18	0.174
Meadow	21	0.204
Meadow	30	0.241

After deducting the amount of nitrogen in the manure added to the meadow land, the annual gain of nitrogen was more than 44 pounds per acre.

If a soil is properly manured and cropped, the nitrogen may be increased. A five-course rotation of small grains, clover, and corn (manured) will generally leave the soil at the end of the period of rotation in better condition as regards nitrogen than at the beginning.

At the Minnesota Experiment Station where wheat, corn, barley, and oats were grown continuously for twelve years, a loss of about 2000 pounds per acre of nitrogen was sustained; from $\frac{2}{3}$ to $\frac{3}{4}$ of the nitrogen being lost in various ways and not utilized as plant food.[85] In experiments covering ten-year periods, it was found that the five-year rotations, in which clover formed an essential part, resulted in a slight increase in the nitrogen content of the soil, — about 300 pounds per acre in excess of that removed in the crops. When timothy and non-legumes were substituted for clover, "a loss of nitrogen from the soil occurred, but the carbon (humus) content was maintained; the loss of nitrogen from the soil only slightly exceeding that removed by the crops." [96]

It is to be regretted that in the cultivation of large areas of land to staple crops, as wheat, corn, and cotton, the methods of cultivation followed are such as to decrease the nitrogen content and crop-producing power of the soil when this might be prevented.

NITRIFICATION

146. Former Views regarding Nitrification. — The presence of nitrates and nitrites in soils was formerly accounted for by oxidation. The theory was held that the production of nascent nitrogen by the decomposition of organic matter caused a union between the oxygen of the air and the nitrogen of the organic matter. Fermentation studies by Pasteur led him to suggest in 1862 that possibly the formation of nitric acid in the soil might be due to fermentation. It was, however, fifteen years later before the French chemists, Schlösing and Müntz, established the fact that nitrification is produced by a living organism. They passed diluted sewage through a glass tube filled with sand to which a little lime was added. The first portions of sewage contained nitrogen in the form of ammonia, but after a number of days nitrates appeared, and the ammonia diminished. When the soil was treated with chloroform vapor, nitrates ceased to be formed; when fresh garden soil was added, nitrates again appeared in the leachings. The bacteria were destroyed by the chloroform, and the medium was reseeded from the garden soil.

147. Nitrification caused by Micro-organisms. — Nitrification is the process by which nitrates and nitrites are produced in soils by the workings of organisms. Nitrification results in changing the complex organic nitrogen of the soil to the form of nitrates or nitrites. Broadly speaking, it is the process by which the inert nitrogen of the soil is rendered available as crop food. The organisms which carry on the work of nitrification were first isolated and studied by Winogradsky.

148. Conditions Necessary for Nitrification are:

1. Presence of the nitrifying organisms and food for them.
2. A supply of oxygen.
3. Moisture.
4. A favorable temperature.
5. Absence of strong sunlight.
6. The presence of some basic compound.

In order to allow nitrification to proceed, all of these conditions must be satisfied. The process is frequently checked because some of the conditions, as presence of a basic compound, are unfulfilled.

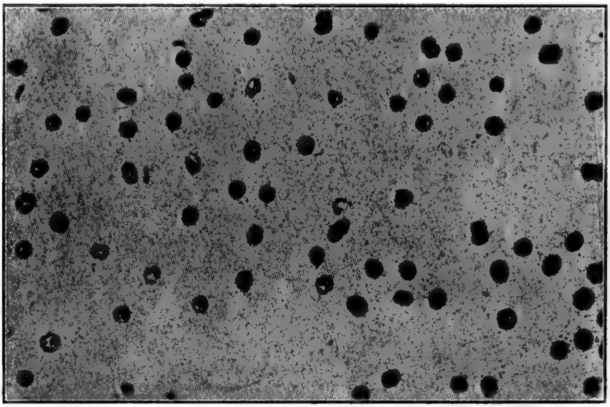


FIG. 32. Nitrous Acid Organisms. (After Winogradsky.)

149. Food for the Nitrifying Organisms. — All living organisms require food, and one of the food requirements of the nitrifying organism is a supply of phosphates and other minerals. In the absence of phosphoric acid, nitrification cannot take place. The change which the phosphoric acid undergoes in serving as food for the nitrifying organism is unknown, but it doubtless makes the phosphoric acid more available as plant food.[91] The principal organic food of the nitrifying organism is the organic matter of the soil, and it is only when organic matter is incorporated with soil that it can serve as food for the nitrifying organism. In the presence of a large amount of organic matter, as in a manure pile, nitrification does not take place. It occurs only when the organic matter is largely diluted with soil. Under favorable conditions, nitrifying organisms

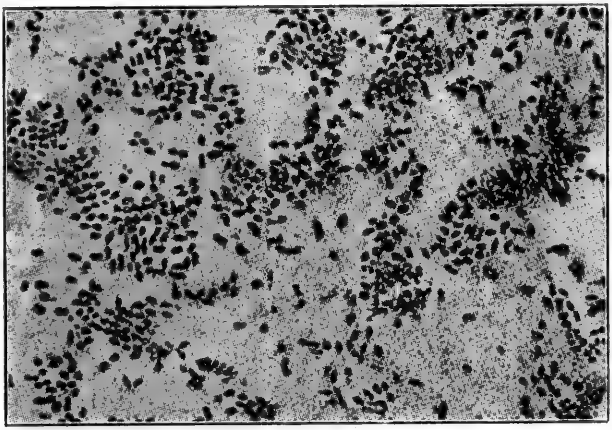


FIG. 33. Nitric Acid Organism. (After Winogradsky.)

may secure all of their food in inorganic forms; that is, nitrification may take place in the absence of organic matter, provided the proper mineral food be supplied. When growth under such conditions takes place the organisms assimilate carbon from the combined carbon of the air, and produce organic carbon compounds. An organism, working in the absence of sunlight and unprovided with chlorophyll, may construct organic compounds containing nitrogen and designated bacterial protein.[44] Nitrification in the absence of nitrogenous organic matter is of too limited a character to supply growing crops with all of their available nitrogen. For general crop production the organic matter of the soil is the source of the nitrogen which undergoes the nitrification process, and which furnishes food for the nitrifying organisms.

150. Oxygen Necessary for Nitrification. — The second requirement for nitrification is an adequate supply of oxygen. The nitrifying organism belongs to that class of ferments (aërobic) which requires oxygen for existence. Oxygen is present as one of the elements in the final product of nitrification as calcium nitrate, $Ca(NO_3)_2$. In the absence of oxygen, nitrification is checked. When soils are saturated with water, the process cannot go on for want of oxygen. The formation of a hard, dry crust in soils also checks nitrification. Cultivation, particularly of clay soils, favors nitrification by increasing the supply of oxygen in the soil.

151. Moisture Necessary for Nitrification. — Nitrification cannot take place in a soil deficient in moisture; as in all fermentation processes, moisture is necessary for the chemical changes to occur. In a very dry time nitrification is arrested for want of water. Water is as necessary to the growth and development of the living organism which carries on the work of nitrification as it is to the life of a plant of higher order.

152. Temperatures Favorable for Nitrification. — The most favorable temperatures for nitrification are between 12° C. (54° F.) and 37° C. (99° F.). It may take place at as low a temperature as 3° or 4° C. (37° and 39° F); at 50° C. (122° F.) it is feeble; while at 55° C. (130° F.) there is no action.[44] In northern latitudes nitrification is checked during the winter, while in southern latitudes this change takes place throughout the entire year. As a result, many soils in southern latitudes contain less nitrogen than soils in northern latitudes where formation and leaching of nitrates are checked by climatic conditions. Crops which require their nitrogen early in the growing season are frequently placed at a disadvantage because there is less available nitrogen in the soil at that time than later.

153. Strong Sunlight checks Nitrification. — Nitrification cannot take place in strong sunlight; it prevents the action of all organisms of this class. In fallow land there is no nitrification at the surface, but immediately below where the sunlight is excluded by the surface soil it is most active. In a corn field it is more active than in a compacted fallow field.

154. Base-forming Elements Essential for Nitrification. — The presence of some base-forming element to combine with the nitric acid produced is a necessary condition for nitrification, and for this purpose calcium carbonate and sodium and potassium compounds are particularly valuable. The absence of alkaline salts is one of the frequent causes of non-nitrification. In acid soils the process is checked for the want of proper basic material. The organisms which carry on the work cannot exist where there are strong acids or alkalies, consequently in such soils nitrification cannot take place.

155. Nitrous Acid Organisms. — There are at least two nitrifying organisms in the soil: one produces nitrates and the other nitrites or nitrous acid. It has been shown that the nitrification process takes place in two stages: first nitrites are produced by the nitrous organism, and then the process is completed by the nitric organism. Warington says that "both organisms are present in the soil in enormous numbers, and the action of the two organisms proceeds together, as the conditions are favorable to both." As a result of the workings of the nitrous acid organism, nitrites are formed, and these are acted upon by the nitric acid organism and changed into nitrates. Nitrites exist in soils as transition products, the amount present in fertile soils being less than one part per million of soil.

156. Ammonia-producing Organisms. — There are also present in the soil organisms which have the power of producing ammonia from proteid bodies. The ammonium compounds produced are acted upon by the nitrifying organisms and readily undergo nitrification.[46, 68] When oxidation of the protein is rapid, nitrogen may be liberated and lost.

157. Denitrification is just the reverse of the nitrification process, and is the result of the workings of a class of organisms which feed upon the nitrates, forming free nitrogen which is liberated as a gas. One of the conditions for denitrification is absence of air, as these organisms belong to the anaërobic class. Denitrification occurs in soils saturated with water, and where the soil is compacted so that air is practically excluded.[47, 68]

158. Number and Kinds of Organisms in Soils. — In addition to the micro-organisms which carry on the work of nitrification, denitrification, and ammonification, there are a great many others, some of which are beneficial while others are injurious to crop growth. It has been estimated that in a gram of an average sample of soil there are from 60,000 to 500,000 beneficial and injurious micro-organisms.[48] There are produced from many crop residues, by injurious ferments, chemical products which may be destructive to crop growth. Flax straw, for example, when it decays in the soil, forms chemical products which are destructive to a succeeding flax crop.

A moist soil, rich in organic matter, and containing various salts, may form the medium for the propagation of many classes of organisms. Sewage-sick soils, clover-sick soils, and flax-diseased lands are all the result of bacterial diseases. Many of the organisms which are the cause of such diseases as typhoid fever and cholera may propagate and develop in a moist soil under certain conditions, and then find their way through drain water into surface wells, and cause these diseases to spread.

159. Products formed by Soil Organisms. — In considering the part which micro-organisms take in plant growth, as well as in all similar processes, there are two important phases: (1) the action of the organism itself, and (2) the chemical action of the product of the organism. In the case of nitrification, the action of the organism brings about a change in the composition of the organic matter of soils producing nitric acid, which is merely a product formed as a result of the action of the organism. The nitric acid then acts upon the soil, producing nitrates. In soils rich in organic matter the fermentation changes, which take place during humification, result in the production of acid products. This is simply the result of the action of the ferments. The acids then act upon the soil bases and produce humates or organic salts. In many fermentation changes there is first the production of some chemical compound, and then the action of this compound upon other bodies. In rendering plant food available, as in humification and nitrification, it is the final and not the first product of the organism, which is of value as plant food.

160. Inoculating Soils with Organisms. — In growing leguminous crops on soils where they have never before been produced, it has been proposed to supply the essential organisms which assist the crops to obtain their nitrogen. For example, if clover is grown on new land, the soil may not contain the organisms which assist in the assimilation of nitrogen and which are present in the root nodules of the plant. If these organisms are supplied, better conditions for growth exist. Some soils are benefited by inoculation, while others are not. Frequently the failure successfully to grow legumes is due to other causes, as poor seed, poor physical condition of the soil, lack of mineral plant food, and adverse climatic conditions rather than to a lack of the necessary nitrogen fixing-bacteria.[68]

In old soils where the process of nitrification is feeble, it has been proposed to inoculate the soils with more active forms of bacteria so as to make the inert humus nitrogen more available as plant food. In order to secure the best results from inoculation, suitable food must be supplied for the organisms, and any adverse condition, as excess of acids or alkalies, must be corrected. Most soils contain the requisite organisms, but frequently they are unable to do their work because of unfavorable conditions, as the presence of injurious matter or the lack of cultivation or food. For the production of legumes, inoculation of the soil is often beneficial. The commercial production and distribution of the organisms forming the nodules on the roots of clover and other leguminous crops, and which cause fixation of atmospheric nitrogen, was first proposed and inaugurated by Nobbe.[94] The method of inoculation consists in first multiplying the organisms in nutritive substances, and then sprinkling seeds with the diluted solution. Inoculation with soil from a field where clover or lupines have previously been grown has also been successful, particularly in reclaiming sandy waste lands where mineral fertilizers containing potash and phosphates are used to furnish these elements, while the more expensive nitrogen is acquired indirectly from the air through the clover. Soils in a high state of productiveness are not usually in need of inoculation as they already contain all the essential soil organisms. Moore's method of distributing the nitrogen-fixing organisms of legumes in the form of cotton cultures has been investigated by a number of experiment stations and found inefficient.[87]

161. Loss of Nitrogen by Fallowing Rich Lands. — Summer fallowing creates conditions favorable to nitrification. A fallow is beneficial to a succeeding crop because of the nitrogen which is rendered available. If a soil is rich in nitrogen and lime, summer fallowing causes the production of more nitrates than can be retained in the soil. The crop utilizes only a part of the nitrogen rendered available, the rest being lost by drainage, ammonification, and denitrification. Hence the available nitrogen is increased while the total nitrogen is greatly decreased.[9]

	Soil before Fallowing	Soil after Fallowing
Total nitrogen	0.154	0.142
Soluble nitrogen	0.002	0.004

The gain of 0.002 per cent of soluble nitrogen was accompanied by a loss of 0.012 per cent of total nitrogen. For every pound of available nitrogen there was a loss of six pounds. Bare fallowing of land for an entire year should not be practiced, except occasionally to destroy weeds or insects, as it results in permanent injury to the soil. A short period of fallow and the practice of green manuring with leguminous crops both enrich the soil with humus and nitrogen, and improve the physical properties.

162. Influence of Plowing upon Nitrification. — In a rich soil containing the necessary alkaline matter, nitrification goes on very rapidly. This is one reason why shallow plowing on new breaking gives better results than deep plowing. Deep plowing at first causes nitrification to take place to such an extent that the crop is over-stimulated in growth, due to an excess of available nitrogen. Deep plowing and thorough cultivation aid nitrification. The longer a soil has been cultivated, the deeper and more thorough must be the cultivation.

Early fall plowing leaves more available nitrogen at the disposal of the crop than late fall plowing. Nitrification takes place only near the surface. Hence when late spring plowing is practiced there is brought to the surface raw nitrogen, while the more active nitrogen has been plowed under, and is beyond the reach of the young plants when they require the most help in obtaining food. The various methods of cultivation, as deep and shallow plowing, spring and fall plowing, and surface cultivation, have as much influence upon the available nitrogen supply of crops as upon the water supply. The saying that cultivation makes plant food available is particularly true of the element nitrogen, the supply of which is capable of being increased or decreased to a greater extent than that of any other element.

NITROGENOUS MANURES

163. Sources of Nitrogenous Manures. — The materials used for enriching soils with nitrogen, to promote crop growth, may be divided into two classes: (1) organic nitrogenous manures, (2) mineral nitrogenous manures.

Each of these classes has a different value as plant food, and in fact there are marked differences in fertilizer value between materials belonging to the same class. The nitrogenous organic materials used for fertilizing purposes are: dried blood, tankage, meat scraps and flesh meal, fish offal, cottonseed meal, and leguminous crops, as clover and peas. The nitrogen in these substances is principally in the form of protein. When peat and muck are properly used they also may be classed among the nitrogenous manures. The mineral nitrogenous manures are nitrates, as sodium nitrate, and ammonium salts, as ammonium sulphate.

164. Dried Blood. — This is obtained by drying the blood and débris from slaughterhouses. Frequently small amounts of salt and slaked lime are mixed with the blood. It is richest in nitrogen of any of the organic manures. When thoroughly dry it may contain 14 per cent of nitrogen. As usually sold, it contains from 10 to 20 per cent of water, and has a nitrogen content of from 9 to 13. Dried blood contains only small amounts of other fertilizer elements; it is strictly a nitrogenous fertilizer, readily yielding to the action of micro-organisms and to nitrification. On account of its fermentable nature, it is a quick-acting fertilizer, and is one of the most valuable of the organic materials used as manure. It gives the best returns on an impoverished soil to aid crops in the early stages of growth, before the inert nitrogen of the soil becomes available. Dried blood may be applied as a top dressing on grass land, and it is also an excellent form of fertilizer for many garden crops; but it should not be placed in direct contact with seeds, as it will cause rotting, nor should it be used in too large amounts. Three hundred pounds per acre is as much as should be applied at one time. When too much is used losses of nitrogen may occur by leaching and by denitrification. It is best applied directly to the soil as a top dressing in the case of grass, or near the seeds of garden crops, and not mixed with unslaked lime or wood ashes, but each should be used separately. As all plants take up their nitrogen in the early stages of growth, nitrogenous fertilizers as blood should be applied before seeding or soon after. An application of dried blood to partially matured garden crops will cause a prolonged growth and very late maturity.

Storer gives the following directions for preserving any dried blood produced upon farms.[22] "The blood is thoroughly mixed in a shallow box with 4 or 5 times its weight of slaked lime. The mixture is covered with a thin layer of lime and left to dry out. It will keep if stored in a cool place, and may be applied directly to the land or added to a compost heap."

The price per pound of nitrogen in the form of dried blood can be determined from the cost and the analysis of the material. A sample containing 9 per cent of nitrogen and selling for $28 per ton is equivalent to 15.55 cents per pound for the nitrogen ($2000 \times 0.09 = 180$. $\$28.00 \div 180 = 15.55$ cents).

165. **Tankage** is composed of refuse matter, as bones, trimmings of hides, hair, horns, hoofs, and some blood. The fat and gelatin are, as a rule, first removed by subjecting the material to superheated steam. This miscellaneous refuse, after drying, is ground and sometimes mixed with a little slaked lime to prevent rapid fermentation.

Tankage contains less nitrogen but more phosphoric acid than dried blood. Owing to its miscellaneous nature, it is quite variable in composition, as the following analyses of tankage from the same abattoir at different times show:[14]

		First Year	Second Year	Third Year
Moisture	per cent	10.5	9.8	10.9
Nitrogen	"	5.7	7.6	6.4
Phosphoric acid	"	12.2	10.6	11.7

As a general rule, tankage contains from 5 to 8 per cent of nitrogen and from 5 to 12 per cent of phosphoric acid. It is much slower in its action than dried blood, and supplies the crop with both nitrogen and phosphoric acid. Tankage is a valuable form of fertilizer for garden purposes. It may also be used as a top dressing on grass lands, or spread broadcast on grain lands. It is best to apply the tankage, when possible, a few days prior to seeding, and it should not come in contact with seeds. Two hundred and fifty pounds per acre is a safe dressing, and when there is sufficient rain to ferment the tankage, 400 pounds per acre may be used. A dressing of 800 pounds in a dry season would be destructive to vegetation. On impoverished soil more may be used than on soils which are for various reasons out of condition. The cost of the nitrogen as tankage is determined from the composition and selling price. If tankage containing 7 per cent of nitrogen and 12 per cent of phosphoric acid is selling for $32 per ton, what is the cost of the nitrogen per pound? The market value of phosphoric acid, in the form of bones, should first be ascertained. Suppose bone phosphoric acid is selling for 4 cents per pound. The phosphoric acid in the ton of tankage would then be worth $9.60, making the nitrogen cost $22.40. The 140 pounds of nitrogen in the ton of fertilizer would be worth $22.40, or 16 cents per pound. In eastern markets the price of tankage is usually higher than near the large packing houses of the West.

166. Flesh Meal. — The flesh refuse from slaughterhouses is sometimes kept separate from the tankage and sold as flesh meal, the fat and gelatin being first removed and used for the manufacture of glue and soap. Flesh meal is variable in composition and may be very slow in decomposing. It contains from 4 to 8 per cent or more of nitrogen, with an appreciable amount of phosphoric acid. Occasionally it is used for feeding poultry and hogs, and cattle to a limited extent. The fertilizer value of the dung is nearly equivalent to the original value of the meal.

167. Fish Scrap. — The flesh of fish is very rich in nitrogen.[49] The offal parts, as heads, fins, tails, and intestines, are dried and prepared as a fertilizer. Some species of fish which are not edible are caught in large numbers to be used for this purpose. In seacoast regions, fish fertilizer is one of the cheapest and best of the nitrogenous manures. It is richer in nitrogen than tankage or flesh meal, and in many cases equal to dried blood. It readily undergoes nitrification and is a quick-acting fertilizer.

168. Seed Residues. — Many seeds, as cottonseed and flaxseed, are exceedingly rich in nitrogen. When the oil has been removed, the flaxseed and cottonseed cake are proportionally richer in nitrogen than the original seed. This cake is usually sold for cattle food, but occasionally is used as fertilizer. It contains from 6 to 7 per cent of nitrogen, and compares fairly well in nitrogen content with animal bodies. Cottonseed cake and meal are not so quick acting as dried blood, but when used in southern latitudes a little time before seeding, the nitrogen becomes available for crop purposes. Oil meals, as cottonseed and linseed, containing a high per cent of oil, are much slower in decomposing than those which contain but little oil. It is better economy to feed the cake to stock and use the manure than to apply the cake directly to the land. Occasionally, however, cottonseed meal has been so low in price that its use as a fertilizer has been admissible.

A ton of cottonseed meal, costing $20 and containing 2 per cent of phosphoric acid and 7 per cent of nitrogen, would be equivalent to 13.1 cents per pound for the nitrogen, which is frequently cheaper than purchasing some other nitrogenous fertilizer.

169. Leather, Wool Waste, and Hair are rich in nitrogen, but on account of their slowness in decomposing are unsuitable for fertilizer purposes. When present in fertilizers they give poor field results.

170. Available Nitrogen. — One of the methods employed to detect, in fertilizers, the presence of inert forms of nitrogen, as leather, is to digest the material in prepared pepsin solution.[50] Substances like dried blood are nearly all soluble in the pepsin, while leather and other inert forms are only partially so. The solubility of the organic nitrogen in pepsin solution determines, to a great extent, the value of the material as a fertilizer.[51]

	Per Cent of Nitrogen Soluble in Prepared Pepsin Solution
Dried blood	94.2
Cottonseed meal	86.4
Ground dried fish	75.7
Tankage	73.6
Hoof and horn meal	30.0
Leather	16.7

Some of the organic forms of nitrogen readily undergo nitrification and become available as plant food, while other forms are inactive. Vegetation tests show that from 60 to 75 per cent of the nitrogen of dried blood, tankage, cottonseed meal, and fish meal are available as plant food the year they are used as fertilizer. The available nitrogen of fertilizers includes nitrates and ammonium salts and such forms of organic matter as readily undergo nitrification. Potassium permanganate with and without sodium hydroxide is also employed as a solvent for available nitrogen.[52]

171. Peat and Muck. — Peat and muck are rich in nitrogen which is in an insoluble form and is with difficulty nitrified. When mixed with lime and stable manure, particularly liquid manure, fermentation is induced and a valuable manure produced. Muck and peat should be dried and sun-cured, and then used as absorbents in stables. Peat differs from muck in being fibrous. If the muck is acid, lime (not quicklime) should be used with it in the stable, as directed under farm manures. When easily obtained, muck is one of the cheapest forms of nitrogen.

COMPOSITION OF DRY MUCK SAMPLES[9]

	NITROGEN PER CENT
Marshy place, producing hay	2.21
Marshy place, dry in late summer	2.01
Old lake bottom	1.81

172. Leguminous Crops as Nitrogenous Manures. — The frequent use of leguminous crops for manurial purposes is the cheapest way of obtaining nitrogen. When the crop is not removed from the land but is plowed under while green, the practice is called green manuring. This does not enrich the land with any mineral material, but results in changing inert plant food to humate forms. Green manuring with leguminous crops should take the place of bare fallow, as its effects upon the soil are more beneficial. With green manuring, nitrogen is added to the soil, while with bare fallow there is a loss of nitrogen. Leguminous crops, as clover, peas, crimson clover, and cowpeas, should be made to serve as the main source of the nitrogen for crop production. A good crop of clover will return to the soil over 200 pounds of nitrogen per acre.

173. Sodium Nitrate. — The nitric nitrogen most frequently met with in commercial forms is sodium nitrate, commonly known as Chili saltpeter. It is a natural deposit found extensively in Chili, Peru, and the United States of Colombia. Various theories have been proposed to account for these deposits, but it is difficult to determine just how they have been formed.[10] The commercial value of nitrogen in fertilizers is regulated mainly by the price of sodium nitrate, which, when pure, contains 16.49 per cent of nitrogen. Commercial sodium nitrate is from 95 to 97 per cent pure. An ordinary sample contains about 16 per cent of nitrogen and costs from $50 to $60 per ton, making the nitrogen worth from 15 to 18 cents per pound. Sodium nitrate is the most active of all the nitrogenous manures. It is soluble and does not have to undergo the nitrification process before being utilized by crops. On account of its extreme solubility it should be applied sparingly, for it cannot be retained in the soil. As a top dressing on grass, it will respond by imparting a rich green color. It may be used at the rate of 250 pounds per acre, but a much lighter application will generally be found more economical. Sodium nitrate should not be used when heavy dressings of farm manure are applied, as denitrification may result from such a practice. In small amounts it is the fertilizer most frequently resorted to when the forcing of crops is desired, as in early market gardening. Its use for fertilizing horticultural crops has become equally as extensive as for general farm crops. Excessive amounts, however, may produce injurious results. Sodium nitrate stimulates a rank growth of dark green foliage and retards the maturity of plants, but when properly used is one of the most valuable of the nitrogenous fertilizers.

174. Ammonium Sulphate. — Ammonium sulphate is obtained as a by-product in the manufacture of illuminating gas and is extensively sold as a fertilizer. It usually contains about 20 per cent of nitrogen, equivalent to 95 per cent of ammonium sulphate, the remaining 5 per cent being moisture and impurities. Ammonium sulphate is not generally considered the equivalent of sodium nitrate, as it is believed it must undergo nitrification before being utilized as plant food. It is, however, a valuable form of nitrogen. Experiments show that plants may utilize ammonia directly without nitrification processes first taking place.[68] The statements regarding the use of sodium nitrate apply equally well to the use of ammonium sulphate. Ammonium chloride and ammonium carbonate are not suitable for fertilizers on account of their destructive action upon vegetation.

175. Calcium Nitrate and Cyanamid, $Ca(NO_3)_2$ and $CaCN_2$. — The nitrogen of these compounds is obtained from the free nitrogen of the air by electrical processes. Calcium nitrate is made by treating lime with nitric acid resulting from the oxides of nitrogen produced in the air by electrical action. It is a valuable form of nitrogen fertilizer. Calcium cyanamid is made by heating together coal and lime in an electrical furnace through which a current of nitrogen gas, obtained from the air, is passed. Experiments with calcium cyanamid as a fertilizer show that the nitrogen undergoes nitrification and becomes available as plant food.[68] It is claimed that these compounds of nitrogen $Ca(NO_3)_2$ and $CaCN_2$, in which the nitrogen is obtained from the air, will eventually be produced at such a low cost as to permit their extensive use as fertilizers.

176. Nitrogen and Ammonia Equivalent of Fertilizers. — Nitrogenous fertilizers are sometimes represented as containing a certain amount of ammonia instead of nitrogen. Fourteen-seventeenths of ammonia is nitrogen, and if a fertilizer contains 2.25 per cent ammonia, it is equivalent to 1.85 per cent of nitrogen. To convert NH_3 results to an N basis, multiply by 0.823.

177. Purchasing Nitrogenous Manures. — In purchasing a nitrogenous manure, the special purpose for which it is to be used should always be considered. Under some conditions, as forcing a crop on an impoverished soil, sodium nitrate is desirable. Under other conditions, tankage, cottonseed cake, or some other form of nitrogen may be better. There is annually expended in purchasing nitrogenous fertilizers a large amount of money which could be expended more economically if the science of fertilizing were given a more careful study, and if a larger share of the nitrogen for crop purposes were obtained indirectly from the air through the agency of legumes. The uses of nitrogenous fertilizers for special crops and the testing of soils to determine any deficiency in nitrogen are discussed in Chapters X and XI, which treat of commercial fertilizers and the food requirements of farm crops.

CHAPTER V

FARM MANURES

178. Variable Composition of Farm Manures. — The term 'farm manure' does not designate a product of definite composition. Manure is the most variable in chemical composition of any of the materials produced on the farm. It may contain a large amount of straw, in which case it is called coarse manure; or it may contain only the solid excrements and a little straw, the liquid excrements being lost by leaching; then again it may consist of the droppings of poorly fed animals, or of the mixed excrements of different classes of well-fed animals.

The term 'stable manure' has been proposed for that product which contains all of the solid and liquid excrements with the necessary absorbent, before any losses have been sustained.[16] The term 'barnyard manure' is restricted to that which accumulates around some barns and farmyards, and is exposed to leaching rains and the drying action of the sun.

179. Average Composition of Manures. — The solid excrements of animals contain from 60 to 85 per cent of water; when mixed with straw, and the liquid excrements are retained, the mixed manure contains about 75 per cent of water. The nitrogen varies from 0.4 to 0.9 per cent, according to the nature of the food and the extent to which other factors have affected the composition. In general, animals consuming liberal amounts of coarse fodders produce manure with a higher per cent of potash than of phosphoric acid. This is because the potash in the food exceeds the phosphoric acid. Farm manures also contain lime, magnesia, and other minerals present in plants and designated as essential ash elements. The average composition of mixed stable manure is as follows:

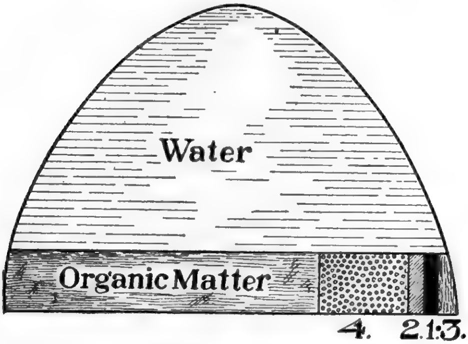


FIG. 34. Average Composition of Fresh Manure.

1. Nitrogen. 2. Phosphoric acid.
3. Potash. 4. Mineral matter.

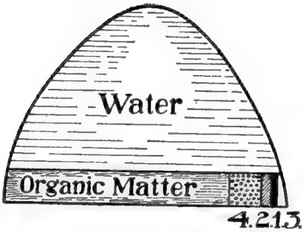


FIG. 35. Manure after Six Months' Exposure.

	AVERAGE PER CENT	RANGE PER CENT
Nitrogen, N	0.50	0.4 to 0.8
Phosphoric acid, P_2O_5	0.35	0.2 to 0.5
Potash, K_2O	0.50	0.3 to 0.9

In calculating the amount of fertility in manures, it is more accurate to compute the value from the food consumed and the conditions under which the manure has been produced, than to use figures expressing average composition.

180. Factors which influence the Composition and Value of Farm Manure. —

I. Kind and amount of absorbents used.
II. Kind and amount of food consumed.
III. Age and kind of animals.
IV. Methods employed in collecting, preserving, and utilizing the manure.

Any one of the above, as well as many minor factors, may influence the composition and value of farm manures.

181. Absorbents. — The absorbent generally used is straw. Wheat straw and barley straw have about the same manurial value; oat straw is more valuable than either. The average composition of straw and other absorbents is as follows:

	STRAW PER CENT	LEAVES PER CENT	PEAT PER CENT	SAWDUST PER CENT
Nitrogen	0.40	0.6	1.0	0.1
Phosphoric acid . . .	0.36	0.3	—	0.2
Potash	0.80	0.3	—	0.4

When a large amount of straw is used the percentage amounts of nitrogen and phosphoric acid are decreased, while the per cent of potash is slightly increased. Sawdust and loam both make the manure more dilute. Dry peat makes the manure richer in nitrogen. The absorptive power of these different materials is about as follows: [14]

	Per Cent of Water Absorbed
Fine cut straw	30.0
Coarse uncut straw	18.0
Peat	60.0
Sawdust	45.0

The proportion of absorbents in manure ranges from a fifth to a third of the total weight of the manure.

182. Use of Peat and Muck as Absorbents. — Because of the high content of nitrogen in peat and the power which it possesses when dry of absorbing water, it is a valuable material to use as an absorbent in stables. As previously stated, peat is slow to decompose, but when mixed with the liquid manure it readily yields to fermentation, particularly if a little land plaster or marl be used in the stable along with the peat. Peat has high absorptive power for gases as well as for liquids, and when used the sanitary condition of stables is improved and the air is rendered particularly free from foul odors.

RELATION OF FOOD CONSUMED TO MANURE PRODUCED

183. Bulky and Concentrated Foods. — The more concentrated and digestible the food consumed, the more valuable is the manure. Coarse bulky fodders always give a large amount of a poor quality of manure. For example, the manure from animals fed on timothy hay and that from animals fed on clover hay and grain show a wide difference in composition. The dry matter of timothy hay is about 55 per cent digestible. From a ton of timothy hay there is about 790 pounds of dry matter in the manure. The nitrogen, phosphoric acid, and potash in the food consumed are nearly all returned in the manure, except under those conditions which will be noted. The manure from a ton of mixed feed, as clover and bran, is smaller in amount but more concentrated than that produced from timothy. In a ton of timothy and in a ton of mixed feed (1500 lbs. clover, 500 lbs. bran) there are present:

	TIMOTHY LBS.	MIXED FEED LBS.
Nitrogen	25.0	40.0
Phosphoric acid	9.0	24.0
Potash	40.0	30.0

The nitrogen, phosphoric acid, and potash of these two rations are retained in the animal body in dissimilar amounts, 10 per cent more of these elements being retained from the more liberal ration, due to more favorable conditions for growth. Because of this fact there is present in the manure from the mixed feed one half more nitrogen, and two and one half times as much phosphoric acid, as in the manure from the timothy hay, which, free from bedding, contains about 790 pounds of indigestible matter, while the manure from the mixed feed contains 760 pounds, the mixed ration being more digestible. If both manures contain the same amount of absorbents, the manure from the ton of mixed clover and bran will weigh slightly less, but contain more fertility than that from the timothy hay.

The value of manure can be accurately determined from the composition of the food consumed and the care which the manure has received. Only a small amount of the nitrogen in the food is permanently retained in the body. The larger portion is used for repair purposes, the nitrogen of the tissues which have been renewed being voided as urea in the liquid excrements. Some of the nitrogenous compounds of the food are utilized for the production of fat, in which case the nitrogen is voided in the excrements. The fact that but little of the nitrogen and mineral matter of the food, under most conditions, is retained in the body is shown by the investigations of Lawes and Gilbert upon the composition of the flesh added to animals while undergoing the fattening process.[55]

INCREASE DURING FATTENING

	WATER	DRY MATTER	FAT	NITROGENOUS MATTER	ASH
Ox	24.6	75.4	66.2	7.69	1.47
Sheep	20.1	79.9	70.4	7.13	2.36
Pig	22.0	78.0	71.5	6.44	0.06

The results of numerous digestion experiments show that when the food undergoes digestion only from 5 to 15 per cent of the nitrogen is, as a rule, retained in the body. The nitrogen of the food is utilized largely to replace that which has been required for vital functions; it enters the body, undergoes digestion changes, is utilized for some vital function, and is then voided in the excrements.

The digestion of food has been compared to the combustion of fuel: the undigested products of the solid excrements represent the ashes, and the urine represents the volatile products. When wood is burned the nitrogen is converted into volatile products. When food is digested and utilized by the body the digestible nitrogen is mainly converted into urea, while the indigestible nitrogen is voided in the dung. In the solid and liquid excrements of animals from 80 to 95 per cent of the nitrogen, phosphoric acid, and potash of the food consumed is present.

184. Comparative Composition of Solid and Liquid Excrements. — In composition the liquid excrements differ from the solids in having a much larger amount of nitrogen and less phosphoric acid.[56]

	WATER		NITROGEN		PHOSPHORIC ACID		POTASH
	Solids Per cent	Liquids Per cent	Solids Per cent	Liquids Per cent	Solids Per cent	Liquids Per cent	Solids Per cent
Cows . .	76	89.0	0.50	1.20	0.35	——	0.30
Horses .	84	92.0	0.30	0.86	0.25	——	0.10
Pigs . .	80	97.0	0.60	0.80	0.45	0.12	0.50
Sheep .	58	86.5	0.75	1.40	0.60	0.05	0.30

The nitrogen in the food consumed influences the amount of water in the manure. As a rule, a highly concentrated nitrogenous ration produces a higher per cent of water than a well-balanced ration. There is but little phosphoric acid in the liquid excrements of horses and cows, while that of sheep and swine contains appreciable amounts.

The liquid manure is more constant both in composition and amount than the solid excrements. This fact may be observed from the following table, which gives the composition of the solid and liquid excrements of hogs when fed on different amounts of grain.[57]

The nitrogenous waste matter in the urine is nearly the same whether an animal be gaining or losing in flesh, and hence it is, the urine is more constant in composition and quantity than the solid excrements.

Lbs.	Kind of Food Daily	Solid Excrements			Liquid Excrements	
		Amount Lbs.	Nitrogen Per cent	Phosphoric acid Per cent	Nitrogen Per cent	Phosphoric acid Per cent
$9\frac{5}{7}$	Barley and shorts	8	0.57	0.72	2.05	0.06
6	Barley	4	0.43	0.70	2.06	0.16
$5\frac{1}{2}$	Corn and shorts	$2\frac{1}{2}$	0.80	——	2.65	0.20
$6\frac{1}{2}$	Corn	$1\frac{5}{7}$	0.82	0.89	2.05	0.29

(In each experiment the amount of liquid excrement was 4 pounds.)

The amount and composition of the solid excrements vary with the amount and kind of food consumed. If the food is indigestible, the solid excrements contain a larger part of the nitrogen as indigestible protein. When an animal is supplied with the proper food for all purposes, normal conditions exist, and the amount of nitrogen voided in the liquid and solid excrements is equal to that supplied in the food consumed, except in the case of growing and milk-producing animals.

Experiments at the Rothamsted Station show that from 57 to 79 per cent of the total nitrogen in the food of farm animals is voided in the liquid excrements, and from 16 to 22 per cent is voided in the solids. Nearly all of the mineral elements of the food are voided in the excrements, less than 4 per cent being retained in the body; in the case of milk cows about 10 per cent of the ash of the food is recovered in the milk.

185. Manurial Value of Foods. — The manurial value of a fodder is determined from the amount and commercial value of the nitrogen, phosphoric acid, and potash present in the fodder. A ton of clover hay, for example, contains 35 pounds of nitrogen, 14 pounds of

	NITROGEN N LBS.	PHOSPHORIC ACID P_2O_5 LBS.	POTASH K_2O LBS.
Timothy hay	25	9	40
Clover hay	35	14	30
Wheat straw	11	4	12
Oat straw	12	4	18
Wheat	45	20	12
Oats	33	16	11
Barley	40	18	11
Rye	42	20	13
Flax	87	32	14
Corn	32	14	8
Wheat shorts	48	31	20
Wheat bran	54	52	30
Linseed meal	100	35	25
Cottonseed meal	130	35	56
Milk	10	3	3
Cheese	90	23	5
Live cattle	53	37	3
Potatoes	7	3	11
Butter	1	1	1
Live pigs	40	17	3

phosphoric acid, and 30 pounds of potash. When the nitrogen is worth 16 cents per pound, the phosphoric acid 6 cents, and the potash 5 cents, the clover hay has a manurial value of $7.94 per ton. Lawes and Gilbert estimate that 80 per cent of the fertility in fodders is, as a rule, returned in the manure.

In the preceding table are given the pounds of nitrogen, phosphoric acid, and potash per ton of some farm products.[58]

186. Commercial Value of Manures. — When the value of farm manure is calculated on the same basis as commercial fertilizers, it will be found that stable manure is worth from $2 to $3.50 per ton. The value of the increased crops resulting from its use varies with conditions. Farm manures favorably influence the yield of crops for a number of years. As for example, a dressing of 8 tons of manure will make average prairie land yield upwards of 20 bushels per acre more corn the first year, 5 bushels more wheat the second year, and 8 bushels or so more of other grains the third year, with slightly increased yields in subsequent years, all due to the original application of the manure. It is often necessary to apply farm manure in order to secure a stand of clover, which enriches the soil with nitrogen. It sometimes takes from two to three years for the manure entirely to repay the cost of its application. Its influence is felt, however, for a much longer time. In calculating the value of farm manure, the returns from its use for a number of years must be considered and also its influence in permanently increasing the value of the land.

It is sometimes stated that the phosphoric acid and potash in stable manure is not so soluble as that in commercial fertilizers, and consequently is worth less. While not so soluble in the form of manure, it frequently happens that the phosphoric acid and potash in the commercial fertilizers become, through fixation processes, less soluble when mixed with the soil than the same elements in stable manure.

Stable manure is valuable not only for the fertility contained but also because it makes the inert plant food of the soil more available and exercises such a favorable influence on the water supply of crops; hence it is justifiable to assign the same, if not a higher, value to the elements in well-prepared farm manures as to those in commercial fertilizers.

INFLUENCE OF AGE AND KIND OF ANIMAL

187. Manure from Young and from Mature Animals. — The manure from older animals is somewhat more valuable than that from young animals, even when fed the same kind of food. This is because more of the phosphoric acid and nitrogen are retained in the body of a young animal. It is not so much a difference in digestive power as a difference in retentive power. In older animals the proportion of new nitrogenous tissue produced is much less than in young animals, and more of the nitrogen of the food is used for repair purposes and subsequently voided in the manure, while with young animals more of the nitrogen is retained for the construction of new muscular tissue.

When an animal is neither gaining nor losing in flesh, and is not producing milk, an equilibrium is established between the nitrogen in the food supply and the nitrogen in the manure, and practically all of the nitrogen of the food is returned in the manure.[57]

188. Cow Manure. — A milch cow when fed a balanced ration will make from 60 to 70 pounds of solid and liquid manure a day, of which 20 to 30 pounds are liquid. The solid excrement contains about 6 pounds of dry matter. When a cow is fed clover hay, corn fodder, and grain, about half of the nitrogen of the food is in the urine, about one fourth in the milk, and the remainder in the solid excrement. Hence, if the solid excrement only is collected, but a quarter of the nitrogen of the food is recovered; while if both solids and liquids are utilized, three quarters of the nitrogen is secured. Cow manure is extremely variable in composition and is the most bulky of any manure produced by domestic animals. A well-fed cow will produce about 80 pounds of manure per day, including absorbents.

189. Horse Manure. — Horse manure contains less water than cow manure, and is of a more fibrous nature, doubtless due to the horse possessing less power for digesting cellulose material. Horse manure readily ferments and gives off ammonia products. When the manure becomes dry, fire-fanging results, due to rapid fermentation followed by the growth of fungous bodies, and there is a heavy loss of nitrogen. Horse manure is sometimes considered of but little value. This is because it so readily deteriorates that when used it has often lost much of its nitrogen by fermentation. When mixed with cow manure, both are improved, the rapid fermentation of the horse manure is checked, and at the same time the cow manure is improved in texture. It is estimated that horses void about three fifths of their manure in the stable. A well-fed horse at ordinarily hard work produces 50 pounds per day, of which about one fourth is urine. A horse produces nearly 6 tons of manure per year in the stable. If properly preserved and used, it is valuable and quick-acting; but if allowed to ferment and leach, it gives poor results.

190. Sheep Manure. — Sheep produce a small amount of concentrated manure, containing less water than that of any other domestic animal. It readily ferments and is a quick-acting fertilizer. When combined with horse and cow manure the mixture ferments more slowly. Because of the small amount of water it contains, sheep manure is very concentrated in composition. It is valuable for general gardening purposes and whenever a concentrated, quick-acting manure is desired.

191. Hog Manure. — Hog manure is not constant in composition on account of the varied character of the food consumed. The manure from fattening hogs which are well fed compares favorably in composition and value with that produced by other animals. It contains a high per cent of water, and, like cow manure, may be slow in decomposing. On account of containing so much water, losses by leaching readily occur. From a given weight of grain, pigs produce less dry matter in the manure than do sheep or cows. The liquid excrements of well-fed hogs are rich in nitrogen, containing, on an average, about 2 per cent. The solids when leached, fermented, and deprived of the liquid excrements have little value as fertilizer.

192. Hen Manure. — Like all other farm manures, hen manure is variable in composition. The nitrogen is mainly in the form of ammonium compounds, making it a quick-acting fertilizer. When fowls are well fed the manure contains about the same amount of nitrogen as that of sheep. Hen manure readily ferments and if not properly cared for losses of nitrogen, as ammonia, occur. It is not advisable to mix with it hard wood ashes or ordinary lime, because the ammonia is so readily liberated by alkaline compounds. The value of hen manure is due to its being a quick-acting fertilizer rather than to its containing a large amount of fertility. A hen produces about a bushel of manure per year.

COMPOSITION OF HEN MANURE

	PER CENT
Water	57.50
Nitrogen	1.27
Phosphoric acid	0.82
Potash	0.28

193. Mixing of Solid and Liquid Excrements. — The solid and liquid excrements together make a well-balanced manure. Urine alone is not a complete manure, as it is deficient in phosphoric acid and other mineral matter. The solid excrement and the urine, when combined with soil, readily undergo nitrification. The nitrogen in the solid excrement is in the form of indigestible protein and is rendered available more slowly as plant food. Land dressed with leached manure receives an unbalanced fertilizer deficient in nitrogen but fairly well supplied with mineral matter and may fail to respond because of the unbalanced character of the manure. A large amount of fertility is often lost through poor and leaky stable floors. When the floors and trenches are made of cement, better sanitary conditions prevail and losses of fertility are prevented. The mixing of the solid and liquid excrements and waste bedding should be accomplished in the stable trenches.

194. Volatile Products from Manure. — Fermentation of manure in stables results in the production of a large number of volatile compounds and in loss of manurial value. When urea ferments, ammonium carbonate, a volatile product, results; and where the proteids of manure ferment, ammonia is formed, which combines with the carbon dioxide, always present in stables in liberal amounts as a product of respiration, to form ammonium carbonate, a volatile compound. When the stable atmosphere becomes charged with ammonium carbonate, some of it is deposited on the walls of the stable, forming a white coating. The white coating found on harnesses and carriages stored in poorly ventilated stables is ammonium carbonate. Accumulations of manure in the stable and poor ventilation are the conditions favorable to its production.

195. Human Excrements. — The use of human excrements as manure is sometimes advised, and in some countries they are extensively so utilized. When fresh, they may contain a high per cent of nitrogen and phosphoric acid; but when fermented, a loss of nitrogen has occurred. Heiden estimates 1000 pounds a year of excrements per person, containing $2.25 worth of fertility.[59] For sanitary reasons, human excrements should be used as manure with great care, and it is doubtful, with the abundance and cheapness of plant food, whether the practice is advisable. About 1840 Leibig expressed the fear that the essential elements of plant food would accumulate in the vicinity of large cities and be wasted, and that in time there would be a decline in fertility due to this cause.[60] Many political economists shared the same fear. Since that time the fixation of atmospheric nitrogen through the agency of leguminous crops has been discovered, extensive beds of sodium nitrate, phosphate rock, and Stassfurt salts have been utilized, and larger areas of more fertile soil have been brought under cultivation, so that it is not now so essential to devise means for utilizing human excrements as manure.

THE PRESERVATION OF MANURE

196. Leaching. — Leaching of manure is the greatest source of loss. Experiments by Roberts show that when horse manure is thrown in a loose pile and subjected to the joint action of leaching and weathering it may lose in six months nearly 60 per cent of its most valuable fertilizing constituents. The results of these experiments are tabulated as follows: [61]

	April 25 Lbs.	Sept. 28 Lbs.	Loss Per Cent
Gross weight	4000.00	1730.00	57
Nitrogen	19.60	7.79	60
Phosphoric acid	14.80	7.79	47
Potash	36.00	8.65	76
Value per ton	$2.80	$1.06	—

Cow manure, on account of its more compact nature, does not leach so readily as horse manure. A similar experiment with cow manure, conducted at the same time, showed the following losses:

	April 25 Lbs.	Sept. 28 Lbs.	Loss Per Cent
Gross weight	10,000	5125	49
Nitrogen	47	28	41
Phosphoric acid	32	26	19
Potash	48	44	8
Value per ton	$2.29	$1.60	—

When mixed cow and horse manure was compacted and "placed in a galvanized iron pan with a perforated bottom" for six months, the losses were as follows:

	March 29 Lbs.	Sept. 30 Lbs.	Loss Per Cent
Gross weight	226.00	222.00	——
Nitrogen	1.04	1.01	3.2
Phosphoric acid	0.61	0.58	4.7
Potash	1.20	0.43	35.0
Value per ton	$2.38	$2.16	——

197. Losses by Fermentation. — When rapid fermentation takes place in manure, appreciable losses of nitrogen may occur. When the manure is well compacted and the pile is so constructed as to prevent rapid circulation of air through it, losses are reduced to the minimum. Experiments show that when leaching is prevented, the loss of nitrogen by fermentation of mixed manure is very small. Under poor conditions losses by fermentation may exceed 15 per cent. Hen manure, sheep manure, and horse manure are the most fermentable, particularly when fungous growths and molds are formed. When extreme conditions, as excessive moisture, are followed by drought and high temperature, then the greatest losses occur.

198. Different Kinds of Fermentation. — The large number of organisms present in manure all belong to one of two classes: (1) aërobic, or (2) anaërobic. The aërobic ferments require an abundant supply of air in order to carry on their work. When deprived of oxygen, they become inactive. The anaërobic ferments require the opposite condition. They become inactive in the presence of oxygen and can thrive only when air is excluded. In the center of a well-constructed manure pile anaërobic fermentation occurs, while on the surface aërobic fermentation is active. The anaërobic ferments prepare the way for the action of the aërobic. When aërobic fermentation is completed, the organic matter is converted into water, carbon dioxide, ammonia, and allied gases, and these are lost. Consequently, anaërobic fermentation is the most desirable.

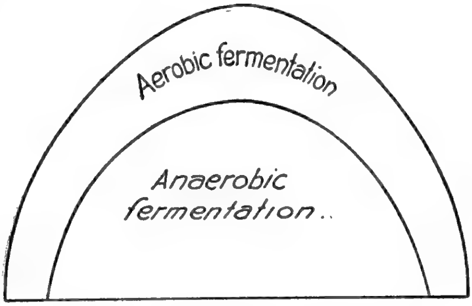


FIG. 36. Fermentation of Manure.

The bacterial content of the soil is greatly increased by the use of farm manures, and also food is supplied to the organisms already in the soil, many of which take an important part in rendering plant food available.

199. Water Necessary for Fermentation. — In order to produce the best results in fermenting manure, water is necessary; for if the manure becomes too dry, abnormal fermentation takes place. Water is always beneficial on manure so long as leaching is prevented, for it encourages anaërobic fermentation by excluding the air. An excess of water, such as falls on manure piles from the eaves of buildings, is more than is required for good fermentation. During a dry time it is beneficial to water the compost pile.

200. Heat produced during Fermentation. — During active fermentation of horse and sheep manure a temperature of 175° F. may be reached by the fermenting mass. Ordinarily, however, the temperature of the manure pile ranges from 110° to 130° F. The highest temperature is near the surface, where fermentation is most rapid. The temperature of fermentation may be sufficiently high to cause spontaneous combustion, if the manure is mixed with litter.

201. Composting Manure may improve its Quality. — Composting manure so that leaching and rapid fermentation do not take place may improve its quality, making it more concentrated. Pound for pound, composted manure is richer in plant food than fresh manure, because, if properly cared for, nearly all of the nitrogen, phosphoric acid, and potash of the original manure are present in smaller bulk. A ton of composted manure is obtained from about 2800 pounds of stable manure. Composting is sometimes resorted to in order to destroy obnoxious weed seeds.

	Fresh Manure Per Cent	Composted Manure Per Cent
Nitrogen	0.50	0.60
Phosphoric acid	0.28	0.39
Potash	0.60	0.80

In composting manure it should be the aim to induce anaërobic fermentation by excluding the air and retaining the water. This can be accomplished best by using mixed manure and making a compact pile, capable of shedding water. The compost pile should be shaded to secure better conditions for fermentation. If the pile becomes offensive, a little earth on the surface will absorb the odors.

202. Use of Preservatives. — The use of preservatives, as gypsum and kainit, has been recommended to prevent fermentation losses. Opinions differ as to the value of this practice. Moist gypsum, when it comes in contact with ammonium carbonate, produces ammonium sulphate, a non-volatile compound,

$$(NH_4)_2CO_3 + CaSO_4 = (NH_4)_2SO_4 + CaCO_3.$$

Gypsum when used should be at the rate of about one half pound per day for each animal.[59] Experiments show that it prevents a loss of 5 per cent of the nitrogen of horse manure. It has no action on the feet of animals, and so may with safety be sprinkled in the stalls. When it is necessary to use gypsum as a fertilizer, it is advantageous to use it in stables. It is not advisable to use lime in any other form than the sulphate. Unslaked lime will decompose manure and liberate ammonia. Neither kainit nor gypsum should be used when manure is exposed to the leaching action of rains. Preservatives cannot be made to take the place of care in handling manure; they should be used only when the manure receives the best of care.

203. Manure produced in Sheds and Box Stalls. — Manure produced under cover, as in sheds and box stalls, is of superior quality. Losses by leaching are thus avoided, the manure is compacted by the tramping of the animals, the solid and liquid excrements are more evenly mixed with the absorbents, and the conditions are favorable for anaërobic fermentation. By no other system is there such a large percentage of the fertility recovered. Manure from well-fed cattle, when collected and prepared in a covered shed, will have about the following composition:

	PER CENT
Water	70.00
Nitrogen	0.90
Phosphoric acid	0.60
Potash	0.70

Manure produced under cover has greater value than when cared for in any other way. Experiments by Kinnard show that such manure produced 4 tons more potatoes per acre than pile manure, while 11 bushels more wheat per acre were obtained on land which had the previous year received the covered manure than on land which received the uncovered manure.[62] Experiments at the Ohio Station show that stall manure gives a larger crop yield than yard manure.[98]

THE USE OF MANURE

204. Direct Hauling to Fields. — It is always desirable, whenever conditions allow, to draw the manure directly to the field and spread it, rather than to allow it to accumulate about barns or in the barnyard. When taken directly to the field from the stable no losses by leaching occur, and the slight losses from fermentation and volatilization of the ammonia are more than compensated for by the benefits derived from the action of the fresh manure upon the soil. When manure undergoes fermentation in the soil, as previously stated, it combines with the mineral matter of the soil and produces humates. The practice of hauling the manure directly to the field and spreading it with a manure spreader is the most economical way of handling it, as the manure is thus evenly spread, and larger crop returns are secured from the lighter and more frequent applications.

With scant rainfall composting the manure before spreading is often necessary, but with liberal rainfall it is not essential. On a loam soil, a direct application of stable manure is more advisable than on heavy clay or light sandy soil. In the case of sandy soils there is frequently an insufficient supply of water properly to ferment the manure. Manure on heavy clay land sometimes fails to show any beneficial effect the first year because of the slow rate of decomposition, but the beneficial effects are noticeable the second and third years.

When conditions will not permit farm manure to be hauled directly to the field and spread, it should be stored in covered manure sheds, so as to prevent leaching and injurious fermentation.

205. Coarse Manure Injurious. — The application of coarse leached manure may cause the soil to be so open and porous as to affect the water supply of the crop, by introducing below the surface soil a layer of straw, and thus breaking the capillary connection with the subsoil. Coarse manure and shallow spring plowing are sometimes injurious, where fine or well-composted manure and fall plowing would be beneficial. Trouble resulting from the use of coarse manure may be due to its being allowed to leach before it is used, so that it does not readily ferment in the soil.

206. Manuring Pasture Land. — In regions where manure decomposes slowly, it is sometimes advisable to use it upon pasture land as a top dressing. The manure encourages growth of the grass, so that it appropriates plant food otherwise lost; it also acts as a mulch, preventing excessive evaporation. Then when the pasture land is plowed and prepared for a grain crop it contains a better store of both water and available plant food. The manuring of pasture lands is one of the best ways of utilizing manure when trouble arises from slow decomposition.

207. Small Manure Piles Undesirable. — It is sometimes the custom to make a number of small manure piles in fields. This is a poor practice, for it entails additional expense later in spreading the manure, and the small piles are usually constructed in such a way that heavy losses occur, so the manure, when finally

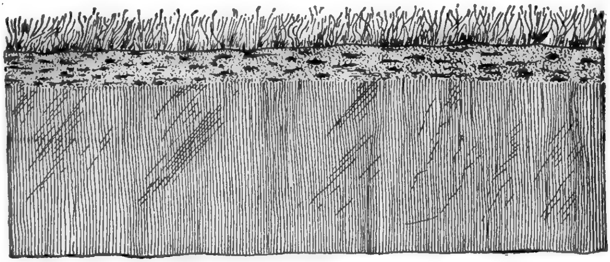


FIG. 37. Manured Land.

spread, is not uniform in composition. Oats grown on land manured in this way presented an uneven appearance. There were small patches, thrifty and overfed, corresponding to the places formerly occupied by the manure piles, while large areas of half-starved oats might be observed.

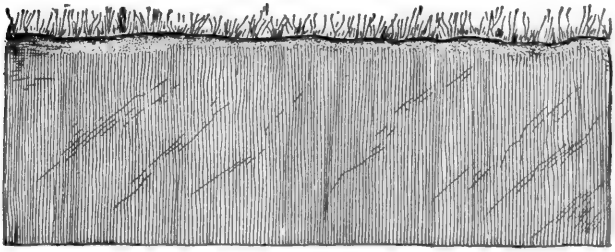


FIG. 38. Unmanured Land.

208. Rate of Application. — The amount of manure that should be applied depends upon the nature of the soil and the crop. On loam soils intended for general truck purposes, heavier applications may be made than when grain is raised. For general farm purposes, 8 tons per acre are usually sufficient. It is better economy to make frequent and light applications than heavier ones at long intervals. When manure is spread frequently the soil is kept in an even state of fertility, and losses by percolation, denitrification, and ammonification are prevented. Too often the manure is not evenly distributed about the farm; fields adjacent to stables are heavily manured, while those at a distance receive none.

For growing garden crops, 20 tons and more per acre are sometimes used. It is better, however, not to use stable manure in excess for trucking, but to supplement it with special fertilizers as the crops may require. Soils which contain a large amount of calcium carbonate will not become acid from farm manure, and hence admit of more frequent and heavier applications than soils which are deficient in this compound. The lime aids fermentation and nitrification. Sometimes a judicious combination of farm manure and commercial fertilizers can be made that will prove more economical than farm manure alone.

209. Crops Most Suitable for Manuring. — Soils which contain a low stock of fertility admit of manuring for the production of almost any crop. Soils well stocked with plant food, like some of the western prairie soils, which are in need of manure mainly for its physical action, will not allow its direct use on all crops. On a prairie soil of average fertility a heavy application of manure may cause wheat and other grain crops to lodge. When manure cannot be applied directly to a crop, it may be used advantageously on a preceding crop and the land thus be brought into good condition for the crop that will not bear direct manuring. Manure never injures corn by causing too rank a growth, and wheat may follow corn which has been manured with but little danger of loss from lodging.

On some soils stable manure cannot be used for growing sugar beets; on others it does not seem to exercise an injurious effect. Tobacco is injured as to quality by manure. Flax, tobacco, sugar beets, and wheat, which should not receive heavy direct applications, all require manuring of the preceding crops. When in doubt as to the crop on which to use the manure, it is always safe to apply it to corn, and then to follow with the crop which would have been injured by its direct application.

That coarse, leached manure may cause trouble in a dry season, and well-rotted manure may cause grain to lodge, are not valid reasons for manure being wasted as it frequently is in western farming, by being burned, thrown away in streams, used in making roads, or for filling up low places.

210. Comparative Value of Forage and Manure. — The manure from a given amount of grain or fodder always gives better results than if the food itself were used directly as manure. The manure from a ton of bran will give better returns than if the bran itself were used. This is because so little of the fertility is lost during the process of digestion, and the action of the digestive fluids upon the food makes the manure more readily available as a fertilizer than the food which has not passed through any fermentation process. It is better economy to use products as linseed meal and cottonseed meal for feeding stock, and then take good care of the manure, than to use the materials directly as fertilizer.

211. Lasting Effects of Manure. — No other manures make themselves felt for so long a time as farm manures. In ordinary farm practice an application of stable manure will visibly affect the crops for a number of years. At the Rothamsted Experiment Station, records have been kept for over fifty years as to the effects of manures upon soils. In one experiment, farm manure was used for twenty years and then discontinued for the same period. It was observed that when its use was discontinued there was a gradual decline in crop-producing power, but not so rapid as of plots where no manure had been used. The manure applied during the twenty-year period made itself felt for an ensuing twenty years.

212. Comparative Value of Manure produced on Two Farms. — The fact that there is a great difference in the composition and value of manures produced on different farms may be observed from the following examples:

On one farm 10 tons of timothy are fed. The liquid manure is not preserved and 25 per cent of the fertility is leached out of the solid excrements, while 5 per cent of the nitrogen is lost by volatilization. It is estimated that half of the nitrogen and potash of the food is voided in the urine. On account of the scant amount and poor quality of the food no milk or flesh is produced.

On another farm 7.5 tons of clover hay and 2.5 tons of bran are fed. The liquid excrements are collected and the manure is taken directly to the field and spread. It is estimated that 20 per cent of the nitrogen and 4 per cent of the phosphoric acid and potash are utilized for the production of flesh and milk.

The comparative value of the manure from the two farms is as follows:

Farm No. 1

	In 10 Tons Timothy Lbs.
Nitrogen	250
Phosphoric acid	90
Potash	400

Loss in Urine

250 ÷ 2 = 125 lbs. nitrogen
400 ÷ 2 = 200 lbs. potash

Loss by Leaching

125 × 0.30 = 37.50 lbs. nitrogen
90 × 0.25 = 22.50 lbs. phosphoric acid
200 × 0.25 = 50 lbs. potash

	Total Loss	
	Lbs.	Per Cent
Nitrogen	162.5	65
Phosphoric acid	22.5	25
Potash	250.0	62

	Present in Final Product Manure from 1 Ton Timothy Lbs.
Nitrogen	8.75
Phosphoric acid	6.75
Potash	15.00
Relative money value	$1.00

FARM NO. 2

	IN 10 TONS MIXED FEED Lbs.
Nitrogen	400
Phosphoric acid	240
Potash	300

	LOSS, SOLD IN MILK AND RETAINED IN BODY Lbs.	Per Cent
Nitrogen, 400 × 0.20	80	20
Phosphoric acid, estimated	10	4
Potash	12	4

	PRESENT IN FINAL PRODUCT MANURE FROM 1 TON FEED Lbs.
Nitrogen	32.0
Phosphoric acid	23.0
Potash	29.0
Relative money value	$3.80

213. Summary of Ways in which Stable Manure may be Beneficial. — Farm manures act upon soils chemically, physically, and bacteriologically.

(*a*) Chemically:

1. By adding new stores of plant food to the soil.

2. By combining with the soil, forming humates, and rendering the inert mineral plant food more available.

3. By raising the temperature of the soil, as the result of oxidation.

(*b*) Physically:

1. By making the soil darker colored.

2. By enabling soils to retain more water and to give it up gradually to growing crops.

3. By improving the tilth of sandy and clay soils.

4. By preventing the denuding effects of heavy wind storms.

(*c*) Bacteriologically:

1. By increasing the number of soil organisms.

2. By promoting fermentation changes.

3. By supplying food to the organisms which assist in rendering plant food available.

CHAPTER VI

FIXATION

214. Fixation, a Chemical Change. — When a fertilizer is applied to a soil, chemical reaction takes place between the soil and the fertilizer. There is a general tendency for the soluble matter of fertilizers to undergo chemical change and become insoluble. This process is known as fixation. If a solution of potassium chloride be percolated through a column of clay, the filtrate will contain scarcely a trace of potassium chloride, but instead calcium and other chlorides. The element potassium of the potassium chloride has been replaced by the element calcium present in the soil, and as a result of this exchange of base elements an insoluble compound of potash is formed. Independent of chemical action, a small amount of soluble salts are absorbed physically by soils and retained by molecular force. Absorption is a physical property of soils, while fixation is due to a chemical change.

215. Fixation due to Zeolites. — It has been shown by experiments, particularly those of Way and Voechler,[53] that fixation is due mainly to zeolitic silicates. Sandy soils containing but little clay have only feeble power of fixation. Clay soils when digested with hydrochloric acid to remove the zeolitic silicates lose their power of fixation. The fixation of potassium chloride and the liberation of calcium chloride may be illustrated by the following reaction:

$$\overset{\text{Zeolite}}{\left.\begin{array}{l}Al_2O_3\\ CaO\\ Fe_2O_3\\ \text{etc.}\end{array}\right\} x\cdot(SiO_2)x\cdot H_2O} + 2\,KCl = \overset{\text{Zeolite}}{\left.\begin{array}{l}Al_2O_3\\ K_2O\\ Fe_2O_3\\ \text{etc.}\end{array}\right\} x(SiO_2)x\cdot H_2O} + CaCl_2.$$

216. Humus may cause Fixation. — Also other compounds of the soil, as humus and calcium carbonate, take an important part in fixation. In the case of humus, a union occurs between the minerals in the fertilizer and the organic acids formed from the decay of the humus in the soil, resulting in the production of humates.

217. Variations in Fixative Power of Soils. — All soils do not possess the power of fixation to the same extent. Heavy clays have the greatest fixative power, while sandy soils have the least. As a general rule, soils of high fertility show good fixative power. Hence it is that a fertilizer, after being applied to a soil, may be entirely changed in composition, so that the plant feeds on the chemical products formed, rather than on the original fertilizer.

218. Fixation of Phosphates. — The phosphates of fertilizers readily undergo fixation by combination with the iron and aluminum compounds of soils, forming insoluble phosphates. Experiments show that in a loam soil from 2000 to 8000 pounds per acre of phosphoric acid may undergo fixation. Drainage waters contain only traces of phosphates. At the Rothamsted Experiment Station the plots receiving an annual dressing of phosphates for fifty years contained 83 per cent of the surplus fertilizer, half of which was in available forms soluble in one per cent citric acid.[95]

219. Fixation of Potash.—The potash compounds of fertilizers readily undergo fixation, the sodium and calcium of the soil being replaced by the potassium of the fertilizer. Drainage waters contain larger amounts of sodium than of potassium compounds, due to greater insolubility of the potash of the soil. Fixation of potash occurs mainly in the surface soil, where it is held in forms insoluble in water, a portion being soluble in dilute acids.

220. Nitrates cannot undergo Fixation. — Nitrogen in the form of nitrates or nitrites cannot undergo fixation. This is because all of the ordinary forms of nitrates are soluble. If potassium nitrate be added to a soil, calcium or sodium nitrate will be obtained as the soluble compound. The potassium undergoes fixation, but the nitrate radical does not. Chlorides also are incapable of undergoing fixation, because all of the chlorides found in soils are soluble.

221. Fixation of Ammonia. — Ammonium compounds readily undergo fixation, particularly in the presence of clay. (See experiment No. 17.) The ammonium radical, NH_4, like potassium, is capable of replacing soil bases. After undergoing fixation, the ammonium compounds readily yield to nitrification (see Section 156), hence they serve as a temporary but important form of insoluble nitrogen. The general tendency of the nitrogen compounds of the soil is to pass from insoluble to soluble forms through processes of decay, and to resist fixation changes.

222. Fixation may make Plant Food Less Available. — If a very heavy dressing of potash or phosphate fertilizer be applied to a heavy clay soil, what is not utilized the first few years may undergo fixation to such an extent that part becomes unavailable as plant food. It is not well to apply unnecessarily heavy dressings of fertilizers at long intervals because of fixation. It is always best to make light and frequent applications.

223. Fixation, a Desirable Property for Soils. — If it were not for the process of fixation, soils in regions of heavy rains would soon become sterile. When the plant food has become insoluble, it is retained in the soil. That which undergoes fixation is, as a rule, in an available condition or may readily become so by cultivation unless the soil be one of unusual composition. The process of fixation regulates the supply of plant food in the soil. Many fertilizers, if they did not undergo this process, would be injurious to crops, for there would be an abnormal amount of soluble alkaline or acid compounds which would be destructive. When the process of fixation takes place, it removes, to a great extent, injurious water-soluble salts, particularly when the reaction is one of union rather than replacement. Then the plant is free to render soluble its own food in quantities and at times desired.

FIG. 39. Plants grown in Normal Soil.

Farm manures and commercial fertilizers alike undergo the process of fixation and, in studying fertilizers, their action upon the soil and the products of fixation are matters of prime importance.

224. Soil Solution. — Soil water obtained by leaching soils is an exceedingly dilute solution of various mineral salts and organic compounds. Through rock disintegration, mineral matter is rendered soluble, but the process of fixation prevents accumulation in the soil solution of compounds of such elements as potassium and phosphorus. As a result of disintegration and fixation, numerous chemical changes take place in the soil, and the soil solution is an important factor in bringing about these changes. Many of the phenomena which have been studied in connection with solutions in physical chemistry take place in the soil. Diffusion, absorption, osmotic pressure, and ionization,[88] — disassociation of the molecule in solution, — all occur in soils and are due

FIG. 40. Plants grown in Sand and watered with Leachings (Soil Solution) from Soil as used in Fig. 39.

largely to the physical and chemical action of the soil solution. The soil solution from different soils varies with the composition and degree of disintegration of the soil particles, and in the same soil at different times there are variations in its composition. The soil solution is more important as an agent for bringing about chemical and physical changes in the soil than as a storehouse of plant food. It is not possible to exhaust a soil of all of its water-soluble salts by one or more leachings. There appears to be a variable but fairly continuous solubility of soil constituents. King has shown that soils of high productiveness contain a larger amount of soluble salts than soils of low fertility.[97]

CHAPTER VII

PHOSPHATE FERTILIZERS

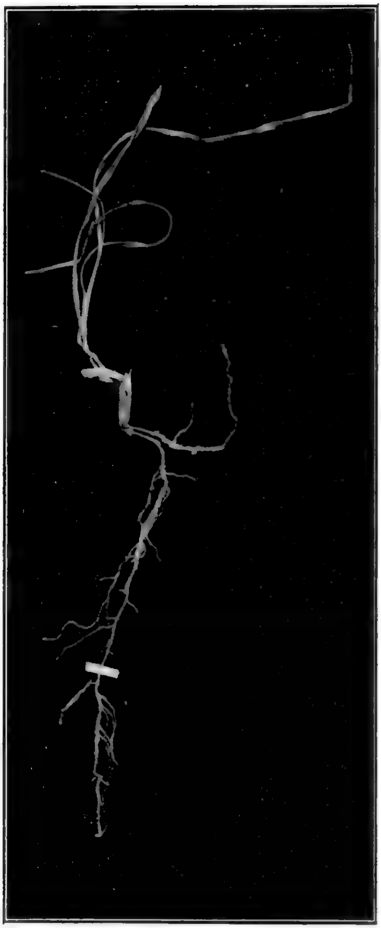


FIG. 41. Oat Plant grown without Phosphates.

225. Importance of Phosphorus as Plant Food. — Phosphorus in the form of phosphates is one of the essential elements of plant food. None of the higher orders of plants can complete their growth unless supplied with this element. The illustration (Fig. 41) shows an oat plant which received no phosphorus compounds, but was supplied with all the other elements of plant food. As soon as the phosphoric acid stored up in the seed had been utilized, the plant ceased to grow, and after a few weeks, died of phosphate starvation, having made the total growth shown in the illustration. All crops demand their phosphorus compounds at an early stage of development. Wheat takes up 80 per cent of its phosphoric acid in the first half of the growing period,[37] while clover has assimilated all it requires by the time the plant reaches full bloom.[43] Phosphorus compounds accumulate, to a great extent, in the seeds of grains, and hence, when grain farming is extensively followed, are sold from the farm. All crops are very sensitive to the absence of phosphoric acid; an imperfect supply results in the production of light-weight grain. The nitrogen and phosphorus are to a great extent stored up in the same parts of the plant, particularly in the seed, which is richer in both of these elements than is any other part. Nitrogen is the chief element of protein, while phosphorus is also necessary for the formation of some of the phosphorus and nitrogen compounds, as the nucleo-albumins and lecithin. Phosphorus aids in the production of the protein compounds. In speaking of the phosphorus compounds in plants and in fertilizers, as well as in soils, the term 'phosphoric anhydride' or 'phosphorus pentoxide,' P_2O_5, commonly called phosphoric acid, is used. This is because phosphorus is an acid-forming element and, as already explained, the anhydride of the element is always considered instead of the element itself.

226. Amount of Phosphoric Acid removed in Crops. — Grain crops remove about 20 pounds per acre of phosphoric acid; the amount removed by other farm crops ranges from 18 to 28 pounds, as will be observed from the following table:

	Phosphoric Acid P_2O_5 Per Acre Lbs.
Wheat, 20 bu.	12.5
Straw, 2000 lbs.	7.5
Total	20.0
Barley, 40 bu.	15
Straw, 3000 lbs.	5
Total	20
Oats, 50 bu.	12
Straw, 3000 lbs.	6
Total	18
Corn, 65 bu.	18
Stalks, 4000 lbs.	4
Total	22
Peas, 3500 lbs.	25
Red clover, 4000 lbs.	28
Potatoes, 150 bu.	20
Flax, 15 bu.	15
Straw, 1800 lbs.	3
Total	18

227. Amount and Source of Phosphoric Acid in Soils. — To meet the demand of growing crops for about 25 pounds of phosphoric acid per acre, there are present in soils from 0.03 to 0.25 per cent. This is equivalent to from 1000 pounds and less to 9000 pounds per acre, of which, however, only a fraction is available as plant food at any one time. The availability of the phosphoric acid has a great deal to do in determining crop-producing power. Many soils contain a large amount of total phosphoric acid which has become unavailable, because of poor cultivation and absence of stable manure and lime to combine with the phosphates and render them available.

The phosphates in soils are derived mainly from the disintegration of phosphate rock and from the remains of animal life. The phosphate deposits found in various localities are supposed to have had their origin either in the remains of marine animals or sea water highly charged with soluble phosphates. These deposits have been subjected to various geological and climatic changes which have resulted in the formation of soft phosphate, pebble phosphate, and rock phosphate.[63]

228. Commercial Forms of Phosphoric Acid. — The sources of phosphate fertilizers are: (1) phosphate rock, (2) bones and bone preparations, (3) phosphate slag, and (4) guano. With the exception of phosphate slag and guano, the prevailing form of phosphorus is tricalcium phosphate. Before being used for commercial purposes the tricalcium phosphate, which is insoluble and unavailable, is treated with sulphuric acid, which produces monocalcium phosphate, a soluble and available form.

$$Ca_3(PO_4)_2 + 2\ H_2SO_4 + 5\ H_2O = CaH_4(PO_4)_2 + H_2O + 2\ CaSO_4,\ 2\ H_2O.$$

In making phosphate fertilizers from bones or phosphate rock, an excess of the rock is used so there will be no free acid in the fertilizer to be injurious to vegetation.

As stated above, the usual form in which calcium phosphate is found in nature is tricalcium phosphate, $Ca_3(PO_4)_2$, and unless associated with organic matter or salts which render it soluble, it is of but little value as plant food. When tricalcium phosphate is treated with sulphuric acid, monocalcium phosphate, $CaH_4(PO_4)_2$, is formed, which is soluble in water and directly available as plant food. When tricalcium and monocalcium phosphate are brought together in a moist condition, dicalcium phosphate is produced.

$$Ca_3(PO_4)_2 + CaH_4(PO_4)_2 = 2\ Ca_2H_2(PO_4)_2.$$

Another form of phosphate of lime, met with in basic phosphate slag, is tetracalcium phosphate, $(CaO)_4P_2O_5$.

229. Reverted Phosphoric Acid. — When mono- and tricalcium phosphate react, the product is known as reverted phosphoric acid, which is insoluble in water, but is not in such form as to be unavailable as plant food ; it is generally considered available. Reverted phosphoric acid may also be formed by the action, upon monocalcium phosphate, of iron and aluminum compounds present as impurities in the phosphate rock. As it is soluble in a dilute solution of ammonium citrate, it is sometimes spoken of as citrate-soluble phosphoric acid, and is not all equally valuable as plant food because of the different phosphate compounds that may be dissolved by this solvent. Citrate-soluble phosphoric acid may be present in an old fertilizer in two forms, — dicalcium phosphate and hydrated phosphates of iron and aluminum.

230. Available Phosphoric Acid. — As applied to fertilizers, the term 'available phosphoric acid' includes the water-soluble and citrate-soluble phosphoric acid. These solvents do not, under all conditions, make a sharp distinction as to the available and unavailable phosphoric acid when it comes to plant growth. Some forms of bone which are insoluble in an ammonium citrate solution are available as plant food, while some forms of aluminum phosphate which are soluble are of but little value. The fineness of division of the fertilizer particles also greatly influences the availability of the phosphoric acid. The terms 'available' and 'unavailable phosphoric acid,' as applied to commercial fertilizers, refer to the solubility of the phosphates, and, as a rule, the value of the phosphates as plant food is in accord with their solubility — the more insoluble the less valuable.

231. Phosphate Rock. — Phosphate rock is found in many parts of the United States, particularly in South Carolina, North Carolina, Florida, Virginia, and Tennessee. The deposits occur in stratified veins, as well as in beds and pockets. There are different types of phosphates, as hard rock, soft rock, land pebble, and river pebble. The pebble phosphates are found either on land or collected in cavities in water courses, and are generally spherical masses of variable size. Soft rock phosphate is easily crushed, while the hard rock requires pulverizing with rock crushers. Phosphate rock usually contains from 40 to 70 per cent of calcium phosphate, the equivalent of from 17 to 30 per cent phosphoric acid. The remaining 30 to 60 per cent is fine sand, limestone, alumina, and iron compounds, with other impurities, which often render a phosphate unsuitable for manufacture into high-grade fertilizer.

232. Superphosphate. — Pulverized rock phosphate, known as phosphate flour, is treated with commercial sulphuric acid to obtain soluble monocalcium phosphate. The amount of sulphuric acid used is determined by the composition of the rock. Impurities as calcium carbonate and calcium fluoride react with sulphuric acid and cause a loss of the acid. Ordinarily, a ton of high-grade phosphate rock requires a ton of sulphuric acid. The mixing is done in lead-lined tanks. A weighed amount of phosphate flour is placed in the tank and the sulphuric acid added, through lead pipes, from the acid tower. The mixing of the acid and phosphate is done with a mechanical mixer, driven by machinery. From the mixing tank the material is passed into other large tanks, where two or three days are allowed for the completion of the reaction. The mass is placed in piles to solidify and is then ground and sold as superphosphate. In the manufacture of superphosphate, gypsum ($CaSO_4.2H_2O$) is always produced. A ton of superphosphate prepared from high-grade rock in the way outlined will contain about 40 per cent of lime phosphate, equivalent to 18 per cent phosphoric acid. If a poorer quality of rock is used, there is a proportionally smaller amount of phosphoric acid. A more concentrated superphosphate is known as double superphosphate and is obtained by producing phosphoric acid from the phosphate rock, and then allowing the phosphoric acid to act upon fresh portions of the rock, the reactions being as follows:[64]

$$Ca_3(PO_4)_2 + 3\,H_2SO_4 = 3\,CaSO_4 + 2\,H_3(PO_4).$$
$$Ca_3(PO_4)_2 + 4\,H_3PO_4 + 3\,H_2O = 3[CaH_4(PO_4)_2,\,H_2O].$$

The phosphoric acid is separated from the gypsum before acting upon the phosphate flour. In this way, superphosphate containing from 35 to 45 per cent of phosphoric acid is produced. When fertilizers are to be transported long distances, this concentrated product is preferable. The terms 'acid' and 'superphosphate' have been generally used to designate the first product resulting from the action of sulphuric acid upon phosphate rock or bones, and the term 'double superphosphate' to mean the concentrated product formed by the action of phosphoric acid.

233. Commercial Value of Phosphoric Acid. — The commercial value of phosphoric acid in fertilizers is determined by the value of the crude phosphate rock, cost of grinding and treating with sulphuric acid, and cost of transportation. The price of phosphoric acid in superphosphates usually ranges from 5 to 6 cents per pound. The field value, that is the increased yields obtained from the use of superphosphates, may or may not be in accord with the commercial value because so many conditions influence crop growth. The phosphoric acid obtained from feed stuffs is usually considered worth about a cent a pound less than that from superphosphates. Water-soluble phosphoric acid is generally rated a half cent per pound higher than citrate-soluble phosphoric acid.

234. Phosphate Slag. — In the refining of iron ores by the Bessemer process, the phosphorus in the iron is removed as a basic slag. The lime, which is used as a flux, melts and combines with the phosphorus of the ore, forming phosphate of lime. The slag has a variable composition. The process by which the phosphorus of pig iron is removed and converted into basic phosphate slag is known as the Thomas process, and the product is sometimes called Thomas' slag. At the present time but little basic slag is produced in this country that is suitable for fertilizer purposes. In Germany and some other European countries large amounts are produced and used. Phosphate slag is ground to a fine powder and is applied directly to the land, without undergoing the sulphuric acid treatment. The phosphoric acid is present mainly in the form of tetracalcium phosphate $(CaO)_4P_2O_5$.

235. Guano is the Spanish for dung and is a concentrated form of nitrogenous and phosphate manure, of interest mainly on account of its historic significance. It is a mixture of sea-fowl droppings, with dead animals and débris, which have accumulated along the seacoast in sheltered regions and undergone fermentation. The introduction of guano into Europe marked an important period in agriculture, inasmuch as its use demonstrated the action and value of concentrated fertilizers. All of the best beds of guano have been exhausted and only a little of the poorer grades is now found on the market. The best qualities of guano contained from 12 to 15 per cent of phosphoric acid, 10 to 12 per cent of nitrogen, and from 5 to 7 per cent of alkaline salts.

BONE FERTILIZERS

236. Raw Bones contain, in addition to phosphate of lime, $Ca_3(PO_4)_2$, organic matter which makes them slow in decomposing and slow in their action as a fertilizer. Before being used as a fertilizer they should be fermented in a compost heap with wood ashes in the following way, a protected place being selected so that no losses from drainage will occur. A layer of well-compacted manure is covered with wood ashes, the bones are then added and well covered with ashes and manure. From three to six months should be allowed for the bones to ferment. The large, coarse pieces may then be crushed and are ready for use. The presence of fatty material in a fertilizer retards its action because fat is so slow in decomposing. Bones from which the organic matter has been removed are more active as a fertilizer than raw bones. There is from 18 to 25 per cent of phosphoric acid and from 2 to 4 per cent of nitrogen in bones. The amount and value of the citrate-soluble phosphoric acid are extremely variable.

237. Bone Ash is the product obtained when bones are burned. It is not extensively used as a fertilizer because of the greater commercial value of bone black. Bone ash contains about 36 per cent of phosphoric acid, and is more concentrated than raw bones.

238. Steamed Bone. — Raw bones are subjected to superheated steam to remove the fat and ossein which are used for making soap and glue. They are then pulverized and sold as fertilizer under the name of bone meal, which contains from 1.5 to 2.5 per cent of nitrogen and from 22 to 29 per cent of phosphoric acid. Steamed bone makes a more active fertilizer than raw bone. Occasionally well-prepared bone meal is used for feeding pigs and fattening stock in the same way that flesh meal is used. The fineness to which the bone meal is ground greatly influences its agricultural value.

239. Dissolved Bone. — When bones are treated with sulphuric acid, as in the manufacture of superphosphates, the product is called dissolved bone. The tricalcium phosphate undergoes a change to more available forms, as described, and the nitrogen is rendered more available. Dissolved bone contains from 2 to 3 per cent of nitrogen and from 15 to 17 per cent of phosphoric acid.

240. Bone Black. — When bones are distilled, bone black is obtained. It is extensively employed for refining sugar, and after it has been used and lost its power of decolorizing solutions it is occasionally sold for fertilizer. It is a concentrated phosphate fertilizer, containing about 30 per cent phosphoric acid.

241. Use of Phosphate Fertilizers. — The amount of a phosphoric acid fertilizer that it is advisable to apply to crops varies with the nature of the soil and the kind of crop to be produced. On a poor soil 400 pounds of acid phosphate per acre is an average application. It is usually applied as a top dressing just before seeding, and may be placed near but not in contact with the seed. It is not advisable to make heavy applications of superphosphates at long intervals, because fixation may take place to such an extent that crops are unable to utilize the fertilizer. Lighter and more frequent applications, as 100 to 200 pounds per acre, are preferable. Phosphates should not be mixed with lime carbonate before spreading, but be applied directly to the land.[22] Phosphates may be used in connection with farm manures. Many soils which contain liberal amounts of phosphoric acid are improved by a light dressing of phosphates, 75 pounds per acre. Such soils, however, should be more thoroughly cultivated, and manured with farm manures, to make the phosphates available. There is frequently an apparent lack of phosphoric acid when in reality the trouble is due to other causes, as a deficiency of lime or organic matter to render the phosphates available. Before using phosphate fertilizers, careful field tests should be made to determine the needs of the soil.

242. How to keep the Phosphoric Acid Available. — Phosphoric acid associated with organic matter in a moderately alkaline soil is more available than that in acid soils. Soft phosphate rock may be mixed with manure or material like cottonseed meal and made slowly available for crops, but where land is high in price such a procedure is not economical. Soils which contain a good stock of phosphoric acid, when kept well manured and occasionally limed if necessary, have a liberal supply of available phosphoric acid. The following is an example of two soils from adjoining farms, which have been cropped and manured differently.[31]

	SOIL WELL MANURED AND CROPS ROTATED PER CENT	NO MANURE AND CONTINUOUS WHEAT RAISING PER CENT
Total phosphoric acid	0.20	0.20
Humus	4.25	1.62
Phosphoric acid dissolved with humus	0.06	0.02

When the soil contains a liberal supply of total phosphoric acid, it is more economical to change the phosphoric acid of the soil to available forms by the use of farm manures, lime, rotation of crops, and thorough cultivation, than it is to purchase superphosphates in commercial forms.

CHAPTER VIII

POTASH FERTILIZERS

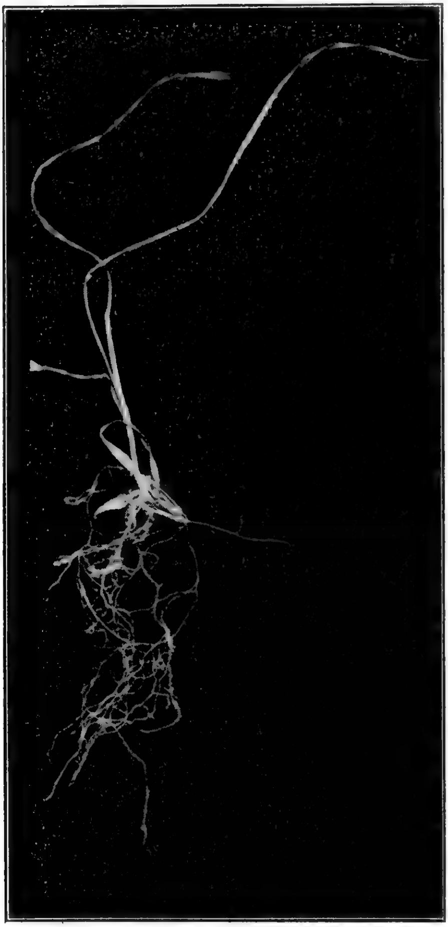


FIG. 42. Oat Plant grown without Potash.

243. Potassium an Essential Element of Plant Food. — Potassium is one of the three elements most essential as plant food. In its absence plants are unable to develop. Oats seeded in a sterile soil from which potassium salts only were withheld made the total growth shown in the illustration (Fig. 42). In discussing the content of potassium compounds in plants, soils, and food stuffs, the term 'potash' (potassium oxide, K_2O) is used. When present in the soil in liberal amounts and associated with other essential elements, potash produces vigorous plants. Like phosphoric acid and nitrogen, it is utilized by crops in the early stages of growth. It does not accumulate in seeds to the same extent as phosphoric acid and nitrogen, but is present mainly in stems and leaves; consequently when straw crops are utilized in producing manure, the potash is not lost, or as in the case of nitrogen, sold from the farm. But with ordinary grain farming excessive losses of potash do occur, particularly when the straw is burned and the ashes are wasted.

244. Amount of Potash removed in Crops. — In grain crops from 35 to 60 pounds of potash per acre are removed from the soil. For grass crops more potash is required than for grains, while roots and tubers require more than grass. The approximate amount of potash removed in various crops is given in the following table:

	Potash per Acre K_2O Lbs.
Wheat, 20 bu.	7
Straw, 2000 lbs.	28
Total	35
Barley, 40 bu.	8
Straw, 3000 lbs.	30
Total	38
Oats, 50 bu.	10
Straw, 3000 lbs.	35
Total	45

	POTASH PER ACRE K_2O LBS.
Corn, 65 bu.	15
Stalks, 3000 lbs.	45
Total	60
Peas, 30 bu.	22
Straw, 3500 lbs.	38
Total	60
Flax, 15 bu.	8
Straw, 1800 lbs.	19
Total	27
Mangels, 10 tons	150
Meadow hay, 1 ton	45
Clover hay, 2 tons	66
Potatoes, 150 bushels	75

245. Amount of Potash in Soils. — Ordinarily there is in soils from 0.1 to 0.5 per cent of potash, equivalent to from 3500 to 18,000 pounds per acre to the depth of one foot. Many soils with apparently a good stock of total potash give excellent results when a light dressing of potash salts is applied. The amount of available potash in a soil is more difficult to estimate than the available phosphoric acid. There is much difference in crops as to their power of obtaining potash; some require greater help in procuring it than others. A lack of available potash is sometimes indirectly due to a deficiency of lime or other alkaline matter in the soil, which prevents the necessary chemical changes taking place in order that the potash may be liberated as plant food.

246. Sources of Potash in Soils. — The main source of the soil's potash is feldspar, which, after disintegration, is broken up into kaolin and potash compounds. Mica and granite also, in some localities, contribute liberal amounts, and the zeolitic silicates are a valuable source of potash. There is but little water-soluble potash except in alkaline soil. By the action of many fertilizers the potash compounds undergo changes in composition. For example, the gypsum which is always present in acid phosphates liberates some potash. The potash compounds of the soil are in various degrees of complexity from forms soluble in dilute acids to insoluble minerals as feldspar.

247. Commercial Forms of Potash. — Prior to the introduction of the Stassfurt salts, wood ashes were the main source of potash. Since the discovery and development of the Stassfurt mines, the natural products, as kainit, and muriate and sulphate of potash, have been extensively used for fertilizing purposes. A small amount of potash is obtained also from waste products, as tobacco stems, cottonseed hulls, and the refuse from beet-sugar factories.

STASSFURT SALTS

248. Occurrence.[64] — The Stassfurt mines were first worked with the view of procuring rock salt. The various compounds of potash, soda, and magnesia, associated with the layers of rock salt, were regarded as troublesome impurities, and attempts were made by sinking new shafts to avoid them, but with the result of finding them in greater abundance. About 1864 their value as potash fertilizer was established. It is supposed that at one time the region about the mines was submerged and filled with sea water. The tropical climate of that geological period caused rapid evaporation, which resulted in forming mineral deposits, the less soluble material as lime sulphate being first deposited, then a layer of rock salt, and finally layers of potash and magnesium salts in the order of their solubility.

249. Kainit is a mineral composed of potassium sulphate, magnesium sulphate, magnesium chloride, and water of crystallization. As it comes from the mine it is mixed with gypsum, salt, potassium chloride, and other bodies. Kainit contains about 12 per cent potash and is one of the most important of the Stassfurt salts. It is extensively used as a potash fertilizer, and is also mixed with other materials and sold as a complete fertilizer. The magnesium chloride causes it to absorb water, and the presence of other compounds results in the formation of hard lumps, whenever kainit is kept for a long time. Kainit is soluble in water and can be used as a top dressing at the rate of 75 to 200 pounds or more per acre.

250. Muriate of Potash. — This is extensively used as a fertilizer and is valuable for general garden and farm crops. It is a manufactured product, — potassium chloride, — and ranges in purity from 60 to 95 per cent, equivalent to from 35 to 60 per cent of potash, the chief impurity being sodium chloride. The grade most commonly found on the market contains about 50 per cent of actual potash, equivalent to 80 per cent of muriate. Potassium chloride is readily soluble and is a quick-acting fertilizer. When used in large amounts, muriate of potash and other chlorides may unfavorably affect the quality of some crops, as potatoes, sugar beets, and tobacco. Ordinarily, muriate of potash is one of the cheapest and most active forms of potash, and can be used as a top dressing at the rate of 200 pounds or more per acre when preparing soils for crops. It is valuable for grass and grain crops, and has given good results on peaty lands.[92]

251. Sulphate of Potash. — High-grade sulphate of potash is prepared from some of the crude Stassfurt salts and may contain as high as 97 per cent K_2SO_4, equivalent to 50 per cent of potassium oxide (K_2O). It is one of the most concentrated forms of potash fertilizer and is particularly valuable because it can be applied safely to crops, as tobacco and potatoes, which would be injured in quality if muriate of potash were used, or if much chlorine were present. Low-grade sulphate of potash is 90 per cent pure.

252. Miscellaneous Potash Salts. — Carnallit, 9 per cent K_2O, — composed of $KCl,MgCl_2,6\,H_2O$. Polyhalit, 15 per cent K_2O, — composed of $K_3SO_4,MgSO_4.(CaSO_4)_2,H_2O$. Krugit, 10 per cent K_2O, — composed of $K_2SO_4,MgSO_4,(CaSO_4)_4,H_2O$. Sylvinit, 16 to 20 per cent K_2O, — composed of $KCl,NaCl$ and impurities. Kieserit, 7 per cent K_2O, — composed of $MgSO_4$ and carnallit.

253. Wood Ashes. — For ordinary agricultural purposes, wood ashes are an important source of potash, although they are exceedingly variable in composition. When leached the soluble salts are extracted and there is left only about 1 per cent of potash. In unleached ashes the amount of potash ranges from 2 to 10 per cent. Soft wood ashes contain much less potash than hard wood ashes. Goessmann gives the following as the average of 97 samples of ashes:[65]

	Average Composition Per Cent	Range Per Cent
Potash	5.5	2.5 to 10.2
Phosphoric acid	1.9	0.3 to 4.0
Lime	34.3	18.0 to 50.9

IN 10,000 POUNDS OF WOOD

	POTASH LBS.	PHOSPHORIC ACID LBS.
White oak	10.6	2.5
Red oak	14.0	6.0
Ash	15.0	1.1
Pine	0.8	0.7
Georgia pine	5.0	1.2
Dogwood	9.0	5.7

254. Action of Ashes on Soils. — Ashes act upon soils both chemically and physically. They are usually regarded as a potash fertilizer only, but they also contain lime and phosphoric acid, and may be very beneficial in supplying these elements. The potash is present mainly as potassium carbonate. Ashes are valuable, too, because they add alkaline matter to the soil, which corrects acidity and aids nitrification. A dressing of ashes improves the mechanical condition of many soils by binding together the soil particles. This property is well illustrated in the so-called Gumbo soils, which contain so much alkaline matter that the soil has a soapy taste and appearance, and when plowed the particles fail to separate.

255. Leached Ashes. — When ashes are leached the soluble salts are extracted; the insoluble matter which is left is composed mainly of calcium carbonate and silica.[66]

	UNLEACHED ASHES PER CENT	LEACHED ASHES PER CENT
Water	12.0	30.0
Silica, etc.	13.0	13.0
Potassium carbonate	5.5	1.1
Calcium carbonate	61.0	51.0
Phosphoric acid	1.9	1.4

256. Alkalinity of Leached and Unleached Ashes. — A good way to detect leached ashes is to determine the alkalinity in the following way: weigh out 2 grams of ashes into a beaker, add 100 cc. distilled water, and heat on a sand bath nearly to boiling, cool and filter. To 50 cc. of the filtrate add about 3 drops of cochineal indicator, and then a standard solution of hydrochloric acid from a burette until the solution is neutral. If a standard solution of acid cannot be procured, one containing 15 cc. concentrated hydrochloric acid per liter of distilled water may be used for comparative purposes. Leached ashes require less than 2 cc. of acid to neutralize the alkaline matter in 1 gram, while unleached ashes require from 10 to 18 cc. In purchasing wood ashes, if a chemical analysis cannot be secured, the alkalinity of the ash should be determined.

257. Coal and Other Ashes. — Since the amount of phosphoric acid and potash in coal ashes is very small, they have little fertilizer value. Soft coal ashes contain more potash than those from hard coal, but it is held in such firm combination as to be of but little value.

The ashes from sawmills where soft wood is burned, and they are unprotected, are nearly worthless. When peat bogs are burned over, large amounts of ashes are produced. If the bogs were covered with timber, the ashes are sometimes of sufficient value to warrant their transportation and use.

	Potash Per Cent	Phosphoric Acid Per Cent
Hard coal ashes	0.10	0.10
Soft coal ashes	0.40	0.40
Sawmill ashes[14]	1.20	1.00
Peat bog ashes[14]	1.15	0.54
Peat bog ashes (timbered)[14]	3.68	2.56
Tobacco stem ash	4.00	7.00
Cottonseed hulls, ash	20.00	7.00

258. Commercial Value of Potash. — The market value of potash is governed by the selling price of high-grade sulphate of potash and kainit. Ordinarily, it varies from 4 to 5 cents per pound. As in the case of nitrogen and phosphoric acid, the market and field values, as determined by crop yields, may be entirely at variance. Before potash salts are used, careful field tests should be made to determine the actual condition of the soil as to its need of potash. (See Chapter X, Commercial Fertilizers.)

259. Use of Potash Fertilizers. — Wood ashes or Stassfurt salts should not be used in excessive amounts. Not more than 300 pounds per acre should be applied unless the soil is known to be markedly deficient in potash, and previous tests indicate that larger amounts are safe and advisable. Potash fertilizers should be evenly spread and not allowed to come in direct contact with plant roots, and should be used early in the spring before seeding or before the crop has made much growth. Wood ashes make an excellent top dressing for grass lands, particularly where it is desired to encourage the growth of clover. There are but few crops or soils that are not greatly benefited by a light application of wood ashes, and none should ever be allowed to leach or waste about a farm.

260. Joint Use of Lime and Potash. — When a potash fertilizer is used, a dressing of lime will frequently be found beneficial. The potash undergoes fixation, and when it is liberated there should be some basic material as lime to take its place. Goessmann observed that land manured for several years with potassium chloride finally produced sickly crops, but an application of slaked lime restored a healthy appearance to succeeding crops.[67] If the soil is well stocked with lime, its joint use with potash fertilizers is not necessary. If it is acid, lime should be used to correct the acidity before the potash is applied. The use of potash fertilizers for special crops is discussed in Chapter X.

CHAPTER IX

LIME AND MISCELLANEOUS FERTILIZERS

261. Calcium an Essential Element of Plant Food.— Calcium is present in the ash of all plants, and is usually more abundant in soils than phosphorus or potassium. It takes an essential part in plant growth, and whenever withheld growth is checked. The effect of withholding calcium is shown in the illustration (Fig. 43), which gives the total growth made by an oat plant under such a condition.

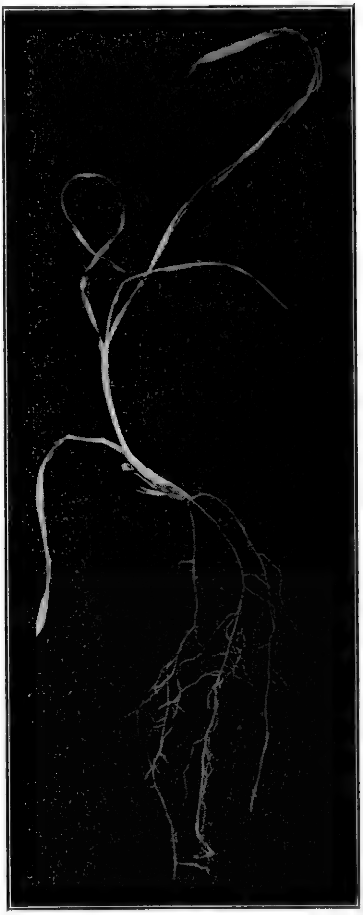


FIG. 43. Oat Plant grown without Calcium.

Plants grown on soils deficient in calcium compounds lack hardiness. They are not so able to withstand drought or unfavorable climatic conditions as plants grown on soils well supplied with this element. Calcium does not accumulate in the seeds of plants, but is present mainly in the leaves and stems, where it takes an important part in the production of new tissue. The term 'lime,' when used in connection with crops and soils, refers to their content of calcium oxide, CaO.

262. Amount of Lime removed in Crops.[38] —

	Pounds per Acre CaO
Wheat, 20 bushels	1
Straw, 2000 pounds	7
Total	8
Corn, 65 bushels	1
Stalks, 3000 pounds	11
Total	12
Peas, 30 bushels	4
Straw, 3500 pounds	71
Total	75
Flax, 15 bushels	3
Straw, 1800 pounds	13
Total	16
Clover, 4000 pounds	75

Clover and peas remove so much lime from the soil that they are often called lime plants. The amount required by grain and hay is small compared with that required by a clover or pea crop.

263. Amount of Lime in Soils. — There is no other element in the soil in such variable amounts as calcium, popularly called lime. It may be present from one hundredth of a per cent to 20 per cent or more. Soils which contain from 0.3 to 0.5 per cent, as carbonate, are usually well supplied. The lime in a soil takes an important part in soil fertility; when it is wanting, humic acid may be formed, nitrification checked, and the soil particles will lack binding material. Calcium carbonate is somewhat soluble in soil water, due to the presence of carbon dioxide. Waters are hard because of the presence of lime. The loss of lime by leaching has caused many soils to become unproductive.

264. Different Kinds of Lime Fertilizers. — By the term 'lime fertilizer' is usually meant land plaster ($CaSO_4$, 2 H_2O). Occasionally quicklime (CaO) and slaked lime ($Ca[OH]_2$) are used on very sour land. In general, a lime fertilizer is one which supplies the element calcium; common usage, however, has restricted the term to sulphate of lime.

265. Action of Lime Fertilizers upon Soils. — Lime fertilizers act both chemically and physically. Chemically, lime unites with the organic matter to form humate of lime and thus prevents the formation of humic acid. It also aids in nitrification and acts upon the soil, liberating potassium and other elements of plant food. Physically, lime improves capillarity, precipitates clay when suspended in water, and prevents losses, as the washing away of fine earth. When soils are deficient in lime, an acid condition may develop to such an extent as to be injurious to vegetation. Nitrogen, phosphoric acid, and potash may all be present in liberal amounts, but in the absence of lime poor results are obtained. Because of the loss by drainage, removal as plant food and the chemical reaction in which it takes a part, there is greater necessity for a liberal supply of active lime compounds in a soil than of any other element of plant food.

266. Lime liberates Potash. — The action of lime upon soils well stocked with potash results in fixation of the lime and liberation of the potash; the reaction takes place in accord with the well-known exchange of bases explained in the chapter on fixation. The extent to which potash may be liberated by lime depends upon the firmness of chemical combination with which the potash is held in the soil. Boussingault found that when clover was limed there was present in the crop three times as much potash as in a similar crop not limed. His results are as follows:[69]

	Kilos per Hectare			
	In Crop not Limed		In Limed Crop	
	First year	Second year	First year	Second year
Lime	32.2	32.2	79.4	102.8
Potash	26.7	28.6	95.6	97.2
Phosphoric acid	11.0	7.0	24.2	22.9

The indirect action of land plaster upon western prairie soils in liberating plant food, particularly potash and phosphoric acid, is unusually marked. Laboratory experiments show that small amounts of gypsum are quite active in rendering potash, phosphoric acid, and even nitrogen soluble in the soil water.[5] Occasionally applications of superphosphate fertilizers give large yields, due to the gypsum which they contain, and not to the phosphorus.

267. Quicklime and Slaked Lime. — When it is desired to correct acidity, slaked lime is used. Air-slaked lime is not so valuable as water-slaked lime. Quicklime cannot be used on land after a crop has been seeded. Both slaked lime and quicklime should be applied some little time before seeding, and not to the crop. The action of quicklime upon organic matter is so rapid that it destroys vegetation. Slaked lime is less injurious to vegetation.

268. Pulverized Lime Rock. — In some localities pulverized lime rock is used. It may be applied as a top dressing in almost unlimited amounts. It is most beneficial on light, sandy soils, where it performs the function of fine clay as well as promoting chemical action. Acid soils also are benefited by its use. Not all soils are alike responsive to applications of limestone, and before using it is best to determine to what extent it is needed. There are no ordinary conditions where limestone is injurious to soil or crop, and it is frequently most helpful.

269. Marl. — Underlying beds of peat, deposits of marl are occasionally found. Marl is a mixture of disintegrated limestone and clay, and contains variable amounts of calcium carbonate, phosphoric acid, and potash. When peat and marl are found together, they may be used jointly with manure as described in Section 182. Many sandy lands in the vicinity of peat and marl deposits would be greatly improved, both physically and chemically, by these materials.

270. Physical Action of Lime. — The addition of lime fertilizers to sandy soils improves their general physical condition. Heavy clays lose their plasticity when limed and the fine clay particles are cemented together and act as sand, which improves the mechanical condition of the soil. The physical action of lime in soils is well illustrated in the case of 'loess soils,' which are composed of clay and limestone. The lime cements together the clay particles to form compound grains, making the soil more permeable and more easily tilled. The better physical condition which follows the application of lime fertilizers is frequently sufficient to warrant their use.

271. Application of Lime Fertilizers. — Lime is generally used as a top dressing on grass lands at the rate of 200 to 500 pounds per acre. Excessive applications are undesirable. Lime as gypsum is particularly valuable when applied to land where crops are grown which assimilate large amounts, as clover and other legumes. It should be remembered that it is not a complete fertilizer, but simply an amendment and an indirect fertilizer.[9] If used to excess it may get the soil in such condition that plant food is not easily rendered available. A common saying is, "Lime makes the father rich but the son poor."[22] This is true, however, only when lime is used in excess. When used occasionally in connection with other manures, it has no injurious effect upon the soil and is a valuable fertilizer, especially where clover is grown with difficulty.

MISCELLANEOUS FERTILIZERS

272. Salt is frequently used as an indirect fertilizer. Sodium and chlorine, the two elements of which it is composed, are not absolutely necessary for normal plant growth. When salt is applied to the soil and the sodium undergoes fixation, potassium may be liberated. An early experiment of Wolff illustrates this point: a buckwheat plot fertilized with salt produced a crop with more potash and less sodium than a similar unfertilized plot.

Salt may be used to check the rank growth of straw during a rainy season, and thus prevent loss of the crop by lodging, although not in excessive amounts, as it is destructive to vegetation; 200 pounds per acre is a fair application. Salt also improves the physical condition of the soil by increasing the surface tension of the soil water. It should not be used on a tobacco or potato crop, because it injures the quality of the product. Salt is beneficial in preventing some forms of fungous diseases from becoming established in soils.

273. Magnesium Salts. — Magnesium is present in the ash of all plants, and is an element essential for plant growth. Usually soils are so well stocked with magnesium that it is not necessary to apply it in fertilizers. Some of the magnesium salts, as the chloride, are injurious to vegetation, but when associated with lime as carbonate, magnesia imparts fertility. In many of the Stassfurt salts, magnesium is found.

274. Soot. — The deposits formed in boiler flues and chimneys when wood and soft coal are burned contain small amounts of potash and phosphoric acid. Soot is valuable mainly as a mechanical fertilizer and is slow in decomposing. It contains but little plant food as shown by the following analysis:

	Soft Coal Soot Per Cent[14]	Hard Wood Soot Per Cent[70]
Potash	0.84	1.78
Phosphoric acid	0.75	0.96

275. Seaweeds. — Seaweeds are rich in potash and near the seacoast are extensively used for fertilizer.

	COMPOSITION OF MIXED SEAWEEDS PER CENT[70]
Water	81.50
Nitrogen	0.73
Potash	1.50
Phosphoric acid	0.18

Weeds and plants produced on waste land along the sea are in some European countries burned and the ashes used as fertilizer. By this means waste land is made to produce fertilizer for fields which are tillable.

276. Weeds. — The amount of fertility removed in weeds is usually more than in agricultural plants, because weeds have greater power of obtaining food from the soil. When wheat or other grain is raised, and a small crop of grain and a large crop of weeds are the result, there is more fertility removed from the soil than if a heavy stand of grain had been obtained. The ashes of strand plants and weeds are extremely variable in composition.

277. Wool Washings and Waste. — The washings from wool contain sufficient potash to make them valuable as fertilizer. In wool there is a high per cent of potash, which is soluble and readily removed in the washings. Wool waste may contain from 1 to 5 per cent of potash and from 4 to 7 per cent of nitrogen in a somewhat inert form.

278. Street Sweepings. — The horse manure and débris collected from paved streets in cities and known as street sweepings have some value as fertilizer, and are occasionally used for market gardening purposes. Street sweepings, because of the loss of the liquid excrements, have a lower value than average stable manure and cannot be used economically when labor and the cost of hauling are high-priced, or when a quick-acting manure is desired. For sanitary reasons, the use of street sweepings is not always desirable, as mixed with the horse droppings frequently are associated accumulations of filth from dwellings contaminated with disease germs. Crude garbage has a low manurial value; when sorted and cremated, the burned residue can be used to better advantage as fertilizer than the raw garbage, and is without the objectionable and unsanitary features.

CHAPTER X

COMMERCIAL FERTILIZERS AND THEIR USE

279. Development of the Commercial Fertilizer Industry. — The commercial fertilizer industry owes its origin to Leibig's work on plant ash. The first superphosphate was made by Sir J. B. Lawes about 1840, from spent bone black and sulphuric acid. His interest had previously been attracted to the use of bones as fertilizer by a gentleman who farmed near him, "who pointed out that on one farm bone was invaluable for the turnip crop, and on another farm it was useless."[44]

Since 1860 the commercial fertilizer industry in this country has developed rapidly, until now large sums of money are annually expended in purchasing commercial fertilizers and amendments, and nearly all in less than a third of the area of the United States.

280. Complete Fertilizers and Amendments. — The term 'commercial fertilizer' is applied to materials made by mixing different substances which contain plant food in concentrated forms. When a commercial fertilizer contains nitrogen, phosphoric acid, and potash, it is called a complete fertilizer, because it supplies the three elements which are liable to be most deficient.

Materials as sodium nitrate which supply only one element are called amendments. It frequently happens that a soil requires only one element in order to produce good crops, and in such cases only the one element needed should be supplied.

Complete fertilizers are often used when the soil is in need of an amendment only.

281. Variable Composition of Commercial Fertilizers. — Since commercial fertilizers are made by mixing various materials which contain different amounts of nitrogen, phosphoric acid, and potash, it follows they are extremely variable in composition and value. No two samples are the same, hence the importance of knowing the composition of every brand purchased. The composition of fertilizers is varied to meet the requirements of different soils and crops. Some fertilizers are made rich in phosphoric acid, while others are rich in nitrogen and potash.

282. How a Fertilizer is Made. — The most common materials used in making complete fertilizers are: nitrate of soda, kainit, and dissolved phosphate rock. These materials have about the following composition:

Nitrate of soda	15.5 per cent nitrogen.
Kainit	12.5 per cent potash.
Dissolved phosphate . . .	14.0 per cent phosphoric acid

The fertilizer may be made rich or poor in any ingredient. Many fertilizers contain about twice as much potash as nitrogen and five times as much phosphoric acid as potash. In order to make a ton of such a fertilizer it would be necessary to take:

	Pounds
Nitrate of soda	225
Kainit	425
Phosphate	1350

The ton of fertilizer would contain about 35 pounds of nitrogen, 189 pounds of phosphoric acid, and 53 pounds potash. These amounts are determined by multiplying the percentage composition by the weight of material taken:

		Pounds
Nitrogen	225 × 0.155 =	34.9
Potash	425 × 0.125 =	53.1
Phosphoric acid	1350 × 0.14 =	189.0

The fertilizer would contain about 1.75 per cent nitrogen, 2.65 per cent potash, and 9.45 per cent phosphoric acid. The percentage amounts are obtained by dividing the total pounds by 20. This fertilizer if made at home from materials purchased in the market, at the prices indicated, would cost, exclusive of transportation and mixing, about $21.47.

	Pounds	Cost
Nitrogen	34.9 @	16 cents = $5.58
Phosphoric acid	189.0 @	7 cents = 13.23
Potash	53.1 @	5 cents = 2.66
		Total $21.47

A more concentrated fertilizer could be prepared by using high-grade sulphate of potash, superphosphate, and ammonium sulphate. A fertilizer composed of these ingredients would contain:

Pounds		Per Cent	Total Lbs.		Value	Percentage Composition of Fertilizer
300	Sulphate of ammonia	20 N	60	@ 16 cents =	$ 9.60	3.00
500	Sulphate of potash .	50 K_2O	250	@ 5 cents =	12.50	12.50
1200	Superphosphate . .	35 P_2O_5	420	@ 7 cents =	29.40	21.00
				Total	$51.50	

So concentrated a fertilizer as the preceding is rarely, if ever, found on the market, although the price, $51.50 per ton, is frequently charged. This example shows the composition and cost of the ingredients in one of the most concentrated fertilizers that can be produced.

The market value of the materials of which commercial fertilizers are made fluctuates like that of other commodities.

Any of the different materials mentioned in the chapters on special fertilizers can be used in making commercial fertilizers, as dried blood, tankage, nitrate of soda, sulphate of ammonia, raw bone, dissolved bone, raw phosphate rock, dissolved phosphate rock, basic slag, kainit, muriate or sulphate of potash, and many others. Inasmuch as each of these materials has a different value, it follows that fertilizers, even of the same general composition, may have widely different crop-producing powers.

283. Inert Forms of Plant Food in Fertilizers. — A fertilizer of the same general composition as the first example, but of different availability of the elements, could be made from feldspar rock, apatite rock, and leather. The leather contains nitrogen, the apatite contains phosphoric acid, and the feldspar, potash. Such a fertilizer would have no value when used on a crop, because all the plant food elements are present in unavailable forms. Hence, in purchasing fertilizers, it is necessary to know not only the percentage composition, but also the nature of the materials from which the fertilizer was made. Inert forms of plant food are akin to indigestible forms of animal food ; it is the food which is assimilated that is of value whether it be by animals or by plants.

284. Inspection of Fertilizers. — In many states, laws have been enacted regulating the manufacture and sale of commercial fertilizers, and provision is made for inspection and analysis of all brands offered for sale. The label on the fertilizer package must specify the percentage amounts of available nitrogen, phosphoric acid, and potash. Inspection has been found necessary in order to protect the farmer and the honest manufacturer. As the result of inspection and analysis, occasionally a fraud is revealed like the following :[71]

NATURAL PLANT FOOD, $25 TO $28 PER TON

COMPOSITION	PER CENT
Total phosphoric acid	22.21
Insoluble phosphoric acid	20.81
Available phosphoric acid	1.40
Potash soluble in water	0.13
Actual value per ton, $1.52	

285. Mechanical Condition of Fertilizers. — In purchasing a fertilizer its mechanical condition should be considered. The finer the fertilizer, as a rule, the better it is for promoting crop growth. Some combinations of plant food produce fertilizers which become so hard and lumpy that it is difficult to crush them before spreading. They should be pulverized so they may be evenly distributed, otherwise the plant food will not be economically used. A fertilizer that passes through a sieve with holes 0.25 mm. in diameter is more valuable and can be used to better advantage than one of the same composition with particles 0.5 mm. in size.

286. Forms of Nitrogen in Commercial Fertilizers. — Nitrogen is present in commercial fertilizers in three forms: (1) Ammonium salts, (2) nitrates, and (3) organic nitrogen. The organic nitrogen is divided into two classes: (*a*) available, and (*b*) unavailable. Pepsin and also potassium permanganate are used as solvents for determining the availability of the organic nitrogen. The relative values of the different forms of nitrogen are discussed in Chapter IV. Three fertilizers may have the same amount of total nitrogen and still have entirely different crop-producing powers.

	No. 1 Per Cent	No. 2 Per Cent	No. 3 Per Cent
Nitrogen as:			
Ammonium compounds	1.75	0.25	0.10
Nitrates	0.15	0.15	0.10
Organic nitrogen:			
Soluble	0.10	1.25	0.55
Insoluble	——	0.35	1.25
Total	2.00	2.00	2.00

In purchasing fertilizers it is important to know not only the amount of nitrogen, but also the form in which it is present. In No. 3 the nitrogen is in an inert form as in leather, while in No. 2 it is largely in the form of dried blood, and No. 1 has mainly ammonium compounds. Each of these fertilizers, as explained in the chapter on nitrogenous manures, has a different plant food value.

287. Phosphoric Acid. — There are three forms of phosphoric acid in commercial fertilizers: (1) water soluble, (2) citrate-soluble, and (3) insoluble. The water and citrate-soluble are called the available phosphoric acid. In most fertilizers the phosphoric acid is derived from dissolved phosphate rock and is in the form of monocalcium phosphate. The citrate-soluble is mainly dicalcium phosphate with variable amounts of iron and aluminum phosphates in easily soluble forms. The insoluble phosphoric acid is tricalcium and other phosphates, as iron and aluminum, which are soluble only in strong mineral acids. The insoluble phosphoric acid in fertilizers is considered as having but little value. As in the case of nitrogen, three fertilizers may have the same total amount of phosphoric acid and yet have entirely different values.

	No. 1 Per Cent	No. 2 Per Cent	No. 3 Per Cent
Water-soluble phosphoric acid . . .	8.00	0.25	0.25
Citrate-soluble phosphoric acid . . .	1.50	8.00	0.75
Insoluble	0.50	1.75	9.00
Total	10.00	10.00	10.00

No. 3 has little value; it contains insoluble phosphate rock or some material of the same nature. No. 1 is the most valuable, because it contains dissolved phosphate rock or dissolved bone and but little insoluble phosphoric acid. No. 2 is composed of such materials as the best grade of basic slag or roasted aluminum phosphate or fine steamed bone.

288. Potash. — The three forms of potash in fertilizers are: (1) water-soluble, (2) acid-soluble, and (3) insoluble. Sulphate of potash, kainit, and muriate of potash are soluble in water and belong to the first class. In some states the fertilizer laws recognize only the water-soluble potash. In the second class are found materials like tobacco stems and other organic forms of potash. Substances like feldspar, which contain insoluble potash, are of no value in fertilizers. As a rule, the potash in commercial fertilizers is soluble in water; in only a few cases are acid-soluble forms met with. Insoluble potash is considered an adulterant.

289. Misleading Statements on Fertilizer Packages. — Occasionally the percentage amounts of nitrogen, phosphoric acid, and potash are stated in misleading ways: as ammonia, sulphate of potash, and bone phosphate of lime. Inasmuch as ammonia contains 14 parts nitrogen and 3 parts by weight of hydrogen, it follows the ammonia content is proportionally greater than the nitrogen content, because of the additional hydrogen carried by the ammonia. And so with sulphate of potash, which contains about 50 per cent potash and 50 per cent of sulphuric anhydride. This method of stating the composition can be considered in no other way than as a fraud, especially when the fertilizer contains no sulphate of potash, but cheaper materials, and the phosphoric acid is not derived from bone.

290. Estimated Commercial Value of Fertilizers. — The estimated value of a commercial fertilizer is obtained from the percentage composition and the trade value of the materials used. Suppose two fertilizers are selling at $28 and $35, respectively, each having a different composition, the estimated value of each could be obtained in the following way:

COMPOSITION OF FERTILIZERS

	No. 1 Selling Price $28 Per Cent	No. 2 Selling Price $35 Per Cent
Nitrogen as nitrates	1.50	2.10
Phosphoric acid, available	8.00	10.00
Phosphoric acid, insoluble	2.00	0.50
Potash (water-soluble)	2.00	3.50

POUNDS PER TON

	No. 1	No. 2
Nitrogen	1.50 × 20 = 30	2.10 × 20 = 42
Phosphoric acid	8.00 × 20 = 160	10.00 × 20 = 200
Potash	2.00 × 20 = 40	3.50 × 20 = 70

ESTIMATED VALUE

	No. 1	No. 2
Nitrogen	30 × 0.16 = $ 4.80	42 × 0.16 = $ 6.72
Phosphoric acid	160 × 0.07 = 11.20	200 × 0.07 = 14.00
Potash	40 × 0.05 = 2.00	70 × 0.05 = 3.50
	$18.00	$24.22

Difference between estimated value and selling price: No. 1, $10.00; No. 2, $10.78.

The trade value of a commercial fertilizer often varies widely from the actual or crop-producing value, for in assigning a trade value simply the cost of the ingredients is considered, and this is not necessarily identical with the actual value secured in increased yield from the use of the fertilizer.

291. Home Mixing of Fertilizers. — At the New Jersey Experiment Station it was shown that "the charges of the manufacturers and dealers for mixing, bagging, shipping, and other expenses are on the average $8.50 per ton, and also that the average manufactured fertilizer contains about 300 pounds of actual fertilizing constituents per ton. These figures are practically true of other states, where large quantities of commercial fertilizers are used."[72] In states where smaller amounts are used the difference between the estimated cost and selling price is greater than $8.50.

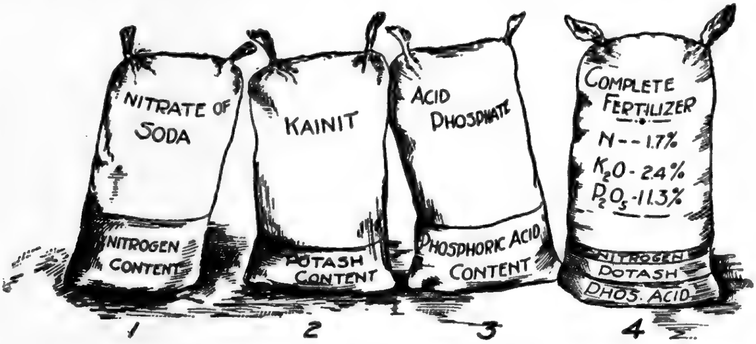


FIG. 44. Composition of Fertilizers.

These facts emphasize the economy of home mixing. The difference in price between the raw materials and the product sold is frequently so great that it is an advantage for the farmer to purchase the raw materials, as sulphate of potash, nitrate of soda, and acid phosphate, and mix them as desired. By so doing fertilizers of any composition may be prepared and there is less danger of securing an inferior article. Of course it is not possible by means of shovels and sieves to accomplish as thorough mixing of the ingredients as with machinery.

Formula No. 1

	Pounds		Pounds	Percentage Composition of Fertilizer
Nitrate of soda	500	containing nitrogen	77.5	3.87
Acid phosphate	1200	containing phos. acid	168.0	8.40
Sulphate of potash	300	containing potash	150.0	7.50
Total			395.5	

Formula No. 2

	Pounds		Pounds	Percentage Composition of Fertilizer
Nitrate of soda	250	containing nitrogen	38.7	1.99
Acid phosphate	900	containing phos. acid	126.0	6.30
Sulphate of potash	450	containing potash	225.0	11.50
Plaster, etc.	400			
Total			389.7	

Formula No. 3

	Pounds		Pounds	Percentage Composition of Fertilizer
Nitrate of soda	200	containing nitrogen	31.0	1.55
Acid phosphate	1500	containing phos. acid	210.0	10.50
Sulphate of potash	150	containing potash	75.0	5.75
Plaster, etc.	150			
Total			316.0	

292. Fertilizers and Tillage. — Commercial fertilizers cannot be made to take the place of good tillage, which is equally as important when fertilizers are used as when they are omitted. Scant crops are as frequently due to the want of proper tillage as to the absence of plant food. Poor cultivation results in getting the soil out of condition; then, instead of thoroughly preparing the land, commercial fertilizers are resorted to, and the conclusion is reached that the soil is exhausted, when in reality it is suffering for the want of cultivation, for a dressing of land plaster, for farm manures, or for a change of crops. There is no question but what better tillage, better care and use of farm manures, culture of clover and systematic rotation of crops would result in greatly reducing the amount annually spent for commercial fertilizers, without reducing the yield of crops, as well as securing larger returns for the fertilizers used. In general, the better the cultivation the less the amount of commercial fertilizer required for average farm crops. Cultivation cannot, however, entirely take the place of fertilizers.

293. Abuse of Commercial Fertilizers. — When a soil produces poor crops, a complete fertilizer is frequently used where only an amendment is needed. Restricted crop production on long-cultivated prairie soils is often due to poor physical condition, deficiency of humus and available nitrogen, or, in some cases, to lack of a mineral element as potash or phosphoric acid. If the nitrogen is supplied by legumes, and the one element of fertility needed is added, improved cultivation together with the chemical action of the humus on the minerals of the soil will generally furnish the necessary available plant food. Instead, however, of providing the one element needed, others which may already be present in the soil in liberal amounts are often supplied at an unnecessary expense, instead of being made available by cultivation. Another abuse of fertilizers is their application to the wrong crop. A heavy application of potash fertilizer to a wheat crop grown on a rich clay soil, or of nitrate of soda on land seeded to clover, or of land plaster to flax grown on a limestone soil, would be a waste of money.

294. Judicious Use of Fertilizers. — In order to make the best use of commercial fertilizers, both the soil and the crop must be carefully considered. All soils do not alike respond to commercial fertilizers, and farm crops possess different powers of assimilating food; turnips, for example, have very restricted power of phosphate assimilation, hence they require phosphate manures, and wheat may need help in obtaining its nitrogen. A wheat crop will starve for want of nitrogen, while an adjoining corn crop will scarcely feel its need. Wheat has strong power of assimilating potash, while clover has less. Hence in the use of fertilizers the ability of the plant to obtain its food must be considered. A light application of either a special purpose or a complete fertilizer at the time of seeding is often advantageous, as it encourages plant growth by supplying food when it is most needed. There should be some at this time in a highly available condition for the use of the young plants, after that stored up in the seed has been exhausted, and before they are strong enough to make available their own food.

FIG. 45. Wheat Plots fertilized in Different Ways.
(From left to right.)

Complete Fertilizer (Com.). Phosphate Fertilizer, P.
Potash Fertilizer, K. Nitrogen Fertilizer, N.
No Fertilizer, Check.

Commercial fertilizers may assist in promoting desirable bacterial changes in soils resulting in the elaboration of plant food. Before they are used, however, careful field trials should be made.

295. Experimental Plots. — A piece of land well tilled and of uniform texture should be used for field trials with fertilizers. After preparation for the crop, small plots 1/20 of an acre are staked off. A convenient size is, length 204 feet, width 10 feet 8 inches, area 2176 square feet. Between each plot a strip 3 feet wide is left. The plan is to apply one element or a combination of elements to a plot and compare the results with plots differently treated.[70]

296. Preliminary Trial. — It is best to make a preliminary trial one year and verify the conclusions the next. In making the tests, eight plots are necessary and fertilizers are applied in the following way:

The first plot receives no fertilizer and is used as the basis for comparison.

The second plot receives a dressing of 8 pounds nitrate of soda, 16 pounds acid phosphate, and 8 pounds sulphate or muriate of potash.

The third plot receives nitrogen and phosphoric acid.

The fourth plot receives nitrogen and potash.

The fifth plot receives nitrogen.

The sixth plot receives phosphoric acid and potash.

The seventh plot receives potash.

The eighth plot receives phosphoric acid.

No fertilizer	N P_2O_5 K_2O	N P_2O_5	N K_2O
1	2	3	4

N	P_2O_5 K_2O	K_2O	P_2O_5
5	6	7	8

Should good results be obtained on plot No. 3, the indications are that there is a deficiency of the two elements, nitrogen and phosphoric acid. An increased yield from No. 4 indicates deficiency of nitrogen and potash. Under such conditions the use of a complete fertilizer would be unnecessary. If No. 5 gives an additional yield, the soil is in want of nitrogen. From the eight plots it will be seen which of the various elements it is advisable to use. The fertilizers should be applied after the land has been thoroughly prepared and before seeding. Corn is a good crop for the first trial. The number of plots may be increased by using well-prepared stable manure and gypsum on plots 9 and 10, respectively. The second year the results should be verified.

297. Deficiency of Nitrogen. — If the results indicate a deficiency of nitrogen, select two crops, one as wheat, which is particularly benefited by dressings of nitrogen, and another as corn which has less difficulty in obtaining this element. The cultivation of each crop should be that which experience has shown to be the best. On one wheat and one corn plot 8 pounds of nitrate of soda should be used, a plot each of wheat and corn being left unfertilized. If both the corn and the wheat are benefited by the nitrogen, the soil is in need of this element. If, however, the wheat responds and the corn does not, the soil is not in great need of nitrogen, but does not contain an abundance in available forms.

298. Deficiency of Phosphoric Acid. — In experimenting with phosphoric acid, turnips are grown on two plots and barley on two plots. To one plot of each, 16 pounds of acid phosphate are applied. If both crops show additional yields, the soil is in need of available phosphoric acid. If only the turnips respond while the barley is indifferent, the soil contains a fair amount. Barley and turnips are used because there is such a marked difference in their power to assimilate phosphoric acid.

299. Deficiency of Potash. — In order to determine the condition of the soil as to potash, potatoes and oats may be used as the trial crops, and 8 pounds of sulphate of potash should be applied to one plot of each. Additional yields indicate a poverty of available potash; an increased potato crop and an indifferent oat crop indicate potash not in the most available form. If no additional yields are obtained with either crop, the soil is not in need of potash.

300. Deficiency of Two Elements. — If the preliminary trial indicates a deficiency of two elements, as nitrogen and phosphoric acid, in verifying these results, both elements are used together, in the same way as described for deficiency of nitrogen, with additional plots for the separate application of nitrogen and phosphoric acid.

301. Importance of Field Trials. — While it is a difficult matter to determine the actual needs of a soil, it will be found that both time and money are saved by a systematic study of the question. Suppose fertilizers are used in a 'hit or miss' way year after year on a soil deficient only in phosphoric acid, it might take eight years to indicate what the soil really lacks if a different fertilizer is used each year, and during all this period either the soil fails to receive its proper fertilizer, or expensive and unnecessary plant food is provided. Field tests to be of value must be continued for a number of years and the results verified.

302. Will it pay to use Commercial Fertilizers? — This question can be answered only by trial. If a soil is in need of available plant food, the additional yield should pay for the fertilizer and the expense of using it. Some fertilizers have an influence on two or three successive crops, and only partial returns are received the first year. When large crops must be produced on small areas, as in truck farming, commercial fertilizers are generally necessary. They have not yet been extensively used in the western prairie states in the production of large tracts of staple crops, as wheat and corn.

If there is a good stock of natural fertility in the soil and it is well tilled, with farm manures used and the crops systematically rotated, commercial fertilizers will not be needed. With poor cultivation and a soil that has been impoverished by injudicious cropping, they are necessary. Commercial fertilizers sometimes fail to give good results because of an excessively acid or alkaline condition of the soil.

303. Amount of Fertilizer to use per Acre. — When commercial fertilizers are used in general farming, just enough should be applied to produce normal yields. Heavy applications at long intervals are not so productive of good results as light applications more frequently. From 400 to 600 pounds per acre is as much as should be used at one time unless previous trials have shown that heavier applications are necessary. The way in which the fertilizer is to be applied, as broadcast or otherwise, must be determined by the crop to be grown. The fertilizer should not come in contact with seeds, neither should it be plowed under nor worked into the soil to such a depth that it may be lost by leaching before it can be appropriated by the crop.

304. Excessive Applications of Fertilizers Injurious. — An overabundance of plant food has an injurious effect upon crop growth. Plants take their food from the soil in dilute solutions, and when the solution is concentrated abnormal growth results. Potatoes heavily manured with nitrate of soda produce luxuriant vines, but only a few small tubers. When a medium dressing is used along with potash and phosphoric acid, a more balanced growth and better yield result.

Heavy applications of nitrate of soda produce a rank growth of straw, with a low yield of grain. The excess of nitrogen causes the mineral matter to be utilized for straw and leaves only a small amount for grain production. When applications of commercial fertilizers are too heavy, plants take up unnecessary amounts of food and fail to make good use of it. In fact, crops may be overfed, or fed an unbalanced ration, the same as animals. Hence in the use of fertilizers excessive and unbalanced applications are to be avoided.

305. Fertilizing Special Crops. — There are crops which need special help in obtaining some one element, and in using fertilizers the rule should be to help those crops which have the greatest difficulty in obtaining food. When the soil does not show a marked deficiency in any one element, light dressings of special purpose manures may be made to the following crops:

Wheat. — Nitrogen first, then phosphoric acid. In the case of some soils, phosphoric acid and potash produce larger yields than nitrogen.

Barley, oats, and rye require manuring like wheat, but to a less extent. Each crop has a different power of assimilating nitrogen. Wheat requires the most help and barley and rye the least.

Corn. — Phosphoric acid first, then nitrogen and potash.

Potatoes. — General manuring, reënforced with potash.

Mangels. — Nitrogen.

Turnips. — Phosphoric acid.

Clover. — Lime and potash.

Timothy. — General manuring.

306. Commercial Fertilizers and Farm Manures. — Commercial fertilizers should not replace farm manures, but simply reënforce them. Although commercial fertilizers are called complete manures, they fail to supply organic matter. It is more important in some soils than in others that the organic matter be maintained, because in some soils the organic matter takes a more important part in crop production than does the food applied in commercial forms. When a rich prairie soil is reduced by grain cropping and is allowed to return to pasture, heavier yields of grain are afterward obtained than from similar land which has received only applications of commercial fertilizers. This is due to the action of the humus in the soil. At the Canadian Dominion Experimental Farms, where comparative trials have been made for eighteen years with farm manures and commercial fertilizers, it has been found that farm manures, even on new lands, give better results than commercial fertilizers for the production of wheat and corn.[93]

CHAPTER XI

FOOD REQUIREMENTS OF CROPS

307. Amount of Fertility removed by Crops. — The amount of fertility removed from an acre of soil producing average crops varies between wide limits. For example, an acre of mangels removes 150 pounds of potash, while an acre of flax removes 27 pounds; an acre of corn removes 75 pounds of nitrogen, while an acre of wheat removes 35 pounds. Crops which remove the most fertility do not always require the most help in obtaining their food. This is because the amount of plant food assimilated is not a measure of the power of crops to obtain food. An acre of corn requires over twice as much nitrogen as an acre of wheat, but wheat often leaves the soil in a more impoverished condition than corn, because corn has greater power to procure nitrogen and utilize that formed by nitrification after the wheat crop has completed its growth. The available nitrogen if not utilized by a crop may be lost in various ways. Mangels require twice as much phosphoric acid as flax, but are a strong feeding crop and need less help in obtaining this element. It was formerly believed the plant food in the matured crop indicated the kind and amount of fertilizing ingredients to apply, and that a correct system of manuring required a return to the soil of all elements removed in the crop. Experiments show this view to be incorrect.

POUNDS PER ACRE OF PLANT FOOD REMOVED BY CROPS[88]

Crops	Gross weight	Nitrogen	Phosphoric acid	Potash	Lime	Silica	Total ash
Wheat, 20 bu. . .	1200	25	12.5	7	1	1	25
Straw	2000	10	7.5	28	7	115	185
Total	. . . .	35	20	35	8	116	210
Barley, 40 bu. . .	1920	28	15	8	1	12	40
Straw	3000	12	5	30	8	60	176
Total	. . . .	40	20	38	9	72	216
Oats, 50 bu. . . .	1600	35	12	10	1.5	15	55
Straw	3000	15	6	35	9.5	60	150
Total	. . . .	50	18	45	11.0	75	205
Corn, 65 bu. . . .	2200	40	18	15	1	1	40
Stalks	3000	35	2	45	11	89	160
Total	. . . .	75	20	60	12	90	200
Peas, 30 bu. . . .	1800	. . .	18	22	4	1	64
Straw	3500	. . .	7	38	71	9	176
Total	. . . .	. . .	25	60	75	10	240
Mangels, 10 tons .	20000	75	35	150	30	10	350
Meadow hay, 1 ton	2000	30	20	45	12	50	175
Clover hay, 2 tons .	4000	. . .	28	66	75	15	250
Potatoes, 150 bu. .	9000	40	20	75	25	4	125
Flax, 15 bu. . . .	900	39	15	8	3	0.5	34
Straw	1800	15	3	19	13	3	53
Total	. . . .	54	18	27	16	3.5	87

For example, an acre of wheat contains 35 pounds of nitrogen, while an acre of clover contains 70 pounds; if 70 pounds of nitrogen were applied to an acre of clover and 35 pounds to an acre of wheat, poor results would follow, because clover can obtain its own nitrogen while wheat is less able to do so, and the 35 pounds would not necessarily come in contact with the roots so that all could be assimilated. While the amount of plant food removed in crops cannot serve as the basis for their manuring, valuable results are obtained from a study of the different elements of fertility which they contain. In making use of the preceding table, other factors, as the influence of the crop upon the soil and the power of the crop to obtain its food, must also be considered.

308. Plants exert a Solvent Power in Obtaining Food. — It is believed that crops procure some of their food from minerals insoluble in water. Experiments by Liebig demonstrate that plants have the power of rendering a portion of their food soluble, provided it does not exist in forms too inert to undergo chemical change. Liebig grew barley in boxes so constructed that all of the water-soluble plant food could be secured. Two of the boxes were manured and two left unmanured. In one box which received manure and one which received none, barley was grown. One each of the manured and unmanured boxes was left barren. He collected all of the drain waters and determined the soluble mineral matter present, also weighed and analyzed the plants. His results showed that 92 per cent of the potash was obtained from forms insoluble in water.[78]

The soluble plant food from a fertile soil is not generally sufficient for plant growth.[85] When oats, wheat, and barley were seeded in prepared sand and watered with the leachings from a pot of fertile soil, they made only a limited growth. Oats grown in prepared sand and watered with soil leachings assimilated only 25 per cent as much phosphoric acid as plants grown in fertile soil. See Section 224. The character and concentration of the soil solution are, however, important factors in crop production and some soils may contain sufficient amounts of water-soluble elements to produce crops. The relative amounts of food which plants take from the soil solution and that which they render soluble have not been extensively investigated.

In the roots of plants there are various organic acids and salts. Between the root and the soil is a layer of water. The plant sap and the soil water are separated by plant tissue, which serves as a membrane. All of the conditions are favorable for osmosis. The sap from the roots finds its way into the soil in exchange for some of the soil water. The acid and other compounds, excreted by the roots, act upon the mineral matter, rendering portions of it soluble, and then it is taken up by the plant. Different plants contain different kinds and amounts of solvents, as well as present different areas of root surface to act upon the soil, and the result is that agricultural crops have different powers of assimilating food. This action of living plant roots upon soils is a digestion process which is somewhat akin to the digestion of food by animals.

Plants not only possess the power of rendering a portion of their food soluble, but they are also able to select, and to reject that which is unnecessary. For example, wheat grown on prairie soil with soda in equally abundant and soluble forms as the potash will contain relatively little soda compared with the potash; also many seaweeds contain more potash than soda, although the sea water in which they grow has an excess of sodium salts.

For the feeding of crops, a nutritive soil solution is desirable, and the soil should have a good stock of reserve material that can be utilized either by action of the plant roots or readily pass into solution in the soil water.

CEREAL CROPS

309. General Food Requirements. — Cereal crops contain a high per cent of silica and evidently possess the power of feeding upon some of the simpler silicates of the soil,[74] liberating the base elements and using them as food, while the silica is deposited in the outer surface of the straw. As previously stated, cereal crops, although they do not remove large amounts of total nitrogen from the soil, require special help in obtaining this element. There is, however, a great difference among the cereals as to power of assimilating nitrogen. Next to nitrogen they stand most in need of phosphoric acid. There exists in many soils a greater deficiency of available phosphoric acid and potash than of nitrogen, although, in general, cereal crops are better able to procure these elements than they are nitrogen. The humic phosphates are utilized by nearly all the cereals.

310. Wheat. — This crop is more exacting in its food requirements than barley, oats, or rye. It is comparatively a weak feeding crop, and the soil should be in a higher state of fertility than for other grains. The extensive experiments of Lawes and Gilbert give valuable information regarding the effects of manures on wheat. Their results are given in the following table:[75]

AVERAGE YIELD OF WHEAT PER ACRE

	BUSHELS
No manure for 40 years	14
Minerals alone for 32 years	15¼
Nitrogen alone for 32 years	23½
Farmyard manure for 32 years	32⅜
Minerals and nitrogen for 32 years[1]	36¼
Minerals and nitrogen for 32 years[2]	32¾

[1] 86 pounds of nitrogen as sodium nitrate.
[2] 86 pounds of nitrogen as ammonium salts.

The food requirements of wheat are such that it should be given a favored position in the rotation. It may follow clover, provided the clover sod is light and is fall plowed.

On some soils, however, wheat does not thrive following a sod crop, as it takes nearly a year for a heavy sod residue to get into suitable food forms for a wheat crop, and under such a condition, oats should first be sown, then wheat may follow. On average soil, a medium clover sod, plowed late in summer or in early fall, and followed by surface cultivation, leaves the land in good condition for spring wheat. It is not advisable to have wheat follow barley, because the soil will be too porous, and barley being a stronger feeding crop leaves the land in a poor state as to available plant food. When corn has been well manured, wheat may follow. The food requirements of wheat are best satisfied following a light, well-cultivated clover sod, or following oats, which have been grown on heavy sod, or following corn that has been well manured. When wheat is judiciously grown in a rotation and farm manures are used, it is not an exhausting crop. Light dressings of farm manure may be used on land that is being prepared for wheat. On many western prairie soils, dressings of phosphate and potash, either alone or in combination, materially increase the yield and improve the quality of the crop. Potash fertilizers have a tendency to produce strong bright straw that is more resistant to fungous diseases. Nitrogen alone does not give as good results as when combined with minerals.

311. Barley. — While wheat and barley belong to the same general class of cereals, they differ greatly in their habits and food requirements. Barley is a stronger feeding crop, has greater root development near the surface, and can utilize food in cruder forms. In many of the western states, soils which produce poor wheat crops, from too long cultivation, give excellent yields of barley. This is due to changed conditions, of both the chemical and mechanical composition of the soil. Long cultivation has made the soil porous, and reduced the nitrogen content. Barley thrives best on a rather open soil, and has greater nitrogen assimilative power than wheat. Barley, however, responds liberally to manuring, particularly to nitrogenous manures. The experiments of Lawes and Gilbert on the growth of barley are briefly summarized in the following table: [76]

AVERAGE YIELD OF BARLEY PER ACRE FOR 34 YEARS

	BUSHELS
No manure	17[illegible]
Superphosphate alone	23[illegible]
Mixed minerals	24¼
Nitrogen alone	30¾
Nitrogen and superphosphate	45
Farmyard manures	49½

312. Oats. — Oats can obtain food under more adverse conditions than either barley or wheat. They are also less exacting as to the physical condition of the soil. The oat plant will adapt itself to either sandy or clay soil, and will thrive in the presence of alkaline matter or humic acid where wheat would be destroyed. In a rotation, oats usually occupy a position less favored by manures; they are, however, greatly benefited by fertilizers, particularly those of a nitrogenous nature. The oat crop responds liberally to manuring. Light dressings of farm manure can be applied directly to oat land when well worked into the soil before seeding.

313. Corn. — Experiments with corn indicate that under ordinary conditions it requires most help in obtaining phosphoric acid. Corn removes a large amount of gross fertility, and if its production is long-continued without the use of manures it impoverishes the soil. Its habits of growth, however, are such that it generally leaves an average prairie soil in better mechanical condition for succeeding crops. Corn is not injured as are many grain crops by heavy applications of stable manure, and does not, like flax, produce waste products which are destructive to itself. The conditions are better for wheat culture after one or two corn crops have been removed from rich, newly broken prairie soil. The food requirements of corn are satisfied by applications of stable manure, occasionally reënforced with a little nitrogen and phosphoric acid, and in the case of some soil potash. After clover, corn gives excellent returns, and when corn is the chief market crop it should be favored by having the best position in the rotation.

MISCELLANEOUS CROPS

314. Flax is very exacting in food requirements and for its culture the soil must be in a high state of fertility. It is a type of weak feeding crop. There are but few roots near the surface and consequently it has restricted power of nitrogen assimilation.[38] Flax should be indirectly manured. Direct applications of stable manure produce poor crops, but when the manure is applied to the preceding crop, excellent results are obtained. Flax does not remove a large amount of fertility, but if grown too frequently the tendency is to get the land out of condition, rather than to exhaust it. The best conditions for flax culture require that it should be grown on the same land only once in five years. Flax straw does not form suitable manure for flax lands. Dr. Lugger demonstrated that there are produced, when the roots and straw of flax decay, products which are destructive to succeeding flax crops.[77] Also flax diseases are introduced into land by the use of diseased flax seed. The food requirements of flax are met when it follows corn which has been well manured, or a sod which has been given the cultivation described for wheat. Flax and spring wheat are much alike in food requirements.

315. Potatoes. — Potatoes are surface feeders, and when grown continuously upon the same soil without manure, the yield per acre decreases more rapidly than that of any other farm crop. Experiments with potatoes by Lawes and Gilbert, using different manures, gave the following results:[78]

AVERAGE YIELD PER ACRE FOR 12 YEARS

	TONS	CWT.
No manure	1	19¾
Superphosphate	3	5
Minerals alone	3	7¾
Nitrate of soda alone	2	4⅝
Mixed manures and nitrogen	5	17⅜
Farm manures, alternate years	4	3¾

Potatoes require liberal general manuring reënforced with wood ashes or other potash fertilizer. In the rotation they should follow grain or pasture, provided the fertility of the soil is kept up. Commercial fertilizers for potato production should contain a fair amount of available nitrogen (2 to 3 per cent) and a more liberal supply of phosphoric acid and potash. See Section 324.

316. Sugar Beets. — This crop is more exacting in its food requirements than any other root crop. Excessive fertility is not conducive to a high content of sugar. Soils in good mechanical condition and medium state of fertility usually give the best results.[79] Sugar beets should not receive heavy dressings of stable manure, because an abnormal growth results. Nitrogenous fertilizers may be applied only in limited amounts, heavier dressings of potash and phosphoric acid are admissible. When sugar beets follow corn which has been manured, or grain which has left the soil in an average state of fertility, and a medium dressing of commercial fertilizer is applied, the food requirements of the crop are well met.

317. Roots. — Mangels are gross feeders and remove a larger amount of fertility from the soil than any other farm crop.[74] When fed to stock and the manure is returned to the soil, they materially aid in making the plant food more available for delicate-feeding crops. Mangels are better able to obtain phosphoric acid than are turnips and need the most help in the way of nitrogen. Turnips are surface feeders with stronger power of nitrogen assimilation than the grains, but with restricted power of phosphate assimilation. Manures for turnips should be phosphatic in nature.

318. Rape is a type of strong feeding plant capable of obtaining its food under conditions adverse to grain crops. When grown too frequently upon the same soil, it does not thrive. On account of its great capacity for obtaining food, it is a valuable crop to use for green manuring purposes.[80] Farm manure is the most valuable fertilizer for rape.

319. Buckwheat is a strong feeding crop, and its demands for food are easily met. On rich soil, a rank growth of straw results, with poor seed formation.

Buckwheat is usually sown upon the poorest soil of the farm. Because it is a strong feeder it is frequently used as a manurial crop, being plowed under while green to serve as food for weaker feeding crops. On poor soils a moderate use of mineral fertilizers and a small amount of nitrogen are beneficial.

320. Cotton. — On average soils cotton stands in need first of phosphoric acid and second of nitrogen.[81] It is most able to obtain potash. Organic nitrogen as cottonseed meal and stable manure appear equally as effective as nitric nitrogen. Phosphoric acid must be applied in the most available forms, although the crop uses but little. The fertilizers should be drilled in at the time of planting. The use of green manuring crops as cowpeas, with an application of marl, gives beneficial results. Marl, which is composed mainly of calcium carbonate, combines with the acids formed from the decay of the vegetable matter and as a result the plant food of the soil is made more available, which is beneficial to both soil and crop. There are but few crops which respond so readily to fertilizers as cotton. It does not remove a large amount of fertility, but when not systematically grown in a rotation exhausts the soil in the same way as when grain is grown continuously.

321. Hops. — The hop plant is exacting in its food requirements. An excess of easily soluble plant food is injurious, while a lack is equally so. An abundance of food in organic forms is most essential. Heavy dressings of farm manures may be applied. Where hops are grown there is a tendency to use all the manure on the hops, while the rest of the farm is left unmanured. Very light applications of commercial fertilizers may be used in connection with stable manure, but such use should be made only after a preliminary trial on a small scale.

322. Hay and Grass Crops. — Most grass crops have shorter roots than grain crops; they are surface feeders and not so able to secure mineral food. When a number of crops have been removed, the soil may stand in need of available mineral matter. Farm manures are particularly well adapted for fertilizing grass. Applications of nitrogenous manures result in discouraging the growth of clover. Heavy manuring of grass land has a tendency to reduce the number of species, and one kind is apt to predominate.[82] On some soils ashes, and on others lime fertilizers, have been found very beneficial. The manuring of grass must be varied to meet the needs of different soils. Permanent meadows require different manuring from meadow introduced as an important crop in the rotation. Permanent meadows should receive an annual dressing of farm manure or of a commercial fertilizer containing phosphoric acid, potash, and a fair amount of nitrogen.

323. Leguminous Crops. — For leguminous crops potash and lime fertilizers have been found of special value. Analyses of clover and peas show large amounts of both potash and lime. In some cases an application of phosphate fertilizer is necessary before a crop of clover can be secured. Farm manure on sandy or heavy clay soils will materially assist in the production of clover. Sometimes clover fails when grown too frequently upon the same soil, not because the soil is exhausted but because of the development in the soil of organic products which are destructive to growth. As the result of growing leguminous crops, the food requirements of which are inexpensive, the soil is enriched with nitrogen, and the phosphoric acid is changed to available forms.

324. Garden Crops. — For general garden purposes, there should be a liberal supply of plant food. Well-composted farm manure can advantageously be reënforced with commercial fertilizers. A liberal use of manure insures not only the maximum yield, but crops of the best quality. Maturity of crops also is influenced by fertilizers.

Voorhees[89] recommends as a fertilizer for general garden purposes one containing:

	Per Cent
Nitrogen	4.00
Phosphoric acid	8.00
Potash	10.00

This and similar fertilizers can be applied at the rate of 1000 pounds per acre. To meet the requirements of special crops, as spinach and cabbage, an additional dressing of nitrate of soda may be used. Asparagus should preferably be fertilized after harvesting the crop, so as to encourage new growth and the storing up of reserved building material in the roots for next year's growth.

For early maturing garden crops, a fair but not excessive amount of nitrogen should be applied; also a liberal supply of phosphates will be found advantageous. Some garden crops, as cucumbers, pumpkins, and squash, thrive best when their food is in organic forms, as the humate compounds derived from farm manures. A continuous supply of available plant food is thus furnished to the growing crop. Onions are benefited by a generous dressing of soluble nitrogen. Celery also should be well supplied with soluble nitrogen combined with soluble forms of mineral food. Tomatoes require general fertilizing; for early maturity, nitrogen, as nitrate of soda, is beneficial, but an excess should be avoided; for late maturity, farm manures and commercial fertilizers containing less nitrogen may be used. For general garden purposes, a complete fertilizer is preferable to an amendment, as a better balanced growth is secured which favorably affects both the yield and the quality.

325. Fruit Trees. — In the manuring of fruit trees, the first object is to produce thrifty trees, as subsequent fertilizing for fruit will not give satisfactory results with poorly grown and partially developed trees. In order to promote growth, a liberal supply of a complete fertilizer should be used, and the soil should be kept in the best mechanical condition. When an orchard is in full bearing, there is as heavy a draft upon the soil as when a wheat crop is grown.[90] To meet this, farm manures and commercial fertilizers should be used liberally. The productive period of an orchard is materially lengthened by judicious use of fertilizers. The quality of the fruit is often adversely affected by a scant supply of plant food. A quick acting fertilizer, containing kainit, nitrate of soda, and dissolved phosphate rock, should be used in the spring, followed if necessary by a light dressing of some manure which yields up its fertility more slowly. An excess of nitrogen, however, should be avoided. Stone fruits are benefited by the addition of lime to the fertilizer. Lime fertilizers impart hardiness to fruit trees.

326. Small Fruits. — On account of the comparatively limited bearing period of small fruits, the land should be brought to a high state of productiveness and good physical condition by liberal use of farm manures previous to planting. Quick acting fertilizers are the most suitable for small fruits. Dressings of nitrate of soda, 50 to 100 pounds per acre, can be applied early in the season to promote leaf activity. This should be followed by an application of a general fertilizer containing about 3 per cent of available nitrogen, 8 per cent of phosphoric acid, and 10 per cent of potash. The amount used should range from 200 to 400 pounds per acre until the character and needs of the soil are determined. It will often be found that large amounts can be used economically.

327. Lawns. — In making a lawn, a mixture of six parts of bone ash, two parts of muriate of potash, and one part of nitrate of soda can be applied at the rate of 5 to 7 pounds per square rod prior to seeding. A good lawn should have a subsoil that is fairly retentive of moisture, one containing 10 to 15 per cent of clay or a large amount of fine silt. Too much potash and lime encourage exclusive growth of clover and crowding out of grasses. During the season, two or three applications can be made of a commercial fertilizer containing about 3 per cent of nitrogen, 10 per cent of phosphoric acid, and 3 per cent of potash, at the rate of one pound per square rod. When part of the nitrogen is in the form of nitrates and part as ammonium salts, better results are secured than when the nitrogen is all in one form. It is also advisable to supply the phosphoric acid in more than one form. An even application of fertilizer to a lawn is quite necessary, otherwise the growth is "patchy." Hard wood ashes evenly spread at the rate of 1 to 2 pounds per square rod and reënforced with nitrate of soda can be used advantageously as a lawn fertilizer.

CHAPTER XII

ROTATION OF CROPS AND CONSERVATION OF SOIL FERTILITY

328. Object of Crop Rotation. — The object of systematic rotation of crops is to conserve the fertility of the soil and at the same time to produce maximum yields. In order to accomplish this, the food requirements of different crops must be met by good cultivation and judicious manuring. Rotations must be planned according to the nature of the soil and the system of farming that is to be followed. For general grain farming a different rotation is required than for exclusive dairying. Whatever the nature of farming, the whole farm should gradually undergo a systematic rotation. If the farm is uneven in soil texture, different rotations may be practiced on the various parts. There is no way in which soils are more rapidly depleted of fertility than by the continued culture of one crop. In exclusive wheat raising, for example, the losses are not confined to the fertility removed in the crop, but other losses occur as described in the chapter on nitrogen. When wheat is systematically grown in alternation with other crops, losses of nitrogen are reduced to the minimum.

When remunerative crops can no longer be produced, the soil is said to be exhausted. Soil exhaustion may be due either to a lack of plant food, to bacterial products, or to poor physical conditions arising from the soil being temporarily out of condition because of a one-crop system and poor methods of cultivation.

329. Principles involved in Crop Rotation. — There are a few fundamental principles with which all rotations should conform. Briefly stated these are:

1. Deep- and shallow-rooted crops should alternate.
2. Humus-consuming and humus-producing crops should alternate.
3. Crops should be rotated so as to make the best use of the preceding crop residue.
4. Crops should be rotated so as to secure nitrogen indirectly from atmospheric sources and to promote desirable bacterial activities in the soil.
5. Crops should be rotated so as to keep the soil in the best mechanical condition.
6. In arid regions, crops should be rotated so as to make the best use of the soil water.
7. An even distribution of farm labor should be secured by a rotation.
8. Farm manures and fertilizers should be used in the rotation where they will do the most good.
9. Rotations should be planned so as to produce fodder for stock, and so that every year there will be some important crop to be sold.

330. Deep- and Shallow-rooted Crops. — When deep- and shallow-rooted crops alternate, the draft upon the surface soil and subsoil is more evenly distributed and the physical condition of the soil is improved. In many soils, nitrogen and phosphoric acid are more abundant in the surface soil while potash and lime predominate in the subsoil. When such a condition exists the alternating of deep- and shallow-rooted crops is very beneficial, because the surface soil is gradually enriched by accumulations of fertility from the subsoil, deposited by decay of the residue of the deep-rooted crops.

331. Humus-consuming and Humus-producing Crops. — When grain or hoed crops are grown continuously, oxidation of the humus occurs, and the chemical and physical properties of the soil are entirely changed by loss of the humus. The rotating of grass and grain crops and the use of stable manure serve to maintain the humus equilibrium. On some soils lime may be required along with the humus to prevent the formation of humic acid, and in such cases the best conditions exist when both lime and humus materials are supplied. Alternation of humus-producing and humus-consuming crops is one of the essentials of a rotation.

332. Crop Residues. — Crop residues should always be placed at the disposal of weak feeding crops. After a light clover and timothy sod, wheat or flax should be grown in preference to barley or mangels. The weak feeding crop should be followed by a strong feeding crop, and then each is properly supplied with food. It would be poor economy, on an average soil, to follow clover and timothy with mangels, then with barley, and finally with flax, because the flax would be placed at a serious disadvantage following two strong feeding crops. If reversed, the crops would be placed in order of assimilative power, and the best use would be made of the sod-crop residue. When crops of dissimilar feeding habits follow each other, not only are the crop residues used to the best advantage, but the soil is relieved of excessive demands on special elements. For example, wheat and clover take different amounts of potash and lime from the soil. Wheat has the power of feeding upon silicates of potash which clover cannot assimilate, hence wheat and clover in rotation relieve the soil of excessive demands on the potash.

333. Nitrogen-consuming and Nitrogen-producing Crops. — It is possible in a five-course rotation to maintain or even increase the nitrogen of the soil without the use of nitrogenous manures. In Section 145 an example is given of a rotation which has left the soil with a better supply of nitrogen than at the beginning. When a soil produces a good clover crop once in five years, and stable manure is used once during that time, the soil nitrogen is not decreased. Not only is nitrification influenced by cultivation and crop rotation, but other bacterial changes are also affected. The entire bacterial flora of a soil may be changed by modifications of systems of cultivation, cropping, and manuring. By means of rotating nitrogen-producing and nitrogen-consuming crops, grain can be sold from the farm without purchasing nitrogenous manures. Conservation of the nitrogen and humus of the soil is one of the most important points to consider in the rotation of crops.

334. Influence of Rotation upon the Mechanical Condition of Soils. — With different kinds of crops the mechanical condition of soils is constantly undergoing change. Grain crops and hoed crops tend to make the soil open in texture. Grass crops have the opposite effect. All soils should undergo periodic compacting and loosening. Some require more of one treatment than of the other. In a rotation the action of the crop upon the mechanical condition of the soil should be considered, otherwise the soil may get into poor condition to retain water or become so loose that heavy losses occur through wind storms. Sandy soils are improved by methods of cropping which compact the soil, while heavy clays require the opposite treatment. The rotation should be made to conform to the requirement of the soil.

335. Economic Use of Soil Water. — The rotation should not be of such a nature as to make excessive demands upon the soil water. For example, after a grain crop has been produced, it is best in regions of scant rainfall to plow the land and get it into condition to conserve the water for the next year's crop, rather than to attempt to raise a catch crop the same year. During years of heavy rainfall catch crops may be grown for green manure to increase the humus content of the soil. Crops removing excessive amounts of water should not be grown too frequently. Sunflowers, for example, remove twenty times more water than grain crops, and cabbage removes more water than many other crops. With a good rotation and systematic cultivation a water balance may be carried in the soil from one year to the next, so that crops will be supplied in times of drought.

336. Rotation and Farm Labor. — The rotation of crops should be so planned that there is an even distribution of farm labor. The importance of this is so plain that its discussion seems unnecessary. It is one of the most important points to consider in economic farming, and should not be lost sight of in planning rotations.

337. Economic Use of Manures. — Farm manure should be applied to those crops which experience has shown to be the most benefited by its use. At least once during a five years' rotation the land should receive a dressing of stable or some other manure.

When commercial fertilizers are used, they should be applied to the crops which need the most help in obtaining food. With the growing of clover and the use of farm manures, the minimum amount of commercial fertilizer is required for general crop production. It is more economical to reënforce the farm manures with fertilizers especially adapted to the soil and crop than to purchase complete fertilizers for all crops.

FIG. 46. A Wheat Field. This crop was grown on land where farm manure was used and a rotation of crops practiced. Ayer, Photographer.

338. Salable Crops. — In all farming, something must be sold from the farm. It should be the aim to sell products which remove the least fertility, or if those are sold which remove large amounts, to return in cheaper forms the fertility sold. In a good rotation it is the plan to have at least one salable crop each year. The whole farm need not undergo the same rotation at the same time, and the rotation may be subject to minor changes, as circumstances require. To illustrate, wheat and flax occupy about the same position in a rotation. If at seeding time the indications are that wheat will be a poor paying crop and flax command a high price, flax should be sown. The rotation should be such that one of two or three crops may be grown as circumstances require. A rotation should be reasonably flexible.

339. Rotation Advantageous in Other Ways. — A good rotation will be found advantageous in other ways than those mentioned. With one line of cropping, land becomes foul with weeds and insects which do not thrive when crops are rotated. Frequently the rotation must be planned so as to reclaim the land from weeds and ravages caused by insect pests. Many insects are capable of living only on a special crop ; when this crop is grown continuously on the same land the best conditions for insect ravages exist, and relief is secured only by rotation of crops. Fungous diseases also are most liable to occur on soils which produce annually the same crop, as the conditions are favorable for the propagation and hibernating of the disease-producing spores.

340. Long- and Short-course Rotations. — Rotations vary in length from 2 to 17 years. Long-course rotations are more generally followed in European and other of the older countries. The length of the rotation can be determined only by the conditions existing in different localities. As a general rule, long-course rotations should be attempted mainly on large farms and after a careful study of all of the conditions relating to the system of farming that it is desired to follow. For northern latitudes a rotation of four or five years gives excellent results. In some localities three-course rotations are the most desirable.

A rotation that is suitable for one locality or kind of farming may be unsuitable for other localities and conditions. Because of variations in soil, climate, and rainfall, no definite standard rotation can be proposed that will be applicable to all cases.

341. Example of Rotation. — In dealing with the subject of rotations it is best to take actual problems as they present themselves and plan rotations that will best meet all of the conditions. For example, a farm of 160 acres is to be rotated with the main object of producing fodder for live stock, and a small amount of grain for sale. To meet these requirements the rotation outlined on pages 282 and 283 is suggested.[83]

The farm is divided into eight fields of 20 acres each; seven fields are brought under the rotation, while one field is left free for miscellaneous purposes. Each year

ROTATION FOR DAIRY FARM

Field No.	1	2	3	4
1st year	Corn (manured).	Pasture.	Meadow.	Oats (clover and timothy).
2d year	One half wheat, one half flax.	Corn (manured).	Pasture.	Meadow.
3d year	Barley (manured).	One half wheat, one half flax.	Corn (manured).	Pasture.
4th year	One fourth potatoes, one fourth peas, one fourth rye, one fourth corn fodder.	Barley.	One half wheat, one half flax.	Corn (manured).
5th year	Oats (clover and timothy).	One fourth potatoes and roots, one fourth peas, one fourth rye, one fourth corn fodder.	Barley.	One half wheat, one half flax.
6th year	Meadow.	Oats (clover and timothy).	One fourth potatoes and roots, one fourth peas, one fourth rye, one fourth corn fodder.	Barley.
7th year	Pasture.	Meadow.	Oats (clover and timothy).	One fourth potatoes, one fourth peas, one fourth rye, one fourth corn fodder.

ROTATION FOR DAIRY FARM

Field No.	5	6	7	8
1st year	One half wheat, one half flax.	Barley (manured).	One fourth potatoes, one fourth rye, one fourth peas, one fourth corn fodder.	Reserved for miscellaneous crops and farmstead.
2d year	Barley (manured).	One fourth potatoes, one fourth rye, one fourth peas, one fourth corn fodder.	Oats (clover and timothy).	
3d year	One fourth potatoes, one fourth rye, one fourth peas, one fourth corn fodder.	Oats (clover and timothy).	Meadow.	
4th year	Oats (clover and timothy).	Meadow.	Pasture.	
5th year	Meadow.	Pasture.	Corn (manured).	
6th year	Pasture.	Corn (manured).	One half wheat, one half flax.	
7th year	Corn (manured).	One half wheat, one half flax.	Barley (manured).	

there are produced 20 acres of corn, 20 acres of timothy and clover hay, 10 acres each of wheat and flax, 20 acres of barley, and 5 acres each of corn fodder, rye, peas, and potatoes, while 20 acres are reserved for pasture. The main income is derived from the sale of live stock and dairy products.

Problems on Rotation

1. Plan a rotation for general farming (160 acres), using the following crops: clover, timothy, barley, oats, potatoes, and corn. The soil is in an average state of fertility. Twenty-five head of stock are kept.

2. Plan a three-course rotation for a sandy soil, the main object being potato culture.

3. Plan a seven-year rotation for grain farming, using manure and a commercial fertilizer once during the rotation. The soil is a clay loam in a good state of fertility.

4. Plan a rotation for general farming on a sandy loam.

5. How would you proceed to bring an old grain farm from a low to a high state of productiveness? Begin with the feeding of the stock.

6. Using commercial and special purpose manures, how would you proceed to raise wheat, potatoes, and hay in a suitable rotation and continuously?

7. Plan a rotation for a northern latitude, where corn cannot be grown, except for fodder, and where clover and timothy fail to do well; wheat and all small grains thrive, also millet, bromus inermis, rape, and some of the root crops. The soil is a clay loam, resting on a marl subsoil. Manure is very slow in decomposing. The rotation should be suited to general farming, wheat or flax being the important market crop.

8. Plan for a southern farm a rotation in which cotton forms an important part.

9. Plan a rotation for a market milk farm of 90 acres. One hundred head of stock are kept and mostly mill feed purchased. Soiling crops are to be provided; corn silage and clover are the main coarse fodders.

CONSERVATION OF FERTILITY

342. Manures Necessary for Conservation of Fertility. — In order to conserve the fertility of the soil, not only must a systematic rotation be practiced, but a proper use must be made of the crops produced. When crops are sold from the farm and no restoration is made, soils are gradually depleted of their fertility. No soil has ever been found that will continue to produce crops without the use of manures. Many prairie soils give large yields for long periods without manuring, but they are never able to compete in productiveness with similar soils that have been systematically cropped and manured. With a fertile soil the decline in fertility is so gradual that it is not observed unless careful records are kept of the yields from year to year.

343. Use of Crops. — The use made of crops whether as food for stock or sold directly from the farm determines the future crop-producing power of the soil. With different systems of farming different uses are made of crops. When exclusive grain farming is followed there is no restoration of fertility, while in the case of stock farming, the manure produced contains fertility in proportion to the food consumed. If good care is taken of the manure, and in place of the grains sold mill products are purchased and fed, there is no loss but often a gain of fertility. Between these two extremes, exclusive grain farming and stock farming, many different systems are practiced which remove from the soil various amounts of fertility.

344. Two Systems of Farming Compared. — Losses of fertility from farms are determined by the products sold, the care of the manure, and the fertility in the materials purchased and used on the farm. If an account were kept of the income and outgo of the fertility it would be found that with some systems the soil is gaining, while with others a rapid decline is occurring. In studying the income and outgo of fertility, it is necessary to calculate the amounts of the three principal elements, nitrogen, phosphoric acid, and potash in the crops and other products sold. For making these calculations, tables are given in Sections 185 and 307. In the handling of manure it is impossible to prevent losses, but it is possible to reduce them to very small amounts. Hence in the calculations, a loss of 3 per cent is allowed for mechanical waste and for uneven distribution of the manure; that is, in addition to the fertility sold from the farm a mechanical loss of 3 per cent is allowed for all crops raised and consumed as food by stock.

On one farm the crops raised and sold are: flax 40 acres, wheat 50 acres, oats 20 acres, barley 50 acres.

No stock is kept, the straw is burned, and the ashes are wasted. In addition to the nitrogen removed in the crops other losses must be considered. Experiments show that when exclusive grain farming is practiced, for every pound of nitrogen removed in the crop, 4 pounds are lost from the soil in other ways. This would make the total loss of nitrogen over 28,500 pounds, or 177 pounds per acre, which large as it may seem is the actual loss from the soil when grain only is raised and it is sold. Experiments at the Minnesota Experiment Station with a soil that had been cultivated 40 years, showed the annual loss per acre of nitrogen in exclusive wheat raising to be 25 pounds through the crop and 146 pounds due to oxidation of the nitrogenous humus of the soil.[9]

EXCLUSIVE GRAIN FARMING

Sold from the Farm

	NITROGEN POUNDS	PHOSPHORIC ACID POUNDS	POTASH POUNDS
Flax, 40 acres	1600	600	800
Flax straw	600	120	320
Wheat, 50 acres	1250	625	350
Wheat straw	500	375	1400
Oats, 20 acres	700	240	200
Oat straw	300	120	700
Barley, 50 acres	1400	750	400
Barley straw	600	250	1500
Total	6950	3080	5670

When exclusive grain farming was followed, the annual losses of fertility from this farm of 160 acres were 28,500 pounds of nitrogen, 3000 pounds of phosphoric acid, and 5500 pounds of potash.

On a similar farm of 160 acres the crops are rotated as described in Section 341. The amounts of fertility in the crops raised and consumed as fodder, in the products sold, and in the food and fuel purchased, are given in the following table:

STOCK FARMING

Sold from the Farm

	Nitrogen Pounds	Phosphoric Acid Pounds	Potash Pounds
Butter, 5000 pounds	5	5	5
Young cattle, 10 head	200	190	16
Hogs, 20 of 250 pounds each	100	40	10
Steers, 2	48	38	4
Wheat, 10 acres	250	125	70
Flax, 10 acres	390	150	190
Rye, 10 acres	285	128	85
Total	1278	676	380

Raised and Consumed on the Farm

	Nitrogen Pounds	Phosphoric Acid Pounds	Potash Pounds
Clover, 20 tons	...	270	600
Timothy, 20 tons	600	180	800
Corn, 20 acres	1500	300	800
Corn fodder, 1 acre	75	15	60
Mangels, 2 acres	150	70	300
Potatoes, 1 acre	40	20	75
Straw, 40 tons	400	200	1000
Peas, 5 acres	...	85	200
Oats, 20 acres	700	240	200
Barley, 20 acres with straw	800	400	760
Total	4265	1780	4795
Mechanical loss of food consumed, 3 per cent	128	53	144

Food and Fuel Purchased

	Nitrogen Pounds	Phosphoric Acid Pounds	Potash Pounds
Bran, 5 tons	275	260	150
Shorts, 5 tons	250	150	100
Oil meal, 1 ton	100	35	25
Hard wood ashes	. . .	25	100
Total	625	470	375
Mechanical loss of material purchased, 3 per cent	19	14	10
Sold from farm	1278	676	380
Loss of food consumed, etc.	128	53	144
Total	1425	743	534
Food and fuel purchased	625	470	375
Balance lost from farm	800	273	159

The manure produced and used on this farm results in larger crop yields than is the case with exclusive grain culture. The nitrogen gained by the clover and peas more than balances the loss of nitrogen in other crops. Experiments show that a rotation similar to this caused an increase in soil nitrogen.[18] Manure, meadow, and pasture all tend to increase the soil's humus and nitrogen. The losses of phosphoric acid and potash are very small, averaging about a pound per acre of each. The manure on this farm is continually bringing into activity the inert plant food of the soil so that every year there is a larger amount of more active plant food, which results in producing larger yields per acre.

The method of farming has a marked effect upon crop yields. The average yield of wheat in those counties in Minnesota where live stock is kept and crops are rotated, is over 10 bushels per acre greater than in similar counties where exclusive grain farming is followed.

Problems

Calculate the income and outgo of fertility from the following farms:

1. Sold from the farm: wheat 40 acres, oats 40 acres, barley 40 acres, rye 20 acres, flax 10 acres. The straw is burned and no manures are used.

2. Sold from the farm: wheat 20 acres, barley 20 acres, flax 5 acres, 1000 pounds of butter, 10 hogs, and 10 steers. Purchased: bran 3 tons, shorts 2 tons, oil meal 1 ton. Crops produced and fed on farm: clover and timothy hay 40 tons, corn fodder 3 acres, corn 10 acres, oats and peas 10 acres, roots 1 acre, millet 1 acre, and barley 5 acres.

3. Sold from the farm: wheat 10 acres, sugar beets 5 acres, milk 100,000 pounds, butter 500 pounds, 20 pigs, 6 head of young stock, 2 acres of potatoes. Purchased: 5 tons of bran, 2 tons of oil meal, 1 ton of cottonseed meal, 15 cords of wood, 1 ton of acid phosphate, 1000 pounds of potassium sulphate, and 500 pounds of sodium nitrate. Raised and consumed on the farm: corn fodder 15 acres, mangels 1 acre, peas and oats 5 acres, clover 20 tons, timothy 10 tons, straw from grain sold, oats 10 acres, corn 20 acres.

4. Calculate the income and outgo of fertility from your own farm.

CHAPTER XIII

PREPARATION OF SOILS FOR CROPS

345. Importance of Good Physical Condition of Seed Bed. — But few soils are in suitable condition for seeding without further preparation than simply plowing the land. If the plowing is poorly done, a good seed bed cannot be made. The depth of plowing is of prime importance and is determined largely by the kind of soil, as sand, clay, or loam. (See Section 35.) The condition of the seed bed is influenced not only by the depth of plowing but by its nature as the way in which the furrow slice is left. The treatment after plowing, as disking, harrowing, cultivating, and light rolling, must be determined largely by the character of the soil. Too frequently the preparation of the soil is not given sufficient attention and the crop suffers because of a poorly prepared seed bed. Low yields are more generally due to poor physical condition of the soil than to any other factor. Without the requisite cultivation the natural fertility is not used to the best advantage.

346. Influence of Methods of Plowing upon the Condition of the Seed Bed. — A poor seed bed is sometimes due to complete inversion of the furrow slice and the soil not being sufficiently pulverized. If a heavy sod has simply been inverted, subsequent harrowing and cultivation fail to pulverize and loosen the tough sod in the lower part of the furrow slice. A good seed bed cannot be made upon such a foundation. When the land is plowed so the furrow slice is left at an angle of 30° to 45°, the surface is corrugated and all vegetation is buried in loose soil. When land that has been plowed in this way is cultivated and harrowed, a better seed bed is formed than is possible on a completely inverted furrow slice.

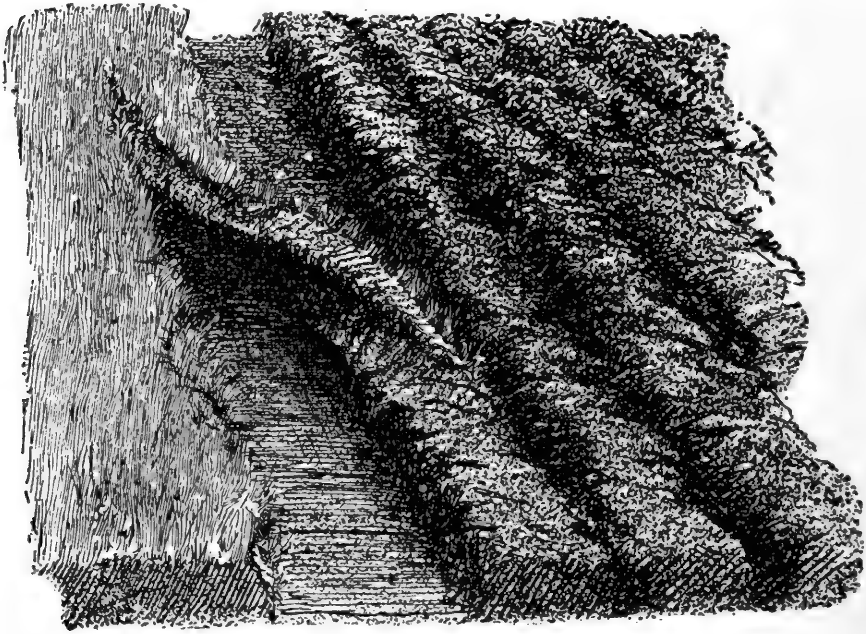


FIG. 47. Complete Inversion of the Furrow Slice (after Roberts). A poor way of plowing sod land.

The plowing should thoroughly pulverize the soil, completely bury all surface vegetation, and leave the land in a corrugated condition with the furrow slice at an angle but firmly connected with the subsoil. There should be as thorough disintegration of the soil as possible, and this can best be accomplished by the use of a plow with a bold rather than too flat a moldboard.

FIG. 48. The Furrows standing nearly edgewise (after Roberts). A good way to leave fall plowed land to undergo weathering during the winter, to be followed by thorough cultivation in the spring.

Roberts states that only about 10 per cent of the energy required for plowing is used by the friction of the moldboard: "about 35 per cent of the power necessary to plow is used by the friction due to the weight of the plow, and 55 per cent by severing the furrow slice and the friction of the land slide." Hence in the preparation of the seed bed, it is economy to secure as much pulverization of the soil by the action of the plow as possible rather than to leave too much for subsequent treatment. The plow is the most economical implement for pulverizing the land.

347. Influence of Moisture Content of the Soil at the Time of Plowing. — The condition of the soil, particularly its moisture content, at the time of plowing, has much to do with the formation of a good seed bed. If soils are too dry when plowed, they fail to pulverize, and then disking, harrowing, and in some cases light rolling, which make additional expense, must be resorted to in order to produce a fine, mediumly compact, and well-pulverized seed bed. If clay soils are plowed when too wet, the pores of the subsoil become clogged, a condition known as puddling takes place, and the furrow slice dries and forms hard lumps and clods. The condition in which the soil is left after plowing, particularly in the case of clay soils, has much to do with the character of the seed bed and the subsequent yield of the crop. At the Oklahoma Station, winter wheat land plowed in July was moist and mellow, while that plowed

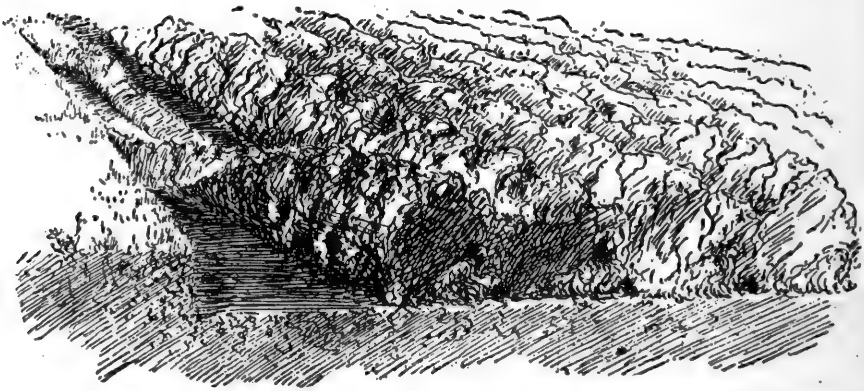


FIG. 49. Ideal Plowing (after Roberts). The land left in a formed, pulverized condition and all the sods turned under.

in September was dry and lumpy; the early plowed mellow land gave a yield of 31.3 bushels per acre and the late plowed lumpy land produced only 13.3 bushels.

348. Influence upon the Seed Bed of Pulverizing and Fining the Soil. — If the land is lumpy and the lower stratum of the seed bed is not pulverized and firmed, the soil water is readily lost by percolation, evaporation takes place rapidly, and the crops are poorly fed because the roots are unable to penetrate the hard lumps and secure plant food. If a soil is inclined to be lumpy, the cultivation, including the plowing, should be carried on largely with the view of thorough pulverization. When a seed bed is well prepared, the soil warms up more readily; the loosening and pulverizing enable the heat of the sun's rays to more readily penetrate the soil and bring it into good condition for promoting growth.

349. Aëration of Seed Bed Necessary. — Crop roots require air for functional purposes. In sand and loam the air spaces make up half or more of the total volume. It is not necessary to cultivate such soil with the view of increasing the air spaces, but with compact soils, as heavy clays, plowing should result in aëration of the soil and an increase in the number of air spaces, as the air of the soil takes an important part in rendering plant food available. (See Section 59.) If soils are plowed when too wet, they are not sufficiently aërated.

The amount and kind of cultivation to secure the ventilation or aëration necessary for crop production must be regulated according to the character of the soil, as sand, clay, or loam, and the climatic conditions. The cultivation which is given soils for moisture conservation also secures the proper aëration.

In discussing the importance of a mellow seed bed, King says;[15] "When a mellow, open seed bed has been prepared, and its temperature has been raised to the proper point, should a rain fall upon it, that water will tend to pass through its wide pores quickly to the deeper soil, and without leaching it as badly as would be the case were the soil more compact; so that in the early season when there is an overabundance of moisture, it is best, for warmth, for aëration, and to lessen loss of fertility by percolation, to have a mellow seed bed."

350. Preparation of Seed Bed without Plowing. — Loam soils which have been subjected to a systematic rotation of crops ending with corn, need not be plowed, but the seed bed for the succeeding grain crop can be prepared simply by disking the corn land. Surface tillage of the corn crop has sufficiently loosened and aërated the soil and has caused an accumulation of available plant food near the surface which would be buried and be less available to the crop if the land were plowed too deeply. On heavy clay lands this method of preparing the seed bed is not advisable; but on the silt soils of the Northwest it has given excellent results and is beneficial in promoting crop growth.

351. Mixing of Subsoil with Seed Bed. — Some soils are improved by deep plowing and mixing the surface and subsoils to form the seed bed. Such soils are usually acid in character and contain a large amount of organic matter, in which case the mixing of the surface and subsoils improves both the physical and chemical properties. With sandy soils the mixing of the surface soil with the subsoil is not advantageous, as it dilutes the stores of plant food which are greater in the surface soil; then, too, the physical properties of the soil are not improved. Combining the surface and subsoils in the case of heavy clays should be done gradually and at each period in the rotation after an application of farm manure. In the cultivation of clay soils it should be the aim to secure a deep layer of thoroughly pulverized, aërated, and fertilized soil. In the preparation of the seed bed, the character and condition of the subsoil is equally as important as of the surface soil.

352. Cultivation to Destroy Weeds. — One of the chief objects of cultivation is to destroy weeds, and for this purpose it should be given early in the year before the weeds become firmly established. Weeds are most easily destroyed at the time of germination and before the leaves appear above ground. The plow should be relied upon largely for the destruction of deep-rooted perennial weeds, while the cultivator is effectual for the destruction of annuals. When weeds are plowed under or destroyed by cultivation they serve as a green manurial crop, adding vegetable matter and humus to the soil and thus improving its condition instead of reducing the yield of crops by appropriating fertility, as they do if allowed to grow and mature. Cultivation which secures aëration of the soil and conservation of the soil moisture is also effectual for the destruction of weeds.

353. Influence of Cultivation upon Bacterial Action. — Cultivation has a marked influence upon bacterial action. Some of the soil organisms, as the nitrifying organisms (see Section 150), require oxygen for their existence, hence cultivation which increases the supply of oxygen in the soil increases the activity of such organisms. In the absence of air, anaërobic fermentation occurs, and such fermentation is unfavorable to crop growth. When acid peaty soils are aërated bacterial action is induced which results in more rapid decay and a lowering of the per cent of total organic matter, including the deleterious organic acids. Neutralizing the organic acids of soils by applications of lime and wood ashes hastens bacterial action, and during the process of nitrification this is not alone confined to the nitrogenous compounds of the soil, as the nitrifying organisms require phosphates as food and these are left after nitrification in a more available condition. The mineral as well as the organic matter of the soil is subject to the action of micro-organisms, and the cultivation which the soil receives can be made either to accelerate or to retard this action. Many of the chemical changes which take place in the soil resulting in the liberation of plant food are induced by aërobic organisms, hence the importance of thorough cultivation to induce bacterial action. Each type of soil has its own characteristic microscopic flora, which can be either favorably or unfavorably influenced by cultivation.

354. Cultivation for Special Crops. — While the general principles of cultivation apply to all crops, the extent to which loosening or compacting should be carried must be determined by the character of the soil and the crop that is to be produced. Methods of cultivation must be varied to meet the requirements of different soils and different crops. The physical condition of the soil for general farm crops is discussed in Chapters I and XI. For the production of a special crop, the cultivation must be adapted to the specific needs as to manner of growth, kind of food needed, physical condition of the soil, temperature, and moisture. A knowledge of these requirements can be obtained only by experimental methods. The cultivation of a new crop should not be attempted on a large scale without a preliminary study of the crop. The production of sugar beets for the manufacture of sugar, of flax for fine fiber, or of tobacco under shade requires a high degree of both knowledge and skill. For the production of special crops the preparation of the seed bed and the subsequent cultivation are matters of prime importance, and should receive careful consideration on the part of the cultivator. Many times agricultural industries undertaken in new countries have failed because the cultivation of the special crop used in the industry has not been successfully accomplished on account of lack of knowledge of the cultural methods necessary.

355. Cultivation to prevent Washing and Gullying of Lands. — In regions of heavy rainfall, rolling land of clay texture often becomes gullied by the water flowing in large amounts over the surface. Under such conditions the preparation of a seed bed, and cultivation of the soil so as to prevent washing are often difficult problems. To prevent gullying, the water currents should be divided as much as possible by plowing narrower lands and by increasing the number of shallow dead furrows. The larger drains should be constructed with the view of preventing the formation of deep gullies, and this can in part be accomplished by encouraging the growth of special grasses with fibrous roots which serve as soil binders. Soils which gully are improved by the addition of farm manures and other humus-forming material which bind together the soil particles; also by seeding and cultivating at right angles to the slope of the land so as to break the force of the water. The water should be encouraged to percolate through the soil rather than to flow over the surface. (See Section 25.)

356. Bacterial Diseases of Soils. — Many of the bacterial diseases to which crops are subject are caused primarily by a diseased condition of the soil. These diseases can often be checked by the right kind of cultivation, by securing good drainage, and by proper soil ventilation supplemented with the application of alkaline matter as wood ashes and land plaster. Undrained soils are unsanitary; the products of decay of the organic matter accumulate in the soil and produce toxic or poisonous compounds which affect crops. When soils are drained, air is admitted which prevents the formation of these products. Both bacterial and fungous diseases of soils may be controlled by cultivation, particularly when it improves the general sanitary condition of the soil. With improvement in sanitary condition, there is less liability of bacterial diseases becoming established and causing destruction of the crop. As a result of some forms of bacterial action, chemical substances injurious to plants are produced, and by controlling bacterial action the formation of these is prevented. Some of the organisms propagated in the soil cause bacterial diseases of dairy and other farm products. The use of soil disinfectants is possible only where a small area is involved; they are not applicable to large tracts as they destroy the beneficial as well as the injurious soil organisms. A good sanitary condition of the soil is as essential for the production of crops as are suitable hygienic surroundings for the rearing of live stock. Sunlight and air are important factors in bringing about an improved sanitary condition of diseased soils.

By the rotation of crops many bacterial diseases, as flax wilt and clover sickness, are controlled. Some of these are disseminated by the use of infected seed. By sprinkling the seed grain with a disinfectant as a dilute solution of formalin (1 pound of formalin in 50 gallons of water) bacterial diseases, as grain smuts, are held in check. Low forms of plants, as fungi, also develop in soils when conditions are favorable, and take an important part in changing the character of the soil. Their action may be either beneficial or injurious, depending upon the condition of the soil. There is a very close relationship between soil sanitation, which results in the avoidance of crop diseases, and the quality and yield of agricultural products.

357. Influence of Crowding Plants in the Seed Bed. — The number of plants which a seed bed should produce is dependent mainly upon the supply of water and plant food. By means of thick or thin seeding, the general character of crops may be influenced within definite limits. Either an excessive or a scant amount of seed gives poor results. If overcrowded, plants fail to develop normally either for want of plant food or water, or because of poor sanitary conditions, or from lack of room for development. Experiments show that an excessive amount of seed wheat as more than 100 pounds per acre of spring wheat does not give good results. Each crop has its limit beyond which it is not desirable to crowd the plants in the seed bed. When there is crowding, unhygienic conditions prevail and the lack of air, sunlight, and good ventilation encourages bacterial diseases, while on the other hand too few plants favor the growth of weeds and an abnormal development of the crop. In the seeding of grains and other farm crops, the amount of seed to be used per acre should be determined by the quality of the seed and the local conditions, as climate and soil, together with any special characteristic desired in the way of composition and character of the crop.

358. Selection of Crops. — The selection of the most suitable crops to be grown is largely a local problem and must be determined by climatic and soil conditions. The preference of farm crops for certain types of soil is discussed in Sections 11 to 17, and it is not advisable to attempt to grow crops upon soils to which they are not naturally adapted or under unfavorable climatic conditions. Practical experience is the best guide in regard to the selection of crops and the most suitable lines of farming to follow, and it will be found that this experience is in harmony with the laws governing the conservation and development of the fertility of the soil.

Temporary methods of farming, as exclusive grain raising, can be followed for a short time on new soils; but it is desirable that each type of soil should be subjected to a judicious system of cultivation, fertilizing, and cropping rather than to the production of one or only a few market crops at random. The selection of the crops and their utilization for market or feeding purposes should be determined mainly by the system of farming that is most adapted to the soil of the farm, and the farm should be managed largely with the view of maintaining the fertility of the soil.

359. The Inherent and Cumulative Fertility of Soils.[95] — There is present in nearly every soil a variable amount of inherent fertility resulting from disintegration and other changes to which soils are subject. In some long-cultivated soils the amount of fertility produced annually by weathering and natural agencies is sufficient to yield from ten to fifteen bushels of wheat per acre. This does not represent the maximum crop-producing power of the soil, but simply the inherent or natural fertility. When the natural fertility is reënforced with farm manures and other fertilizers, culmulative fertility is added and maximum yields are secured. In many soils there are large amounts of cumulative fertility or residues from former applications of manure. The crop-producing power of a soil is dependent upon both the inherent and the cumulative fertility, as well as upon the mechanical condition of the soil. In the production of crops, all of the inherent fertility should be utilized to the best advantage, and cumulative fertility should be added so that the stock of total fertility may be increased. Soils of the highest fertility are those which are composed of a large amount of silt or particles of equivalent value, well drained, but sufficiently retentive of moisture for crop production, and of good capillarity. Such soils are usually deposited by water; they are uniform in texture, of great depth, and contain large amounts of organic matter rich in nitrogen and minerals containing all of the essential elements of plant food. When these soils are cultivated, the organic matter readily undergoes decay with liberation of plant food.

360. Balanced Soil Conditions. — A high state of fertility necessitates a balanced condition of the physical and chemical properties of a soil. Some soils are of good texture and have all the necessary physical requisites for crop production, but fail to produce good crops because of a scant supply of the essential elements of plant food. Other soils contain the necessary plant food but are unproductive because of poor physical condition. Soils may be unproductive on account of either chemical or physical defects, causing the various factors of soil fertility to be unbalanced. In the cultivation of a soil it should be the aim to discover any defect and then to apply the necessary corrective measures. Soil problems are extremely varied in character, and the cultivator of the soil should seek aid jointly from chemistry, physics, biology, and geology, and also from practical experience founded upon observation in the cultivation of soils and the production of crops. The utilization and maintenance of the fertility of the soil of necessity form the basis of any rational agricultural system.

CHAPTER XIV

LABORATORY PRACTICE

THE laboratory practice is an essential part of the work in Soils and Fertilizers, as the experiments illustrate many of the fundamental principles of the subject. The student should endeavor to cultivate his powers of observation so as to grasp the principles involved in the work rather than to do it in a merely mechanical or perfunctory way. Neatness is one of the essentials for success in laboratory practice; an experiment performed in a slovenly manner is of but little value.

A careful and systematic record of the laboratory work should be kept by the student in a suitable note-book. In recording the results of an experiment, the student should give in a clear and concise form the following:

(1) Title of the experiment.
(2) How the experiment is performed.
(3) What was observed.
(4) What the experiment proves.

The note-book should be a complete record of the student's individual work, and should be written up at the time the experiment is performed.

Before an experiment is made the student is advised to review those topics presented in the text which have a bearing upon the experiment, so a clearer conception may be gained of the relationship between the laboratory work and that of the class room.

Students who have had but little laboratory practice are advised to study the chapters on Laboratory Manipulation, and Water and Dry Matter, in "The Chemistry of Plant and Animal Life."

Some of the pieces of apparatus are loaned to the student when needed to perform the experiment; for these a receipt is taken, and he is credited with the apparatus when it is returned.

The following are supplied to each student: —

	No.		No.
1 Crucible Tongs.	1	2 Bottles.	11
1 Pkg. Filter Paper.	2	1 Large Cylinder.	12
1 Test Tube Clamp.	3	1 Sand Bath.	13
1 Evaporator.	4	1 Hessian Crucible.	14
1 Stirring Rod.	5	1 Wooden Stand.	15
3 Beakers.	6	1 Tripod	16
6 Test Tubes.	7	1 Ring Stand and 3 Rings.	17
1 Test Tube Stand.	8	1 Single Clamp.	18
1 Funnel.	9	1 Burner and 2 Ft. Rubber Tubing.	19
1 Mortar and Pestle.	10	1 Brush.	20

Directions for Weighing. — Place the dish or material to be weighed in the left hand pan of the balance. (See Fig. 51.) With the forceps lay a weight from the weight box on the right hand pan. Do not touch the weights with the hands. If the weight selected is too heavy, replace it with a lighter weight. Add weights until the pans are counterpoised; this will be indicated by the needle swinging nearly as many divisions on one side of the scale as on the other. The brass weights are the gram weights. The other weights are fractions of a gram. The 500, 200, 100 mg. (milligram) weights are recorded as .5, .2, and .1 gm. The 50, 20, and 10 mg. weights as 0.05, 0.02, and 0.01 gm. If the 10, and 2 gm. and the 200, the 100, and the 50 gm. weights are used, the resulting weight is 12.35 gms. No moist substance should ever come in contact with the scale pans. The weights and forceps should always be replaced in the weight box. Too much care and neatness cannot be exercised in weighing.

General Direction for Laboratory Practice. — The student should write up the results of his experiments at the time they are per-

FIG. 50. Apparatus for Laboratory Soil Work. See Numbers and Names, page 308.

formed. Careful attention should be given to the spelling, language, and punctuation, and the note-book should represent the student's individual work. He who attempts to cheat in laboratory work by copying the results of others only cheats himself. Care should be exercised to prevent anything getting into the sinks that will clog the plumbing; soil, matches, broken glass, and paper should be deposited in the waste jars. The student should learn to use his time in the laboratory profitably and economically. He should obtain a clear idea of what he is to do, and then do it to the best of his ability. If the experiment is not a success, repeat it. While the work is in progress it should be given undivided attention.

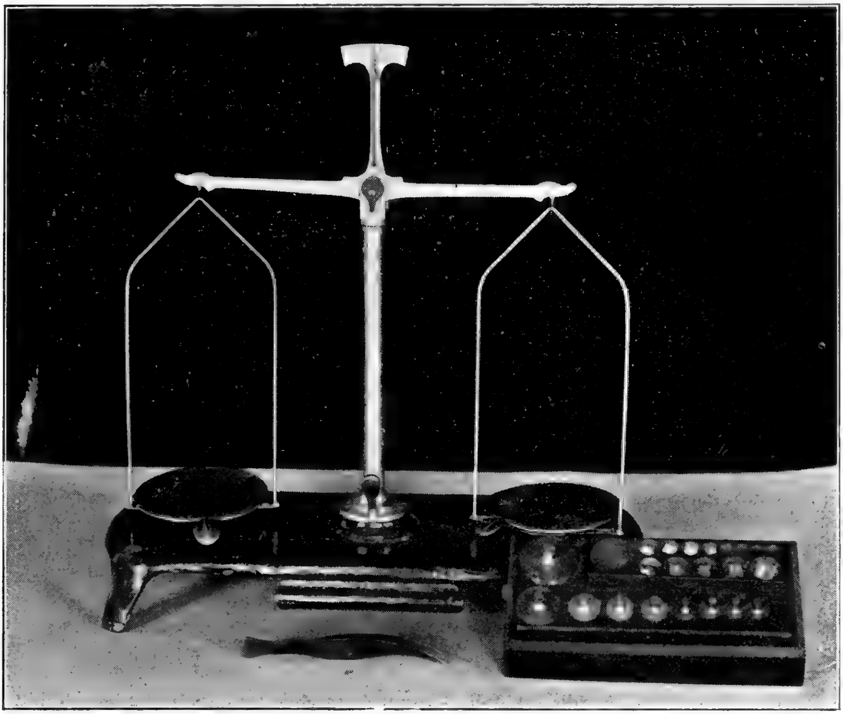


FIG. 51. Balance and Weights.

Experiment No. 1

Determination of the Hydroscopic Moisture and Volatile Matter of Soils

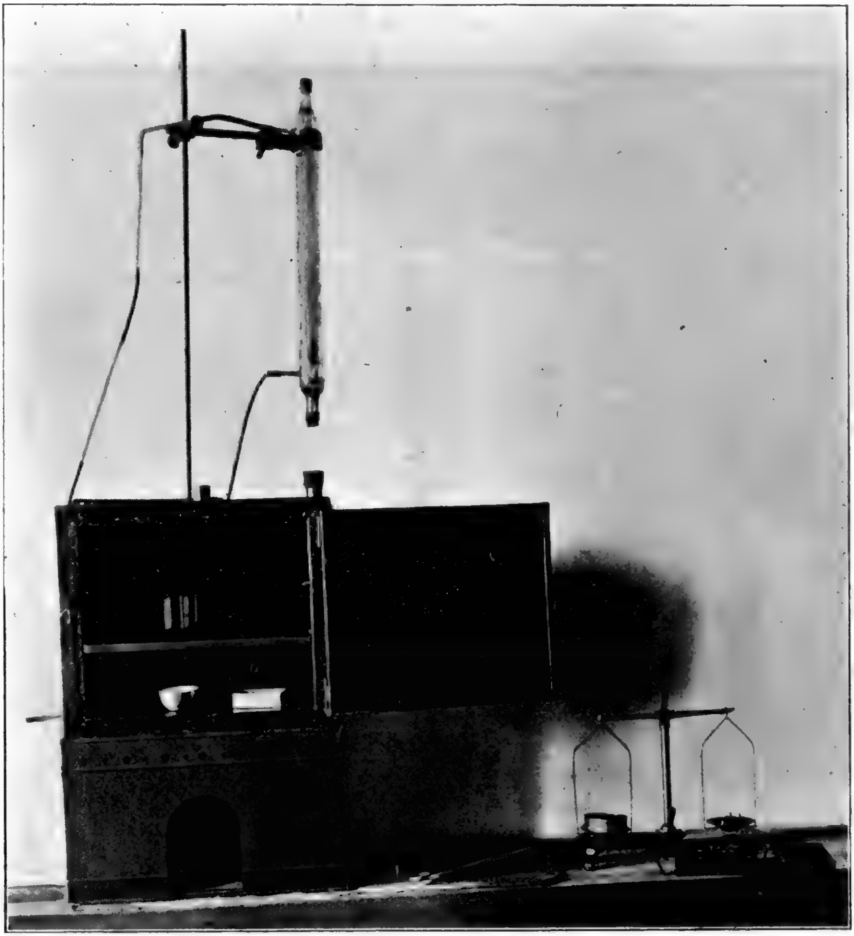


FIG. 52. Apparatus for determining Moisture Content of Soils.

Weigh in grams to the second decimal place a dry Hessian crucible. Place 5 to 10 gms. of air-dried soil in the crucible and weigh again. Then place the dish containing the soil in the water oven and leave it four hours for the soil to dry. Cool and weigh at once so there may be as little absorption of water from the air as possible. From the loss of weight, calculate the per cent of hydroscopic moisture in the soil. Place the crucible containing the dry soil in a muffle furnace and leave until all of the organic matter is volatilized. After the crucible has cooled on an asbestos mat, weigh and calculate the per cent of volatile matter. The volatile matter consists of organic matter and water that is held in chemical combination with the silicates. (Soils from the students' home farms are to be used in Experiments Nos. 1, 2, 4, 6, 9, 12, 16, 18, 19, and 21, each student working with his own soil.)

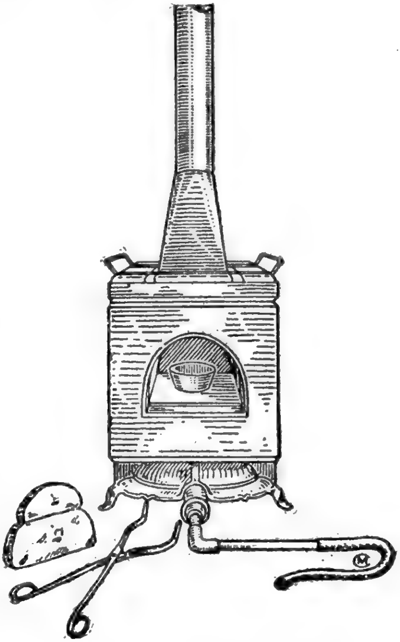


FIG. 53. Muffle Furnace used for determining Volatile Matter.

Experiment No. 2

Determination of the Capacity of Loose Soils to absorb Water

To 100 gms. of air-dried soil in a beaker add 100 cc. of water. Mix the soil and water, then pour the mixture on a saturated but not dripping filter paper fitted into a funnel. For transferring the soil, 50 cc. more water may be used. Measure the drain water in a graduate. To prevent evaporation, keep the moist soil in the funnel covered with a glass plate. Deduct the leachings from the total water used. Calculate the per cent of water retained by the air-dried soil.

Repeat the experiment, using sand, and note the difference in absorptive power.

Repeat, using 95 per cent of sand and 5 per cent of dry and finely pulverized manure.

Experiment No. 3

Determination of the Capillary Water of Soils

For this experiment a sample of soil directly from the field is to be used. The sample is to be taken at a depth of from 3 to 9 inches or at any depth desired. One hundred grams of soil are weighed into a tared drying pan, exposed in a thin layer to the room temperature for 24 hours and then reweighed. After an interval of from two to four hours the soil is weighed again, and if the weight is fairly constant, the per cent of water lost by air drying, representing the capillary water of the soil at the time of sampling, is calculated. This experiment may be repeated, using different types of soil, as sand, clay, and loam.

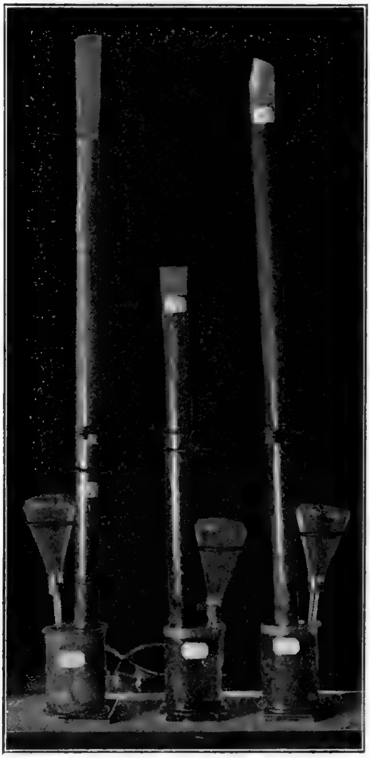


FIG. 54. The Capillary Water of Soils.

Experiment No. 4

Capillary Action of Water upon Soils

Firmly tie a piece of linen cloth over the end of a long glass tube 4 inches in diameter, then fasten a piece of wire gauze over the cloth. Fill the tube with sandy soil (No. 1). Compact the soil after the addition of each measured quantity by allowing the weight from the compaction machine (see Experiment No. 8) to drop twice from the 12-inch mark.

In a similar way, fill a second and a third tube with clay and loam respectively ; immerse the lower ends of the tubes in a cylinder of water and support the tubes, as shown in the illustration. Measure each day for one week the height to which the water rises in the soils. If desired, three more tubes filled loosely with the soils may be added, and the influence of compaction upon the capillary rise of water in the soils noted.

Experiment No. 5

Influence of Manure and Shallow Surface Cultivation upon the Moisture Content and Temperature of Soils

Weigh and fill four boxes, each a foot square and a foot deep, as follows : one with air-dried sand, one with clay, one with loam, and one with sand containing 5 per cent of fine dry manure. Determine the hydroscopic moisture of each sample. Weigh the boxes after adding the soils which should be moderately compacted. To each add the same amount of water slowly from a sprinkling pot, carefully measuring the water used. The soil should be well moistened, but not supersaturated. Each box is to receive shallow surface cultivation, using for the purpose a gardener's small tool. Leave the boxes exposed to the sun or in a moderately warm room. At the end of one or two days take a sample of soil from the center of each box at a depth of 4 to 8 inches and determine the moisture content as directed in Experiment No. 1. Note the differences in moisture content. Weigh the boxes. Take the temperature of the soil in each box.

Experiment No. 6

Weight of Soils

Determine the cubic contents of a box about 4 inches square. Weigh the box. Determine its weight when filled, not compacted, with air-dry sand, with clay, with loam, and with peaty soil. Compute the weight per cubic foot of each soil. Calculate the weight of water held by the box. Determine the apparent specific gravity.

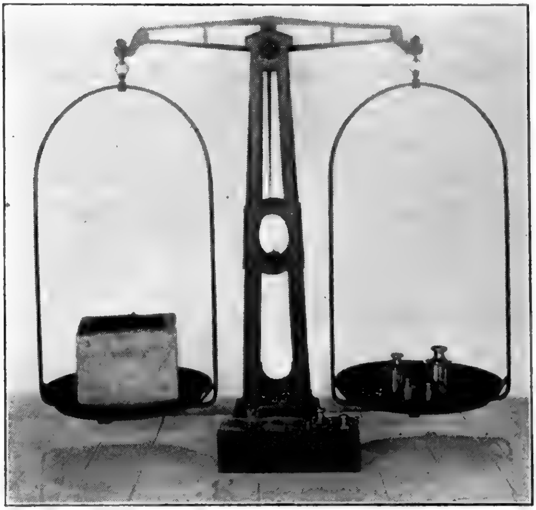


FIG. 55. Determining the Weight per Cubic Foot of Soils.

Experiment No. 7

Influence of Color upon the Temperature of Soils

Expose to the sun's rays, dry clay, dry sand, and moist and dry peat. After two hours' exposure take the temperature of each. The bulb of the thermometer should be just covered with the soil. All of the observations should be made under uniform conditions.

Experiment No. 8

Movement of Air through Soils

Fill, without compacting, a soil tube 12 inches high and 3 inches in diameter with sifted loam soil. Nearly fill the outer cylinder with water, open the stopcock, and allow the inner cylinder to sink in the water, close the stopcock and connect the aspirator to the soil tube with a rubber tube. Adjust the weight, 2, open the stopcock, and note the time required for 5 liters of air to aspirate through the soil. In like manner fill tubes with sand, gravel, peat, and clay, and determine the time required for 5 liters of air to be aspirated through each. In filling the tubes, care should be taken that all are treated alike. Repeat the experiment, using soil from your own farm loosely filling one tube, and moderately compacting another with the compacting machine. Note the difference in time required for the air to pass through the loose and the compacted soil.

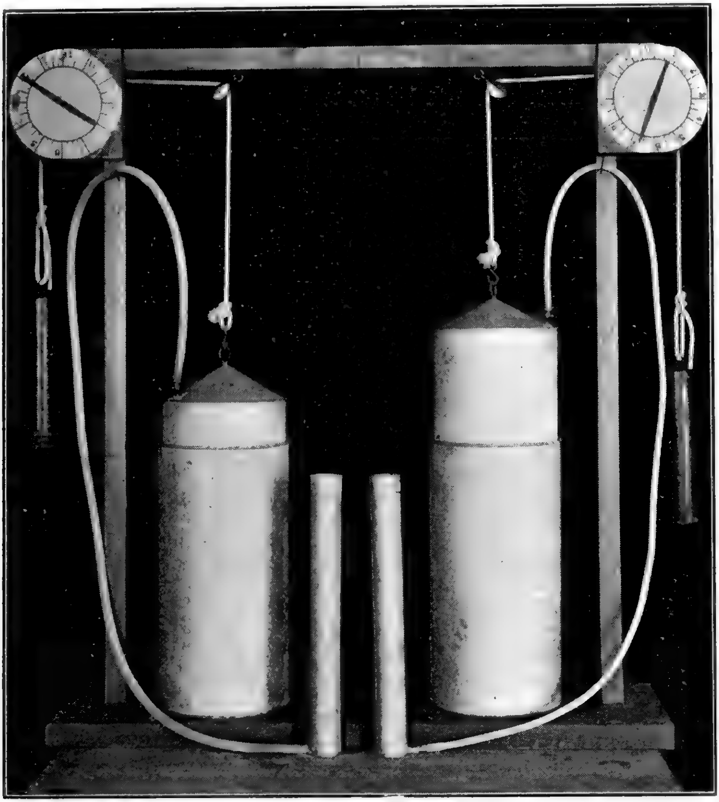


FIG. 56. Aspirator for determining the Rate of Movement of Air through Soils. (Adapted from Bul. 107, U. S. Dept. Agr., Office of Expt. Stations.)

Experiment No. 9

Separation of Sand, Silt, and Clay

For this experiment the student should use some of the soil from his home farm. Ten grams of air-dried and crushed soil which have been passed through a sieve with holes 0.5 mm. in diameter are placed in a mortar and about 20 cc. of water added. The soil is pestled with a rubber-tipped pestle with the object of separating adhering particles without pulverizing the individual soil grains. After two or three minutes' pestling, more water is added and the soil and water are allowed to sediment for about one minute; the turbid liquid is then decanted into a beaker. This process of soft pestling and decantation is repeated two or three times until the remaining soil grains appear free from adhering smaller particles. With some soils this is a tedious process. The contents of the mortar are then transferred to the beaker and enough water added to nearly fill the beaker. The contents of the beaker are thoroughly stirred, and after two or three minutes' sedimentation, the turbid liquid is decanted into a second beaker, leaving the sediment in the first beaker. More water is added to the first beaker, and the stirring, sedimentation, and decantation are repeated until the sediment consists mainly of clean fine sand. After about ten minutes the turbid liquid in the second beaker is decanted into a large cylinder, the sediment in the beaker being washed with more water and the washings added to the cylinder. It is to be noted that the sediment in the second beaker is composed of finer particles than the sediment in the first beaker. The sediment in the first beaker consists mainly of medium and fine sand, and in the second beaker of fine sand and coarse silt. Some

FIG. 57. The Mechanical Analysis of Soils.

sand particles are carried along in the washings into the large cylinder. It is difficult to make even an approximate separation of a soil into sand, silt, and clay particles. In the mechanical analysis of soil, the chemist uses the microscope to determine when the separations are reasonably complete. The sediment in the cylinder consists mainly of silt. The fine particles which remain suspended in the water of the cylinder and cause the roiled appearance are mainly the clay particles. In this experiment note approximately what grades of soil particles predominate in your soil. Save the liquid in the cylinder for the next experiment.

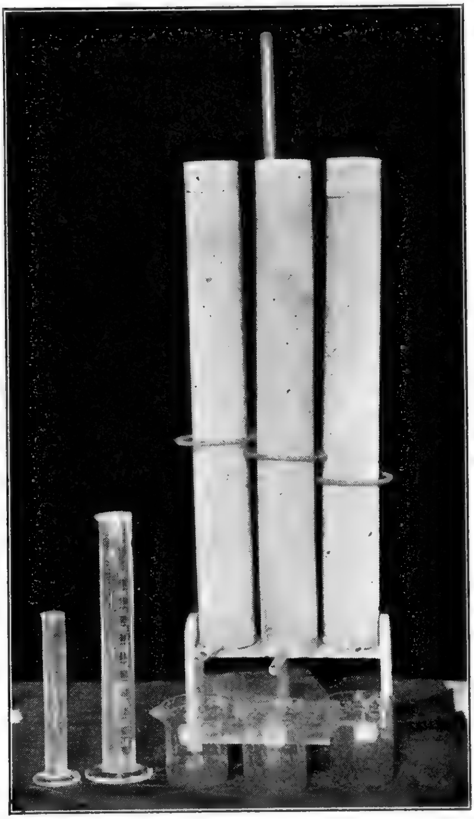


FIG. 58. Movement of Water through Soils.

Experiment No. 10

Sedimentation of Clay

In each of three separate cylinders or beakers place 200 cc. of the turbid liquid saved from Experiment No. 9. To beaker No. 1, add 0.5 gm. calcium hydroxide and stir. To beaker No. 2, add 1 gm. of calcium hydroxide and stir. The third beaker is used for purposes of comparison and no calcium hydroxide is added. After 24 hours examine the three beakers and note the influence of the calcium hydroxide in precipitating the clay and clarifying the liquid.

Experiment No. 11

Deportment of Soils when Wet

Place about 5 gms. of the soil used in Experiment No. 9 in the palm of the hand. Wet and knead. Note whether a plastic mass is formed. If the soil is sticky, it indicates the presence of plastic clay. Rub some of the soil between thumb and finger; if it is composed largely of clay, it will feel smooth and oily. The sand particles impart a sharp gritty feeling; in the presence of clay this is more or less modified. Note whether the lumps of dry soil crush easily. The way a soil responds when crushed, wet, and kneaded, gives some idea of its tillage properties.

Experiment No. 12

Rate of Movement of Water through Soils

Weigh a soil tube and fill it to within two inches of the top with sand. Weigh again. In like manner weigh and fill two other tubes, one with clay and one with loam. Support the tubes from the ring stand as noted in Fig. No. 58. Place a receptacle under the outlet of each tube. Measure into cylinders or large beakers three 500 cc. portions of water. From one of these beakers slowly pour the water into the sand cylinder, and note the length of time required for the water to percolate through the sand, and the amount of water that percolates in a given time. Replenish the water in the beaker with measured amounts as needed. In like manner test the clay and the loam. After the water has ceased dripping from the tubes, weigh and calculate the amount retained by the soils.

Experiment No. 13

Properties of Rocks from which Many Soils are Derived

Study the laboratory samples of rocks and fill out the following table: —

ROCKS	COMPARATIVE HARDNESS	COLOR	GENERAL FORM	SOLUBLE IN HCl
Feldspar	——	——	——	——
Mica	——	——	——	——
Quartz	——	——	——	——
Granite	——	——	——	——
Hornblende . . .	——	——	——	——
Limestone . . .	——	——	——	——

Experiment No. 14

Form and Size of Soil Particles

(Note. Special directions for manipulating the microscope, placing the material on the microscopical object slide, and focusing will be given by the instructor.)

Place on a microscopical object slide a small amount of soil; distribute it in a thin layer, and examine with a low-power microscope. Observe the form and size of the soil particles, distinguish the various grades of sand, silt, and clay, and make drawings of some of the particles.

Experiment No. 15

Pulverized Rock Particles

Examine with a low-power microscope samples of pulverized mica, feldspar, granite, and limestone. Note any similarity to the soil particles examined in Experiment No. 14.

Experiment No. 16

Reaction of Soils

For this experiment use peaty, mildly alkaline, and clay soils. Bring in contact with each soil, after moistening with distilled water, pieces of sensitive red and blue litmus paper. Note any changes in color of the litmus paper and state what the results show. In a similar way test the soil from your own farm.

Experiment No. 17

Absorption of Gases by Soils

Weigh 50 gms. of soil into a wide-mouthed bottle, add 50 cc. of water and 1 cc. of strong ammonia. Note the odor. Cork the bottle, shake, and after 24 hours again note the odor. To what is the fixation of the ammonia due? Is this a physical or a chemical change? Define fixation.

Experiment No. 18

Acid Insoluble Matter of Soils

Weigh 10 gms. of soil into a beaker, add 100 cc. hydrochloric acid (50 cc. strong acid and 50 cc. H_2O); cover the beaker with a watch glass; heat on the sand bath in the hood for two hours, replacing the acid solution in case excessive evaporation takes place. Filter, transfer, and wash the residue, using 50 cc. distilled water. Note the appearance and quantity of insoluble residue. Of what does it consist? What is its value as plant food? How does it resemble the original soil and in what ways does it differ? Save the filtrate for the next experiment.

Experiment No. 19

Acid Soluble Matter of Soils

Divide the filtrate from the preceding experiment into three equal portions. (1) To one portion add ammonia until alkaline. The precipitate formed consists of iron and aluminum hydroxide and phosphoric acid. Note the color and gelatinous appearance of this precipitate. When dried it occupies only a small volume. Filter and remove this precipitate which contains lime, magnesia, potash, and soda. To the filtrate add 20 cc. of ammonium oxalate; warm on the sand bath, and note any precipitate of calcium oxalate that is formed. (2) Evaporate the second portion nearly to dryness. Add 20 cc. distilled H_2O and 3 cc. HNO_3; warm to dissolve any residue. Add 5 to 7 cc. of ammonium molybdate, heat gently, and shake. The yellow precipitate is ammonium phosphomolybdate, which contains the element P in mechanical and chemical combination. (3) Evaporate the third portion in the evaporating dish on the sand bath. Of what does the residue consist and what elements does it contain?

Experiment No. 20

Extraction of Humus from Soils

Place 10 gms. of soil in a bottle (preferably a glass-stoppered one) and add 200 cc. H_2O and 5 cc. HCl. Shake and allow 10 to 24 hours for the acid to dissolve the lime so the humus can be dissolved by the alkali. Filter the acid and wash the soil on the filter with distilled water until the washings are no longer acid to litmus paper. Transfer the soil to the bottle again, add 100 cc. H_2O and 5 cc. KOH solution. Shake, and after two to four hours filter off some of the solution which is dark-colored and contains dissolved humus compounds.

To 10 cc. of the filtered humus solution add HCl until neutral. The precipitate formed is mainly humic acid and soil humates. Evaporate a second portion of 10 to 20 cc. to dryness; the black residue obtained is humus material extracted from the soil.

Experiment No. 21

Nitrogen in Soils

Mix 5 gms. of soil and an equal bulk of soda lime in a mortar; transfer to a strong test tube. Connect the test tube with a delivery tube which leads into another test tube containing distilled water. Heat cautiously for from 5 to 10 minutes, with the Bunsen burner, the test tube containing the soil and soda lime. Test the liquid with litmus paper and note the reaction. Soda lime aided by heat decomposes the organic matter of the soil and forms CO_2, H_2O, and NH_3. The nitrogen in the form of ammonia is distilled and absorbed by the water in the second test tube; the reaction is due to the presence of the ammonia.

Experiment No. 22

Testing for Nitrates

Dissolve about 50 milligrams of sodium or potassium nitrate in 100 cc. H_2O. To 15 cc. of this solution add 2 cc. of a dilute and clear solution of $FeSO_4$, and place the test tube in a cylinder. Through a long-stemmed funnel add 2 or 3 cc. H_2SO_4. Observe the dark brown ring that is formed; H_2SO_4 liberates HNO_3 as a free acid, which in turn changes the iron from the ferrous to the ferric state; the dark brown color is due to the nitric acid forming intermediate compounds during this operation.

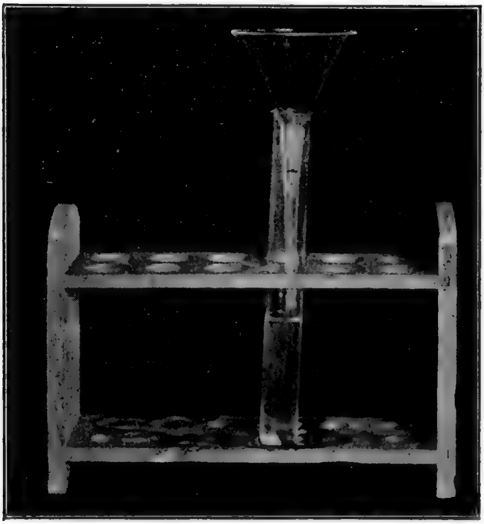


FIG. 59. Testing for Nitrates.

Experiment No. 23

Volatilization of Ammonium Salts

In separate test tubes place about 0.1 gm. each of ammonium carbonate and ammonium sulphate. Apply heat gently to each and observe the result. Observe that the ammonium carbonate readily volatilizes and some is deposited on the walls of the test tube while the ammonium sulphate is much less volatile. In poorly ventilated barns, deposits of ammonium carbonate are frequently found.

Experiment No. 24

Testing for Phosphoric Acid

Dissolve 0.5 gm. bone ash in 15 cc. H_2O and 3 to 5 cc. HNO_3 and filter. To the warm filtrate add 5 to 7 cc. ammonium molybdate and shake. The yellow precipitate formed is ammonium phosphomolybdate. See Experiment No. 19.

In a test tube heat 0.5 gm. of bone ash with 20 cc. distilled H_2O; filter. To the warm filtrate add 5 cc. ammonium molybdate and shake. Note the result as compared with that when HNO_3 was used with the distilled water. What does the result show?

Experiment No. 25

Preparation of Acid Phosphate

Place 100 gms. bone ash in a large lead dish. Add slowly and with constant stirring 100 gms. commercial sulphuric acid, using an iron spatula for the purpose. Transfer the mixture to a wooden box and allow it to act for about three days. Then pulverize and examine. The mixing of the acid and phosphate should be done in a place where there is a good draft. Test ¼ gm. for water soluble phosphates as directed in Experiment No. 24.

Experiment No. 26

Solubility of Organic Nitrogenous Compounds in Pepsin Solution

Prepare a pepsin solution by dissolving 5 gms. of commercial pepsin in a liter of water, adding 1 cc. of strong HCl. Place in separate beakers 0.5 gm. each of dried blood, tankage, and bone ash. Add 200 cc. of pepsin solution to each and place the beakers in a

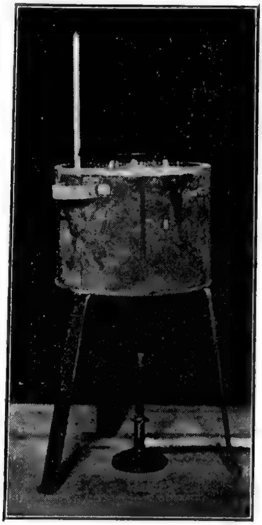


FIG. 60. Determining Digestibility of Organic Nitrogen in Acid Pepsin Solution.

water bath kept at a temperature of about 40° C. Stir occasionally, and at the end of five hours observe and compare the amounts of insoluble matter remaining in the beakers, note also the color and appearance of the solution in each beaker. See Section 170.

Experiment No. 27

Preparation of Fertilizers

Mix in a box 200 gms. acid phosphate (saved from Experiment No. 25), 50 gms. kainit, and 50 gms. sodium nitrate. Calculate the percentage composition of this fertilizer and its trade value.

Experiment No. 28

Testing Ashes

Test samples of leached and unleached ashes in the way described in Section 256.

Experiment No. 29

Extracting Water Soluble Materials from a Commercial Fertilizer

Dry and weigh a 7 cm. filter paper. Fit it in a funnel, and place in it 2 gms. of commercial fertilizer. Pass through the filter, a little at a time, a half liter of pure water at about 40° C. (distilled water preferred). Transfer the filter paper and contents to a watch glass, dry in a water oven, weigh and calculate the per cent of material extracted by the water. If the fertilizer is made of such materials as acid phosphate, kainit, muriate or sulphate of potash, nitrate of soda and sulphate of ammonia, from 60 to 90 per cent will dissolve. Inspect the insoluble residue and note if it is composed of dried blood, bones, or animal refuse material. Of a high-grade complete commercial fertilizer from 40 to 80 per cent or more should dissolve in water.

Experiment No. 30

Influence of Continuous Cultivation and Crop Rotation upon the Properties of Soils

For this experiment a soil that has been under continuous cultivation, and also one of similar character from an adjoining field where the crops have been rotated and farm manures have been applied, should be used. Make the following determinations with each soil: —

Weight per cubic foot.
Capacity to hold water.
Note the color of each.

Experiment No. 31

Summary of Results of Tests with Home Soil

Make a tabulation of your results including:
Hydroscopic moisture as determined in Experiment No. 1.
Volatile matter as determined in Experiment No. 1.
Capacity of the loose soil to absorb water, Experiment No. 2.
Height of rise of capillary water in tube, Experiment No. 4.
Weight per cubic foot, Experiment No. 6.
Prevailing kind of soil particles, Experiment No. 9.
Deportment of soil when wet and kneaded, Experiment No. 11.
Reaction of soil, Experiment No. 16.
Amount of acid soluble matter, Experiment No. 19.
Amount of lime, Experiment No. 19.
Amount of humus extractive material, Experiment No. 20.

Crops most suitable for production upon this soil as indicated by physical and chemical tests.

How does this agree with your experience with the crops raised on the soil?

Probable deficiencies or weak points as indicated by tests or past experience.

What is the most suitable line of farming to follow with this soil in order to conserve its fertility?

Scheme of Soil Classification

(Adapted from Bureau of Soils Report, U. S. Dept. Agr.)

Coarse sand contains more than 20 per cent of coarse sand and more than 50 per cent of fine gravel, coarse sand, and medium sand, less than 10 per cent of very fine sand, less than 15 per cent of silt, less than 10 per cent of clay, and less than 20 per cent of silt and clay.

Medium sand contains less than 10 per cent of fine gravel, more than 50 per cent of coarse, medium, and fine sand, less than 10 per cent of very fine sand, less than 15 per cent of silt, less than 10 per cent of clay, and less than 20 per cent of silt and clay.

Fine sand contains less than 10 per cent of fine gravel and coarse sand, more than 50 per cent of fine and very fine sand, less than 15 per cent of silt, less than 10 per cent of clay, and less than 20 per cent of silt and clay.

Sandy loam contains more than 20 per cent of fine gravel, coarse sand and medium sand, more than 20 per cent and less than 35 per cent of silt, less than 15 per cent of clay, and less than 50 per cent of silt and clay.

Fine sandy loam contains more than 40 per cent of fine and very fine sand and more than 20 per cent and less than 50 per cent of silt and clay, usually 10 to 35 per cent of silt and from 5 to 15 per cent of clay.

Silt loam contains more than 55 per cent of silt and less than 25 per cent of clay.

Loam contains less than 55 per cent of silt and more than 50 per cent of silt and clay, usually from 15 to 25 per cent of clay.

Clay loam contains from 25 to 55 per cent of silt, 25 to 35 per cent of clay, and more than 60 per cent of silt and clay.

Clay contains more than 35 per cent of clay.

Sandy clay contains more than 30 per cent of coarse, medium, and fine sand, less than 25 per cent of silt, more than 20 per cent of clay, and less than 60 per cent of silt and clay.

Silt clay contains more than 55 per cent of silt and from 25 to 35 per cent of clay.

REVIEW QUESTIONS

CHAPTER I

1. From what are soils derived? 2. What are the physical properties of soils? When do soils differ physically, when chemically? 3. Why do soils differ in weight? Arrange clay, sand, loam, and peat in order of weight per cubic foot. 4. When wet, what would be the order? 5. What is the absolute and what the apparent specific gravity of soils? What is pore space? 6. Define the terms: skeleton, fine earth, fine sand, silt, and clay. 7. What are the physical properties of clay? 8. What are the forms of the soil particles? 9. How do different types of soil vary as to the number of particles per gram of soil? 10. How is a mechanical analysis of a soil made? 11. Why do certain crops thrive best on definite types of soil? 12. What factors must be taken into consideration in determining the type to which a soil belongs? 13. Give the mechanical structure of a good potato soil. 14. How does a wheat soil differ in mechanical structure from a truck soil? 15. A good corn soil is also a type for what other crops? 16. How much water is required to produce an average grain crop, and how do the rainfall and the water removed in crops during the growing season compare? 17. In what forms may water be present in soils? 18. What is bottom water and when may it be utilized by crops? 19. What is capillary water? 20. Explain the capillary movement of water. 21. Explain how the capillary and non-capillary spaces in the soil may be influenced by cultivation. 22. What is hydroscopic water and of what value is it to crops? 23. What is percolation? 24. To what extent may losses occur by percolation? 25. What are the factors which influence evaporation? 26. What is transpiration? 27. In what three ways may water be lost from the soil? 28. Why does shallow surface cultivation prevent evaporation?

29. Why is it necessary to cultivate the soil after a rain? 30. Explain the movement of the soil water after a light shower. 31. What influence has rolling the land upon the moisture content of the soil? 32. What is subsoiling and how does it influence the moisture content of soils? 33. What influence does early spring plowing exert upon the soil moisture? 34. What is the action of a mulch upon the soil? 35. Why should different soils be plowed to different depths? 36. What is meant by the permeability of a soil? 37. How may cultivation influence permeability? 38. How may commercial fertilizers influence the water content of soils? 39. Explain the physical action of well-prepared farm manures upon the soil and their influence upon the soil water. 40. What is the object of good drainage? 41. Why does deforesting a region unfavorably influence the agricultural value of a country? 42. What are the sources of heat in soils? 43. To what extent does the color of soils influence the temperature? 44. What is the specific heat of soils? 45. To what extent does drainage influence soil temperature and how does cultivation affect soil temperature? 46. How do manured and unmanured lands compare as to temperature? 47. What relation does heat bear to crop growth? 48. What materials impart color to soils? 49. What is the effect of loss of organic matter upon the color of soils? 50. What materials impart taste to soils? Odor? 51. What effect does a weak current of electricity have upon crop growth? 52. Do all soils possess the same power to absorb gases? Why?

CHAPTER II

53. What is agricultural geology? 54. What agencies have taken part in soil formation? 55. How does the action of heat, cold, air, and gases aid in soil formation? 56. Explain the physical action of water in soil formation. Explain its chemical action. 57. What is glacial action, and how has it been an important factor in soil formation? 58. Explain the action of earthworms and vegetation upon soils. 59. How have micro-organisms aided in soil forma-

tion? 60. Explain the terms: sedentary, transported, alluvial, colluvial, volcanic, and wind-formed soils. 61. What is feldspar and what kind of soil does it produce? 62. Give the general composition of the following rocks and minerals and state the kind of soil which each produces: granite, mica, hornblende, zeolites, kaolin, apatite, and limestone.

CHAPTER III

63. What elements are liable to be the most deficient in soils? 64. Name the acid- and base-forming elements present in soils. 65. What are the elements most essential for crop growth? 66. State some of the different ways in which the elements present in soils combine. 67. Why is it customary to speak of the oxides of the elements and to deal with them rather than with the elements? 68. Do the elements exist in the soil in the form of oxides? 69. What are double silicates? 70. In what forms does carbon occur in soils? 71. Is the soil carbon the source of the plant carbon? 72. What can you say regarding the occurrence and importance of the sulphur compounds? 73. What influence would 0.10 per cent chlorine have upon the soil? 74. In what forms does phosphorus occur in soils? 75. What is the principal form in which nitrogen occurs in soils? 76. What can be said regarding the hydrogen and oxygen of the soil? 77. State the principal forms and the value as plant food of the following elements: aluminum, potassium, calcium, sodium, and iron. 78. For plant-food purposes, what three divisions are made of the soil compounds? 79. Why are the complex silicates of no value as plant food? 80. Give the relative amounts of plant food in the three classes. 81. How is a soil analysis made? 82. What can be said regarding the economic value of a soil analysis? 83. What are some of the important facts to observe in interpreting results of soil analysis? 84. Under what conditions are the results most valuable? 85. Do the terms 'volatile matter' and 'organic matter' mean the same? 86. How may organic acids be employed in soil analysis? 87. Why are dilute organic

acids used? 88. Is the plant food equally distributed in both surface and subsoil? 89. Do different grades of soil particles, from the same soil, have the same composition? 90. What are 'alkali soils'? 91. Why is the alkali sometimes in the form of a crust? What is black alkali? 92. Are all soils with white coating strongly alkaline? 93. Give the treatment for improving an alkali soil. 94. How may a small 'alkali spot' be treated? 95. What are the sources of the organic compounds of soils? What are acid soils? 96. How may the organic compounds of the soil be classified? 97. Explain the term 'humus.' 98. How is the humus of the soil obtained? 99. What is humification? What is a humate? How are humates produced in the soil? 100. Explain how different materials produce humates of different value. 101. Arrange in order of agricultural value the humates produced from the following materials: oat straw, sawdust, meat scraps, sugar, clover. 102. Of what value are the humates as plant food? 103. How much plant food is present in soils in humate forms? 104. What agencies cause a decrease of the humus content of soils? 105. To what extent does humus influence the physical properties of soils? 106. What is humic acid? 107. What soils are most liable to be in need of humus? When are soils not in need of humus? 108. In what ways does the humus of long-cultivated soils differ from that of new soils? 109. How may different methods of farming influence the humus content of soils?

CHAPTER IV

110. What may be said regarding the importance of nitrogen as plant food? 111. What are the functions of nitrogen in plant nutrition? 112. How may the foliage indicate a lack or an excess of this element? 113. In what three ways did Boussingault conduct experiments relating to the assimilation of the free nitrogen of the air? 114. What were his results? 115. What conclusions did Ville reach? 116. Give the results of Lawes and Gilbert's experiments. 117. How did field results compare with laboratory experi-

ments? 118. In what ways were the conditions of field experiments different from those conducted in the laboratory? 119. Give the results of Hellriegel's and Wilfarth's experiments. 120. What is noticeable regarding the composition of clover-root nodules? 121. Of what agricultural value are the results of Hellriegel? 122. What is the source of the soil's nitrogen? 123. How may the organic nitrogen compounds of the soil vary as to complexity? 124. To what extent may the nitrogen in soils vary? 125. To what extent is nitrogen removed in crops? 126. To what extent are nitrates, nitrites, and ammonium compounds found in soils? 127. To what extent is nitrogen returned to the soil in rain water? 128. How may the ratio of nitrogen to carbon vary in soils? Of what agricultural value is this ratio? 129. Under what conditions do soils gain in nitrogen content? 130. What methods of cultivation cause the most rapid decline in the nitrogen content of soils, and how can a nitrogen equilibrium be maintained in the soil? 131. What is nitrification? 132. What are the conditions necessary for nitrification, and what are the food requirements of the nitrifying organism? 133. Why is oxygen necessary for nitrification? 134. How do temperature, moisture, and sunlight influence this process? 135. What part do calcium carbonate and other basic compounds take in nitrification? 136. How is nitrous acid produced? 137. What is denitrification? 138. What other organisms are present in soils besides those which produce nitrates, nitrites, and ammonia? 139. What chemical products do these various organisms produce? 140. Why are soils sometimes inoculated with organisms? When is this necessary and when is it not? 141. Why does summer fallowing of rich land cause a loss of humus and nitrogen? 142. What influence have deep and shallow plowing, and spring and fall plowing, upon the available soil nitrogen? 143. Into what three classes are nitrogenous fertilizers divided? 144. How is dried blood obtained? What is its composition, and how is it used? 145. What is tankage? How is it used, and how does it differ in composition from dried blood? 146. What is flesh meal? 147. What is fish-scrap fertilizer, and what is its comparative value? 148. What seed residues are used as fertilizer? What is their value? 149. What methods are employed to detect the presence of leather, hair, and wool waste in fertilizers? Why are these materials objectionable? 150. How may peat and muck be used as fertilizers? 151. What is sodium nitrate? How is it used, and what is its value as a fertilizer? 152. How does ammonium sulphate compare in fertilizer value with nitrate of soda? What is calcium cyanamid? 153. What is the difference between the nitrogen content and the ammonia content of fertilizers?

CHAPTERS V AND VI

154. What is fixation? What is absorption? Give an illustration. 155. To what is fixation due? 156. What part does humus take in fixation? 157. Why do soils differ in fixative power? Why are nitrates not fixed? Explain the fixation of potash, phosphate, and ammonium compounds. 158. Why is fixation a desirable property of soils? 159. Why is it necessary to study the subject of fixation in the use of manures? Why is the soil solution dependent upon the fixative power of the soil? 160. Why are farm manures variable in composition? 161. What is the distinction between the terms 'stable manure' and 'farmyard manure'? 162. About what per cent of nitrogen, phosphoric acid, and potash is present in ordinary manure? 163. Coarse fodders cause an increase of what element in the manure? 164. What four factors influence the composition and value of manure? 165. What influence do absorbents have upon the composition of manures? 166. What advantages result from the use of peat and muck as absorbents? 167. Compare the value of manure produced from clover with that from timothy hay. 168. How may the value of manure be determined from the nature of the food consumed? 169. To what extent is the fertility of the food returned in the manure? 170. Is much nitrogen added to the body during the process of fattening? 171. Explain the course of the nitrogen of

the food during digestion and the forms in which it is voided in the manure. 172. Compare the solid and liquid excrements as to constancy of composition and amounts produced. 173. What is meant by the manurial value of food ? 174. Name five foods with high manurial value ; also five with low manurial value. 175. What is the usual commercial value of manures compared with commercial fertilizers ? 176. How does the manure from young and from old animals compare as to value ? 177. How much manure does a well-fed cow produce per day ? 178. What are the characteristics of cow manure ? How do horse manure and cow manure differ as to composition, character, and fermentability ? 179. What are the characteristics of sheep manure ? 180. How does hen manure differ from any other manure ? 181. Why should the solid and liquid excrements be mixed to produce balanced manure ? 182. What volatile nitrogen compound may be given off from manure ? 183. What may be said regarding the use of human excrements as manure ? 184. Is there any danger of immediate scarcity of plant food to necessitate the use of human excrements as manure ? 185. To what extent may losses occur when manures are exposed in loose piles and allowed to leach for six months ? 186. What two classes of ferments are present in manure ? How does an application of farm manure affect the bacterial content of soil and what influence does this have upon the plant food of the soil ? 187. Explain the workings of the two classes of ferments found in manures. 188. How much heat may be produced in manure during fermentation ? 189. Is water injurious to manure ? 190. How should manure be composted ? What is gained ? 191. How does properly composted manure compare in composition with fresh manure ? 192. Explain the action of calcium sulphate in the preservation of manure. 193. How does manure produced in barn yards compare in composition and crop-producing value with that produced in covered sheds ? 194. When may manure be taken directly to the field and spread ? 195. How may coarse manures be injurious to crops ? 196. What is gained by manuring pasture land ? 197. Is it economical to make a number of small manure piles in a field ? Give reason. 198. At what rate per acre may manure be used ? 199. To what crops is it not advisable to add stable manure ? 200. How do a crop and the manure produced from that crop compare in manurial value ? 201. Why do manures have such a lasting effect upon soils ? 202. Why does manure from different farms vary so much in value and composition ? 203. In what ways may stable manures be beneficial ?

CHAPTER VII

204. What may be said regarding the importance of phosphorus as plant food ? What function does it take in plant economy ? 205. What is phosphoric acid and how much is removed in ordinary farm crops ? 206. To what extent is phosphoric acid present in soils ? 207. What are the sources of the soil's phosphoric acid ? 208. What are the commercial sources of phosphate fertilizers ? 209. Name the four calcium phosphates and give their relative fertilizer values. 210. Define reverted phosphoric acid. 211. Define available phosphoric acid. 212. In what forms do phosphate deposits occur ? 213. State the general composition of phosphate rock. 214. Explain the process by which acid phosphates are made. Give reactions. 215. How is the commercial value of phosphoric acid determined ? 216. What is basic phosphate slag and what is its value as a fertilizer ? 217. What is guano ? 218. How do raw bone and steamed bone compare as to field value ? As to composition ? 219. What is dissolved bone ? 220. How is bone black obtained, and what is its value as a fertilizer ? 221. How are phosphate fertilizers applied to soils ? In what amounts ? 222. How may the phosphoric acid of the soil be kept in available condition ?

CHAPTER VIII

223. What is the function in plant nutrition of potassium ? 224. What is potash and to what extent is it removed in farm crops ? 225. To what extent is potash present in soils ? 226. What are

the sources of the soil's potash ? 227. What are the various sources of the potash used for fertilizers ? 228. What are the Stassfurt salts, and how are they supposed to have been formed ? 229. What is kainit ? 230. How much potash is there in hard wood ashes ? 231. In what ways do ashes act on soils ? 232. How do unleached ashes differ from leached ashes ? 233. What is meant by the alkalinity of an ash ? 234. Of what value, as fertilizer, are hard- and soft-coal ashes ? 235. What is the fertilizer value of the ashes from tobacco stems ? 236. Cottonseed hulls ? 237. Peat-bog ashes ? 238. Sawmill ashes ? 239. Lime-kiln ashes ? 240. How is the commercial value of potash determined ? 241. How are potash fertilizers used ? 242. Why is it sometimes necessary to use a lime fertilizer in connection with a potash fertilizer ?

CHAPTER IX

243. What can be said regarding the importance of calcium as a plant food ? 244. What is lime, and to what extent is it removed in crops ? 245. To what extent do soils contain lime ? 246. What are the lime fertilizers ? 247. Explain the physical action of lime fertilizers. 248. Explain the action of lime on heavy clays. 249. On sandy soils. 250. In what ways, chemically, do lime fertilizers act ? 251. How may lime aid in liberating potash ? 252. What is marl ? 253. How are lime fertilizers applied ? 254. What is the result when land plaster is used in excess ? 255. Explain the action of salt on soils. 256. When would it be desirable to use salt as a fertilizer ? 257. Is soot of any value as a fertilizer ? Explain its action. 258. Are seaweeds of any value as fertilizer ? What is the fertilizer value of street sweepings ? Of garbage ?

CHAPTER X

259. What is a commercial fertilizer? An amendment? 260. To what does the commercial fertilizer industry owe its origin? 261. Why are commercial fertilizers so variable in composition? 262. Explain how a commercial fertilizer is made. 263. Why are

analysis and inspection of fertilizers necessary? 264. What are the usual forms of nitrogen in commercial fertilizers? 265. Of phosphoric acid and potash? 266. How is the value of a commercial fertilizer determined? 267. What is gained by home mixing of fertilizers? 268. What can be said about the importance of tillage when fertilizers are used? 269. How are commercial fertilizers sometimes injudiciously used? 270. How may field tests be conducted to determine a deficiency in available nitrogen, phosphoric acid, or potash? 271. To determine a deficiency of two elements? 272. How are the preliminary results verified? 273. Why is it essential that field tests with fertilizers be made? 274. Under what conditions does it pay to use commercial fertilizers? 275. What is the result when commercial fertilizers are used in excessive amounts? 276. Under ordinary conditions, what special help do the following crops require: wheat, barley, corn, potatoes, mangels, turnips, clover, and timothy? 277. In what ways do commercial fertilizers and farm manures differ? How do they compare in crop-producing value?

CHAPTER XI

278. Does the amount of fertility removed by crops indicate the nature of the fertilizer required? In what ways are plant-ash analyses valuable? 279. Explain the action of plants in rendering their own food soluble. To what extent does the soil solution supply plant food? 280. Why do crops differ as to their power of procuring food? 281. Why is wheat grown on a clay soil less liable to need potash than nitrogen? 282. What position should wheat occupy in a rotation? 283. In what ways do wheat and barley differ in feeding habits? 284. What can be said regarding the food requirements of oats? 285. Corn removes from the soil twice as much nitrogen as a wheat crop, yet wheat usually thrives after corn. Why? What help is corn most liable to need in the way of food? 286. What is flax wilt? 287. What position should flax occupy in a rotation? 288. On what soils does flax thrive best?

289. What is the essential point to observe in the manuring of potatoes? 290. What kind of manuring is required by sugar beets? 291. Why should the manuring of mangels be different from that of turnips? 292. What may be said regarding the food requirements of buckwheat and rape? 293. What kind of manuring do hops and cotton require? 294. What kind of manuring is most suitable for leguminous crops? For garden crops, for orchards, and lawns?

CHAPTER XII

295. What is the object of rotating crops? 296. Should the whole farm undergo the same rotation system? 297. What is meant by soil exhaustion? 298. What are the important principles to be observed in a rotation? 299. Explain why it is essential that deep- and shallow-rooted crops should alternate? 300. Why is it necessary that humus be considered in a rotation? 301. What is the object of growing crops of dissimilar feeding habits? 302. How may crop residues be used to the best advantage? 303. How is decline of soil nitrogen prevented by a good rotation of crops? 304. In what ways do different crops and their cultivation influence the mechanical condition of the soil? 305. How may the best use be made of the soil water? 306. How may a rotation make an even distribution of farm labor? 307. How are manures used to the best advantage in a rotation? 308. In what other ways are rotations advantageous? 309. What may be said regarding long- and short-course rotations? 310. How is the conservation of fertility best secured? 311. Why does the use made of crops influence fertility? 312. What are the essential points to be observed in the two systems of farming compared in Section 344? 313. Is it essential that all elements removed in crops be returned to the soil in exactly the amounts contained in the crops? Why? 314. How does manure influence the inert matter of the soil? 315. What general systems of farming best conserve fertility? 316. Under what conditions may farms be gaining in reserve fertility? 317. Why in continued

grain culture does the loss of nitrogen from a soil exceed the amount removed in the crop? Will a crop rotation alone maintain the fertility of the soil?

CHAPTER XIII

318. Why do soils need further treatment than plowing for the preparation of the seed bed? 319. Why should different soils receive different methods of treatment in the preparation of the seed bed? 320. How would you determine the best treatment to give a soil for the preparation of the seed bed? 321. How do different methods of plowing influence the condition of the seed bed? 322. Why does complete inversion of sod frequently form a poor seed bed? 323. How should the plowing be done to form a good seed bed? 324. Why is it economy to pulverize the soil as much as possible when it is plowed? 325. What effect does the moisture content of the soil at the time of plowing have upon the condition of the seed bed? 326. What effect does an excess of moisture have upon the plowing and working of clay soils? 327. In what condition should the seed bed be left as to fineness? 328. What is gained by fining and moderately firming the seed bed? 329. Why is aëration of the soil necessary? 330. Why do different soils require different degrees of aëration? 331. Under what conditions can the seed bed be prepared without plowing? 332. On what kinds of soil is such a practice not advisable? 333. When is it advisable to mix the subsoil with the surface soil? 334. When is it not desirable to mix the surface soil and subsoil? 335. How can the plowing and cultivation of the soil best be carried on to destroy weeds? 336. In what way does cultivation influence bacterial action in the soil? 337. What classes of compounds in the soil are subject to bacterial action? 338. How does the action of bacteria affect the supply of available plant food? 339. What is meant by inoculation of soils? 340. In what two ways can this be accomplished? 341. What soils are most improved by inoculation? 342. What soils are least in need of inoculation? 343. What other treatment must often be combined with inoculation? 344. Why do different

crops require different cultivation? 345. How can the best kind of cultivation for a crop be determined? 346. How can soils best be cultivated to prevent washing and gullying? 347. What treatment should such soils receive to be permanently improved? 348. What relationship exists between bacterial diseases of soils and of crops? 349. What treatment should soils receive to prevent bacterial diseases? 350. How can the spreading of bacterial diseases through infected seed be prevented? 351. Why must the sanitary condition of a soil be considered? 352. What are the effects of some forms of fungi upon soils? 353. In what way does thick or thin seeding affect plant growth? 354. What effect does abnormal crowding of plants have upon growth? 355. How would you determine the amount of seed for crop production? 356. How would you determine the most suitable crop for any soil? 357. What should be the aim in selecting crops for soils? 358. Why should the crop selected vary with different types of soil? 359. What is the inherent fertility of soils? 360. What is the cumulative fertility of soils? 361. How can the total fertility of soils be best increased? 362. Describe soils of the highest fertility. 363. Why must the amount of plant food as well as the physical condition of the soil be considered in the improvement of soils? 364. What relation does the fertility of the soil bear to any agricultural system?

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