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ISTRY OF
ACTICE

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KEITT

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FIRST EDITION
FIRST THOUSAND

NEW YORK
JOHN WILEY & SONS, Inc.
London: CHAPMAN & HALL, Limited
1917

PRESS OF
BRAUNWORTH & CO.
BOOK MANUFACTURERS
BROOKLYN, N. Y.

4/25

PREFACE

LIFE, food, and raiment are directly or indirectly dependent upon agricultural products. In the settlement of our country, land was abundant and people were few, consequently little thought was given to the needs of the increasing numbers of succeeding generations. As the land first cultivated lost its fertility, the tide of population turned westward where unlimited areas of virgin soil awaited the herds and plowshares of the settlers. But this fresh area has been occupied, and to maintain the fertility of those fields that are still productive and to restore those that have become exhausted is the problem now facing agriculture.

The maintenance of the fertility of a productive soil demands the intelligent application of the principles of agricultural chemistry. The restoration of wornout fields is a difficult and costly undertaking. The successful farmer must reinforce his art by the application of the fundamental information derived from the study of chemistry, geology, botany, bacteriology, and entomology.

Chemistry aids agriculture in many ways. By means of it, exact data are collected and the fundamental reasons for practical results are explained. Then, too, chemistry invents new or improves old methods of fertilization. The chemist analyzes soils, manures and vegetable products. The value of soil analysis to the practical farmer, perhaps formerly overrated, in more recent years has been underrated. From a soil analysis the farmer can at least learn if his soil is unusually deficient in any important element. Chemistry also protects the agriculturist from the impositions of the unscrupulous fertilizer manufacturer.

The thorough analysis of farm products enables the farmer to know their composition, and how much of each element they contain. This analysis serves a two-fold purpose: First, the composition of a plant shows what elements, and what quantity of each, have been removed from the soil. This, in turn, determines what the soil must contain to grow plants in a healthy condition. Second, in feeding vegetable products to livestock, the composition of these vegetables must be known in order that the rations may be compounded correctly.

Furthermore, chemistry explains how plants grow and are nourished. It shows the kind and the quantity of foods which plants require at various stages of their growth, and this guides the farmer in properly handling his crops. It teaches what purposes the different elements in the food supplied serve in animal economy and how the best results in animal feeding may be obtained with the least outlay of time, labor, and expense.

The purpose of this text is to furnish the knowledge of the fundamentals of chemistry required for intelligent agriculture and to apply this knowledge to the art of agriculture and to the problems of the agriculturist. No attempt has been made to limit its scope to the study of soils, fertilizers, and manures, although these subjects are given careful consideration. In addition, such subjects as feeds, nutrition, sanitary water, boiler water, and insecticides, subjects in which not only the farmer, but the suburban resident is interested—are discussed in as non-technical language as possible.

The student of this book is urgently requested to make a careful study of the first chapters; for in them has been given in as concise and elementary form as is practicable the chemistry applied in the chapters which follow. Each succeeding chapter requires a knowledge of the preceding chapter, consequently they should be studied in sequence.

The author wishes to express here his indebtedness to Professor Charles M. Allen, Pratt Institute, for careful revision of the chapters on General Chemistry and the critical reading of the whole text, and to Dr. C. A. Peters, Amherst Agricultural College, for many helpful suggestions and criticisms. Acknowledgment is made to Mr. J. Ross Hanahan of Planters' Fertilizer Company for Figs. 37, 38 and 39, to Mr. John S. Carroll of the German Kali Company for Figs. 40, 41 and 42 and 52–60, and to Dr. Wm. S. Myers of the Chilean Nitrate Propaganda for Figs. 45–51. The following members of the faculty of Clemson College furnished photographs: Director J. N. Harper, Dr. F. H. H. Calhoun, Prof. W. A. Thomas, and Mr. F. G. Tarbox. Mr. T. C. Hough furnished valuable aid by making drawings. Director Thorne of the Ohio Experiment Station and Director Hartwell of the Rhode Island Experiment Station very kindly gave permission for the reproduction of cuts used to illustrate bulletins of their respective stations. Cuts from Farmers' Bulletins of the United States Department of Agriculture were reproduced as well as cuts from bulletins of the South Carolina Experiment Station.

Standard books that bear on the subject have been freely consulted. Grateful acknowledgment is also due my father, Thomas W. Keitt, for valuable assistance in reading proof.

T. E. KEITT.

CLEMSON COLLEGE, 1916.

EDITOR'S NOTE

THIS little text has been prepared in the belief that boys attending high schools in farming communities and those taking short courses in agricultural colleges should receive instruction in the chemistry applying to farm practice. For such students, there is neither time nor opportunity for the usual formal course in General Chemistry, followed by technical Agricultural Chemistry. A single elementary course combining the two is possible, in which the information furnished is definite, practical and reasonably adequate.

In such a combined course, the essential principles of Chemistry naturally come first, to be followed by their applications to the problems which arise in the life on a farm, in the growing of farm crops, or in the feeding and care of farm animals. This order has been followed by the author in the present text. It is believed that teachers in high schools attended by boys living on farms and in agricultural colleges giving short courses will find in *The Chemistry of Farm Practice* the text-book best suited to their needs. It should prove especially valuable, also, as a reference book for those interested in farming.

THE EDITOR.

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THE CHEMISTRY OF FARM PRACTICE

CHAPTER I

ELEMENTS—ATOMIC WEIGHTS—MOLECULES—SYMBOLS—MOLECULAR WEIGHTS—OXIDATION—REDUCTION

1. Chemistry. Chemistry deals with the composition and properties of substances and the changes which substances undergo. Agricultural chemistry has to do with the application of the knowledge gained through chemistry to the art of agriculture and to the problems which the farmer has to solve. To understand agricultural chemistry we must gain first a knowledge of some of the underlying principles of General Chemistry.

2. Elements. Matter is made up either of simple elements or of these elements combined into compounds of unvarying composition. An element is a simple substance which has certain definite properties and which has not been separated into substances having different properties. Iron is an element. However minutely the piece of iron may be divided, the smallest particle will always have properties identical with the iron before its division.

Somewhat more than eighty elements have been isolated which have resisted all the attempts of present chemical methods at further separation. Each element has certain distinctive properties that prevent it being classed with other elements, although certain elements which are closely related have some of their properties in common.

Only ten elements are necessary to sustain the life of the growing plant; these are *carbon, hydrogen, oxygen, nitrogen, phosphorus, sulphur, potassium, magnesium, calcium* and *iron.* Some of these elements are derived from the atmosphere, some from water and some from the soil. Most of the substances of plants consist of the elements, carbon, hydrogen, and oxygen, which are obtained from the atmosphere, or from water. Nitrogen is the most expensive and the most elusive of the elements required by plants. A part of the nitrogen may be derived from the atmosphere by certain plants under conditions we shall study later, but most of the nitrogen which serves as

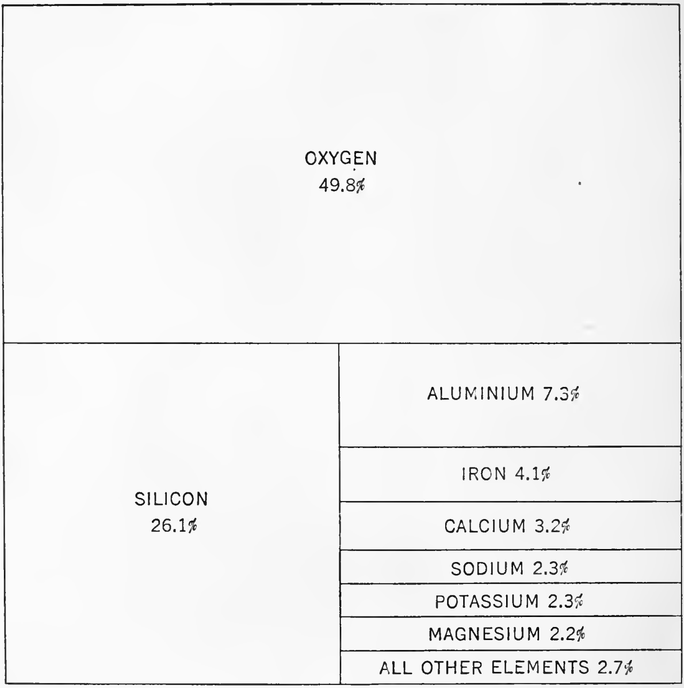


Fig. 1.—Percentage of elements in the combined mass of atmosphere, waters and crust of the earth.

plant food comes from the decomposition of organic substances in the soil. The other six elements necessary for plant growth are required in comparatively small amounts. With the exception of phosphorus, soils usually contain an abundant supply of these "ash elements."

In the diagram, Fig. 1, is shown the relative proportion of eight of the most abundant of the elements as found in the atmosphere, all waters, and the solid parts of the earth's crust which have been examined. It will be noticed that the seventy-five elements not mentioned, altogether, comprise but 2.7 per cent of the earth's constituents. With the exception of a comparatively small quantity of oxygen existing in a free condition in the air, this figure represents the percentage of the elements as they exist in compounds.

3. Composition of Matter. Matter may be divided and subdivided till definite parts called *molecules* are reached. Finally the molecule, by chemical means, may be separated into invisible particles called *atoms*. The atom may be defined as the extremely minute particle of matter that enters as a unit into chemical combinations with other atoms. A molecule is the smallest part of matter that can exist by itself. An atom does not remain free or uncombined; it unites either with other atoms of the same kind to form a molecule of an element or it combines with atoms of a different kind and thus produces a compound.

4. Atomic Weights. Atoms combine chemically according to definite proportion by weight. The smallest amount of hydrogen that will enter into chemical reaction, i.e., the hydrogen atom, is less by weight than the atom of any other element. For this reason hydrogen may be taken as a convenient unit of comparison and its smallest combining weight, which is the weight of its atom, may be assumed to be one. The gases hydrogen and chlorine, when mixed and exposed to light, will form a new substance, *hydrogen chloride*, which in its water solution is called *hydrochloric acid*. When one part by weight of hydrogen is allowed to unite with an excess of chlorine, it is found that it will, in every case, combine with 35.46 times its own weight of the chlorine. Hydrogen chloride therefore contains hydrogen and chlorine in the proportion of 1 to 35.46. There are reasons for believing that the molecule of hydrogen chloride consists of one atom of hydrogen combined with one atom of chlorine. If this is true, then, taking the hydrogen atom as a unit of weight, the chlorine atom weighs 35.46 and the molecule of hydrogen chloride, HCl, weighs 36.46. It has been found that the elements which compose a compound always combine in proportion to their atomic weights or to some multiple of their atomic weights. It will be seen that this must be the case if an atom is indivisible.

The atomic weight of an element is fixed by determining with great care the weight of the element that will unite with another element whose atomic weight has previously been determined. As nearly all the elements form compounds with oxygen, while comparatively few unite with hydrogen, the atom of oxygen with an assigned weight of 16 is really used as the standard instead of the atom of hydrogen, which it will be observed in the table on page 6, weighs 1.008.

5. Molecules of Elements. The common elementary gases, such as oxygen, hydrogen, nitrogen, and chlorine, have molecules consisting of two atoms of each element. The molecules of some of the elements, such as phosphorus, arsenic, and antimony, have four atoms in each molecule, when they are at a temperature slightly above vaporization. In most cases the number of atoms in a molecule of an element depends upon its temperature. Thus sulphur vapor at 468° C. has eight atoms to the molecule; at 860° C. its molecule has but two atoms.

Some elements, such as sodium, potassium, mercury, and zinc, when in a vaporous state, have but one atom to each molecule. Such molecules differ from atoms in that they seem to have lost the chemical affinities which are characteristic of atoms. The number of atoms in a molecule of an element when it is in the solid condition is not known.

6. Symbols. For the sake of convenience, each element is represented by one or more letters. This abbreviation of the name of an element is called its *symbol*. The letter used to represent an element is often the first letter of its name. It is written as a capital, but unlike other abbreviations, it is not followed by a period. The symbol of oxygen is O, of hydrogen is H, of nitrogen is N, and P is the symbol of phosphorus. When the name of more than one element begins with the same letter, the most important or the first discovered of these elements has the single letter for a symbol and to the others an additional letter is assigned. Thus C is the symbol for carbon, Ca the symbol for calcium, Cl the symbol for chlorine, Cr for chromium. It will be noted that the second letter is not written as a capital. Sometimes the symbol is derived from the foreign word which means the element, as Fe from the Latin *ferrum*, meaning iron, K from *Kalium*, the German word meaning potash, which contains potassium, Hg from the Greek, *hydrargyrum*, meaning " water silver," a good description of mercury. Many symbols are taken from the names of countries, as Cu, copper, from the island of Cyprus, Mg, magnesium, from Magnesia in Asia Minor. The symbol of an element represents not only the name of the element, but it means also one atom of the element and consequently is a definite weight. S stands not only for sulphur, but for one atom of sulphur, which weighs 32, or two times the weight of an atom of the standard, oxygen.

7. Molecular Weights. One method for determining molecular weights depends upon an hypothesis proposed by Avogadro, which has been quite universally accepted. This hypothesis states that " under the same conditions

TABLE I.—THE COMMON ELEMENTS

Elements.	Symbols.	Atomic Weights	Usual Valence.
Aluminium	Al	27.1	3
Antimony	Sb	120.2	3 or 5
Arsenic	As	74.96	3 or 5
Barium	Ba	137.37	2
Bismuth	Bi	208.0	3
Boron	B	11.0	3
Bromine	Br	79.92	1
Calcium	Ca	40.07	2
Carbon	C	12.0	4
Chlorine	Cl	35.46	1
Chromium	Cr	52.0	3
Cobalt	Co	58.97	2
Copper	Cu	63.57	2
Fluorine	F	19.0	1
Gold	Au	197.2	3
Hydrogen	H	1.008	1
Iodine	I	126.92	1
Iron	Fe	55.84	2 or 3
Lead	Pb	207.1	2
Lithium	Li	6.94	1
Magnesium	Mg	24.32	2
Manganese	Mn	54.93	2, 4 or 6
Mercury	Hg	200.6	1 or 2
Nickel	Ni	58.68	2 or 3
Nitrogen	N	14.01	3 or 5
Oxygen	O	16.0	2
Phosphorus	P	31.04	3 or 5
Platinum	Pt	195.2	2 or 4
Potassium	K	39.1	1
Radium	Ra	226.4	2
Silicon	Si	28.3	4
Silver	Ag	107.88	1
Sodium	Na	23.0	1
Sulphur	S	32.07	2
Tin	Sn	119.0	2 or 4
Zinc	Zn	65.37	2

of temperature and pressure, all gases have the same number of molecules in equal volumes." While it is quite impossible to isolate and weigh a single molecule, yet if we select as a standard of molecular weight a molecule of oxygen, consisting of two atoms, and assign to it a weight of 32, we may, by assuming the Avogadro hypothesis, obtain the weight of the molecule of any gas. This is done in the case of ammonia by weighing equal volumes of ammonia and of oxygen under the same conditions of temperature and of pressure, and solving for the molecular weight of ammonia in the proportion:

Weight of volume of oxygen : weight of same volume of ammonia = 32 : molecular weight of ammonia.

In this manner we may determine accurately the weight of the molecule of any element or of any compound which may be weighed in a gaseous condition.

8. Oxidation and Reduction. An understanding of the principles of chemistry involved in the processes of oxidation and of reduction is important. It is impossible to obtain a working knowledge of chemistry without gaining a mastery of these processes. A simple case of oxidation takes place when a bright strip of iron is heated over a flame. The oxygen of the air, more active at the high temperature, combines with the metallic iron, rusting it into a black *oxide of iron.* If a silver spoon is exposed to the fumes of sulphur, the silver combines with the sulphur and black *silver sulphide* is formed on the surface of the metal. This is also a case of oxidation, although here there is no oxygen involved.

Oxidation may be defined as the combination of oxygen, or of other elements that act chemically in the same way as oxygen, with other material. Sometimes oxidation takes place in two or more stages. Thus metallic mercury will be oxidized by combining with one atom of chlorine, forming white *mercurous chloride* or calomel, which, in turn, may be further oxidized by adding to itself another atom of chlorine, forming *mercuric chloride* or **corrosive sublimate.**

9. Combustion. Oxidation produces heat as a result of the chemical action taking place. Should oxidation be sufficiently rapid to produce enough heat so that light is evolved, the process is termed *combustion.* When the materials entering into combustion are gases, a *flame* is produced. Burning wood is undergoing combustion, this process of oxidation being supported by the oxygen drawn from the atmosphere entering into rapid union with the hydro-carbon gases produced from the heated wood. The three conditions necessary for combustion are first, a combustible substance; second, a supporter of combustion; third, a kindling temperature. Usually carbon or hydrogen or some of their numerous compounds or the metals that are easily oxidized are regarded as the **combustibles,** while oxygen or some of the elements that act chemically like oxygen are considered the **supporters of combustion.** The material entering into chemical reaction which is the more abundant is likely to be considered the supporter of combustion, and thus the combustible and the supporter of combustion may exchange places.

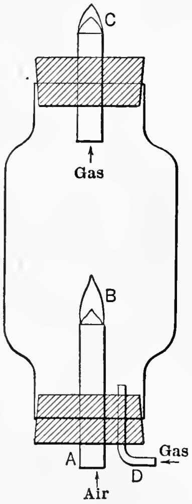


Fig. 2.—Apparatus for showing reversal of flames.

This is seen in the reversal of flames effected by the apparatus in Fig. 2. The lamp chimney is fitted with corks and tubes as in the figure. The straight glass tubes at *A* and *C* are at least $\frac{5}{16}$ of an inch in internal diameter. The glass elbow *D* is connected with the illuminating gas supply. While the finger is placed at *C*, closing the tube, the gas is turned on and allowed to flow till the chimney is surely full of gas, which is escaping at *A*. The gas at *A* is now ignited and the gas cock turned down till a small inverted flame is produced at *A*. The finger is now removed from *C* and the flame at *A* will be seen to ascend the tube and to burn at *B*. The gas issuing at *C* is immediately ignited. If we consider these two flames, we shall see that the one at *C* is composed of illuminating gas burning in an atmosphere of air, and naturally the oxygen of the air would be considered the supporter of combustion, while the gas would be considered the combustible. The flame at *B* is composed of air coming up the tube from *A* which is burning in an atmosphere of illuminating gas, and in this case we should naturally consider the illuminating gas as the supporter of the combustion while the oxygen of the air is the combustible.

10. Kindling Temperature. While oxidation may take place at any temperature, in order to start and to continue combustion, it is necessary for the combustible and the supporter of combustion to be at a certain temperature, known as the *kindling temperature*. Each substance, under the same conditions, has its own definite kindling temperature. Phosphorus has a very low kindling temperature, taking fire spontaneously in the air. This is due to the fact that oxidation raises the temperature of the phosphorus to its kindling point. If a bit of phosphorus as large as a wheat grain is dissolved in a small amount of carbon disulphide and the solution poured upon a filter paper placed in an iron ring, as soon as the carbon disulphide evaporates, the phosphorus will burst into flame. In this case the finely divided condition of the phosphorus exposes a relatively large surface to oxidation. When a candle flame is extinguished by blowing upon it, the blast of air cools the flame below its kindling point.

The *quantity of heat* produced by combustion will depend upon the quantity and the character of the gases entering into reaction, while the *degree of heat* will depend upon the nature of the combining substances and upon how intimately the combustible and supporting gases may be mixed at the point of ignition. Hence a blast is used to provide a large quantity of oxygen which is introduced into the interior of the combustible gas, which is then forced to combine internally with the air of the blast and externally with the oxygen of the atmosphere. The hole near the base of the Bunsen burner, Fig. 3, is required to supply air for combustion. The blacksmith's forge, Fig. 4, must be equipped with a "blower" to furnish enough air for the complete combustion of the large amount of gas.

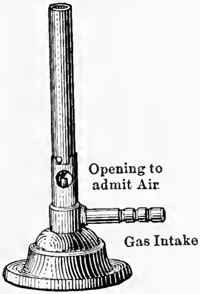


FIG. 3.—Bunsen burner.

In many cases the oxidation is a slow process. This may be seen in the rusting of iron, the tarnishing of copper, the dulling of zinc. When ink that is pale when first applied becomes dark upon exposure, the ink has undergone oxidation. When paper turns yellow with age, it is being slowly oxidized. Almost everything we see about us has been oxidized. Besides the noble metals, such as gold and platinum, it is only those substances that have been artificially deprived of their oxidizing constituent that exist in any other than an oxidized condition.

The rapidity with which oxidation takes place does not affect the total quantity of heat produced. An iron wire may be burned in a jar of oxygen and the combustion may last but a few seconds, or the wire may be rusted by exposure to moist air, and the oxidation may take a month to complete itself, but when the two actions are complete, if the same iron oxide is finally produced and in the same quantity, the total amount of heat will be identical in the two cases. Although combustion cannot take place without light, yet light may be produced by other means than combustion, as in the case of the carbon filament of an electric light bulb.

11. Spontaneous Combustion. If the heat produced in slow oxidation is not allowed to be dissipated, the temperature of the combustible which is being oxidized may gradually be raised till it attains its kindling temperature and it will then burst into flame. This is quite likely to happen in the case of vegetable or animal oils with which cloths may have been saturated. These oils are "drying oils," that is, they are easily oxidized as shown by the necks and stoppers of their containers, which are gummed upon standing. This combustion is produced spontaneously, that is, by the internal development of heat without

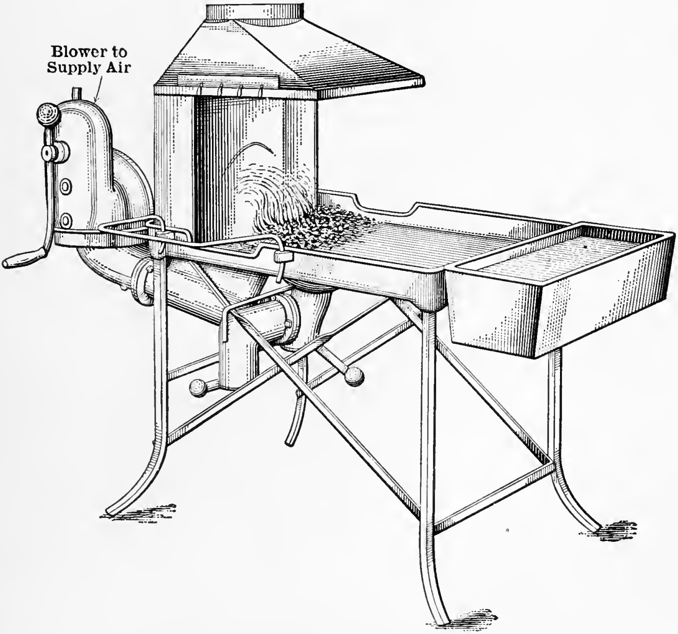


Fig. 4.—A down-draft forge.

the action of an external agent other than the oxidizer. Heaps of finely divided coal may in the same way be set on fire by the spontaneous combustion occasioned by the oxidation of their sulphur or oil content.

12. Reduction. This process is the reverse of oxidation. It is the subtraction from a compound of oxygen or of the element which plays the role of oxygen. The extraction of the common metals from their ores is a process of reduction. This process is brought about by subjecting the material to be reduced to certain reducing agents which have a stronger affinity for the oxygen part of the compound than does the metal originally combined with that part. The most useful of these reducing agents are carbon, in the form of charcoal or coal, hydrogen and the hydro-carbon compounds and certain active metals, such as sodium or aluminium. Carbon monoxide gas, which needs more oxygen so as to make itself into carbon dioxide, a more stable compound, is a very valuable reducing agent. In the highly heated areas of the blast furnace in the process of iron reduction, the carbon monoxide takes away the oxygen of the iron ore and leaves metallic iron.

CHAPTER II

COMPOUNDS—MIXTURES—VALENCE—FORMULAS—EQUATIONS

13. Conservation of Matter. Chemical changes neither create nor destroy matter. By chemical means matter may be converted into new forms having different properties, *but the total weight of the substances before chemical action will equal the total weight of the substances after the action has been completed.* Sulphur, when burning, combines with the oxygen of the air, and when the sulphur is entirely consumed, the weight of the choking fumes of sulphur dioxide produced will exactly equal the sum of the weights of the sulphur burned and the oxygen with which it combined.

FIG. 5.—The black solid, carbon, combined with the yellow solid, sulphur, forms the colorless liquid carbon disulphide.

14. Compounds. Two or more elements when chemically combined form *compounds.* A chemical compound is composed always of the same elements combined in the same proportion by weight. A compound possesses properties which differ from those of the elements of which it is composed. Chemists have recognized many thousands of compounds, each of which has a characteristic set of properties which is constant and differs from that of other compounds.

The element carbon, a black solid, will combine chemically under certain circumstances with the yellow solid, sulphur, and form a compound, carbon disulphide, which is a transparent liquid with a characteristic odor, and very volatile at ordinary temperatures. The formation of compounds is due to the chemical attraction existing between the atoms of the elements which causes them to combine to form the molecules of the compound.

15. Mixtures. Two or more substances may be ever so intimately blended together, but, if no chemical combination takes place, there is no compound produced. Such a mingling is termed a *mixture.* A mixture differs from a compound in two ways: First, it possesses the characteristic properties of all of its ingredients; second, the proportion of its constituents may vary each time the mixture is made. In this respect a mixture differs from a compound in which the percentage content of its constituents does not vary.

16. Valence. When hydrogen gas is mixed with chlorine gas and exposed to diffused light, it is found that hydrogen chloride, a compound whose molecules consist of one atom of each element, is produced. While the reason for the affinity between atoms of hydrogen and of chlorine is not known, yet there is some kind of attraction, possibly electrical, which draws and binds these atoms together. We may imagine that each hydrogen atom has a string attached to it by means of which it unites itself to other atoms. The hydrogen atom seems to have but one of these strings which may be called *bonds* or valences, and it is therefore called a monad, or *univalent* element. The chlorine atom usually acts as a monad and we may picture that, when hydrogen chloride is produced, the bond of a chlorine atom ties itself to the bond of a hydrogen atom, thereby making a stable molecule. One atom of chlorine will combine with one atom of potassium to form a molecule of potassium chloride. The potassium atom is therefore univalent.

The atoms of some elements have the capacity to hold in combination two atoms of a univalent element. We may think of such elements as having two bonds attached to each atom; two atoms of hydrogen are required to unite to one atom of oxygen so as to form water, therefore, the valence of oxygen is two. Oxygen is called a diad or *bivalent* element. A number of important elements are bivalent, such as calcium, magnesium, and zinc. One atom of nitrogen unites with three atoms of hydrogen to form ammonia. Therefore nitrogen in this case is a triad or *trivalent* element. Other elements usually trivalent are phosphorus and aluminium. Carbon as indicated by the four atoms of hydrogen, which unite with one atom of carbon to form marsh gas, is *tetravalent.*

Sometimes an element may develop one valence under one set of conditions and a different valence under other conditions. Hydrogen never changes valence, oxygen practically never, and the same is true of some of the metallic elements, such as calcium, sodium, and potassium. When oxygen combines with an element it is liable to develop in that element an increase in its valence. For example, when sulphur unites with hydrogen to produce the ill-smelling gas, hydrogen sulphide, the valence of the sulphur atom is two, as indicated by the two atoms of hydrogen which it requires. When sulphur is burned in air, most of the resulting compound is sulphur dioxide, the two oxygen atoms of the compound indicating that sulphur has four bonds; in this action a small amount of sulphur trioxide is produced and this compound with its three oxygen atoms shows that the sulphur atom develops six bonds. In the table of elements given on page 6 the usual valence of each element is given. The theory of valence is used with advantage in fixing in the mind the formulas of compounds.

17. Formulas. The attraction existing between atoms binds them into molecules. These may be represented by formulas which are made up of a combination of symbols. The formula HCl denotes one atom of hydrogen chemically combined with one atom of chlorine. It also indicates a weight of hydrogen chloride equal to the combined weight of its atoms. This is the molecular weight and is equal to $1+35.46$ or 36.46. Two molecules of hydrogen chloride are expressed $2HCl$. The molecule of water is expressed by the formula H_2O, indicating two atoms of hydrogen united with one atom of oxygen. A molecule of sulphuric acid is H_2SO_4. This indicates that it is composed of two atoms of hydrogen, one of sulphur, and four of oxygen. Three molecules of sulphuric acid would be expressed by the term $3H_2SO_4$. In this latter formula there are in all six atoms of hydrogen, three of sulphur, and twelve of oxygen. The formula $2Ca_3(PO_4)_2$ means two molecules of calcium phosphate. The two molecules contain six atoms of calcium, four atoms of phosphorus, and sixteen atoms of oxygen. It will be seen that each of the coefficients 3 and 2 in these two examples multiplies each of the symbols following it, taken as many times as is indicated by the subscript following each symbol. Each of the symbols within the parenthesis is in turn multiplied by the subscript following the parenthesis.

18. Hydrates. Many salts are loosely combined with water to form *hydrates;* thus, when copper sulphate is dissolved in water and the water is slowly evaporated there will form blue crystals which contain five hydrating molecules, and this formula of the resulting blue vitriol is written

$CuSO_4 \cdot 5H_2O$. Likewise, the formula of gypsum, or hydrated calcium sulphate, may be written $CaSO_4 \cdot 2H_2O$. When this is heated, it loses three-fourths of its water, and the resulting plaster of Paris has the formula $(CaSO_4)_2 \cdot H_2O$.

The number of bonds which each component part of a compound possesses determines its formula. Thus, in sodium chloride, sodium and chlorine each have one bond, and therefore the formula is $NaCl$. In sodium sulphide, the sulphur atom has two bonds, and therefore requires two sodium atoms, each with its one bond, to satisfy it; consequently the formula is Na_2S. In arsenious oxide, it requires two arsenic atoms, each with three bonds or six together, and three oxygen atoms, each with two bonds, to make the formula, As_2O_3, in which the total bonds of the arsenic atoms shall equal the total bonds of the oxygen atoms. In some conditions, arsenic develops five bonds, and consequently the formula of arsenic oxide is As_2O_5.

19. Criss-cross Rule. In compounds which are composed of two units, the formula may be determined by taking as many atoms or parts of one component as there are bonds of the other component. This is more apparent, if, first, the bonds of each part are indicated. Thus, in determining the formula of aluminium oxide, write the symbols and indicate the bonds of each, $Al'''O''$, then, applying the "criss-cross" rule, the formula becomes Al_2O_3. In the formula for copper sulphide the bonds would be $Cu''S''$, and the formula, Cu_2S_2; but it is customary to reduce such formulas to their lowest terms, which in this case will be CuS.

In formulas having more than two components, very frequently two or more of the elements group themselves together and act as a unit. Such groups do not generally separate when they take part in a chemical reaction. They are termed **radicals.** Thus, in the formula of phosphoric acid, H_3PO_4, the PO_4 acts as a radical, and in the formula for ammonium carbonate $(NH_4)_2CO_3$, the NH_4 and the CO_3 are each radicals. Radicals may be considered as having free bonds, the same as elements. In H_3PO_4 the PO_4 has three bonds. This is indicated by the fact that it requires three monovalent hydrogen atoms to saturate it.

In acids the portion after subtracting the acid hydrogen is a radical, and its bonds are indicated by the number of acid hydrogens subtracted. In salts the portion transferred from the acid from which it was derived is a radical with the same number of bonds as in the acid. In bases, the hydroxyl, OH, is a radical, each hydroxyl having one free bond.

By following these directions, the formulas of the common compounds may be written, provided the bonds of the elements and the formulas of the acids are in mind. On the other hand, the bonds of elements and radicals may be inferred if the formulas of compounds are known.

The formula of the salt, calcium silicate, may be derived as follows: This silicate salt is related to silicic acid. Silicic acid has the formula H_4SiO_4. Its acid radical is SiO_4, which has four bonds, as shown by the four hydrogen atoms. Calcium is a bivalent radical. This could be inferred if a formula of any common substance containing calcium is known, e.g., $CaCl_2$ or $Ca(OH)_2$. Chlorine, we know, has one bond, and applying the criss-cross rule, we have $Ca''Cl_2'$, therefore, calcium is bivalent. Now, writing for calcium silicate, $CaSiO_4$, and inserting the marks for the bonds, $Ca''(SiO_4)''''$, and applying the criss-cross rule, $Ca_4(SiO_4)_2$, and reducing to its lowest terms, we have the correct formula Ca_2SiO_4.

We may derive the formula for aluminium sulphate in a similar way. A sulph*ate* is related to sulphu*ric* acid, H_2SO_4. The acid radical SO_4 has two bonds, because of its two hydrogen atoms. Aluminium has three bonds, as indicated by the formula for its oxide, $Al_2'''O_3''$. So, inserting the bonds, we have $Al'''(SO_4)''$, and applying the rule, the correct formula would be $Al_2(SO_4)_3$.

20. Equations. Chemical reactions are expressed by equations which show in a condensed form the kind and the quantities both of the substances entering into the reaction and of the products formed. Equations may be placed in four classes:

(1) *Combination.* When two or more substances unite to form a new combination, as, by example,

$$Fe + S = FeS.$$

This equation is read, one atom of iron unites with one atom of sulphur to produce one molecule of iron sulphide.

It also indicates that one atomic weight of iron, 56, is uniting with one atomic weight of sulphur, 32, and producing a molecular weight of iron sulphide, 88.

$$H_2 + O = H_2O.$$

This may be translated, one molecule of hydrogen weighing 2, unites with one atom of oxygen weighing 16, and produces one molecule of water weighing 18.

(2) *Decomposition.* When a substance is separated into two or more substances, the analysis may be expressed as follows:

$$H_2CO_3 = H_2O + CO_2.$$

This may be read, one molecule of carbonic acid, weight 62, is decomposed into one molecule of water, weight 18, and one molecule of carbon dioxide, weight 44.

$$Fe_2O_3 = 2Fe + 3O.$$

One molecule of ferric oxide yields two atoms of iron and three atoms of oxygen.

It is known that oxygen in a free condition exists as molecules of two atoms each. The number of atoms in a molecule of metallic iron has not been determined. Therefore, by doubling the equation above, it may be so written as to meet these conditions.

$$2Fe_2O_3 = 4Fe + 3O_2.$$

This is read, two molecules of ferric oxide will produce four atoms of iron and three molecules of oxygen.

(3) *Substitution.* Frequently an element may be substituted for a portion of a compound, provided it is chemically equivalent to the displaced portion.

$$Mg + 2HCl = MgCl_2 + H_2.$$

One atom of bivalent magnesium here substitutes for two atoms of monovalent hydrogen.

The formula for water, H_2O, may be written HOH, in which OH is a radical. Metals such as sodium react with water as shown by the substitution equation.

$$Na + HOH = H + NaOH.$$

This equation doubled,

$$2Na + 2HOH = H_2 + 2NaOH,$$

would be read, two atoms of sodium plus two molecules of water will produce one molecule of hydrogen and two molecules of sodium hydroxide.

When iron is exposed to steam the reaction would be expressed,

$$Fe + 3HOH = Fe(OH)_3 + 3H,$$

or better,

$$2Fe + 6HOH = 2Fe(OH)_3 + 3H_2.$$

(4) *Double Decomposition.* When acids or bases or salts react with one another, there is a simple exchange between the parts of the decomposing substances. This is the most common sort of chemical equation.

In writing such equations, first indicate this change. Thus, in the case of the reaction between nitric acid and copper hydroxide,

$$HNO_3+Cu(OH)=CuNO_3+HOH.$$

Then indicate the bonds of the different radicals and elements

$$H(NO_3)'+Cu''(OH)'=Cu''(NO_3)'+H''(OH)'.$$

Next correct the formulas by noting the bonds and employing the criss-cross rule,

$$HNO_3+Cu(OH)_2=Cu(NO_3)_2+HOH.$$

Select one of the more complicated formulas, such as $Cu(NO_3)_2$, and check off its parts to see if an equal number of such parts appear on the other side of the equation. Note that it has two (NO_3) radicals, which, to balance the equation, must appear in the left-hand, or factor side of the equation: so take $2HNO_3$. Likewise note the two OH of $Cu(OH)_2$, and provide for their appearance on the right or product side of the equation, i.e., 2HOH. The equation now becomes,

$$2HNO_3+Cu(OH)_2=Cu(NO_3)_2+2HOH.$$

Finally, check off each element or radical and see that it appears an equal number of times on each side of the equation. The equation then balances and will be correct.

In a similar manner, the equation expressing the reaction between the two salts, antimony sulphide and sulphuric acid may be balanced.

$SbS+H_2SO_4 \quad =SbSO_4+H_2S$ (exchanging radicals),
$Sb'''S''+H_2SO_4 =Sb'''(SO_4)''+H'S''$ (indicating bonds),
$Sb_2S_3+H_2SO_4 \quad =Sb_2(SO_4)_3+H_2S$ (correcting formulas),
$Sb_2S_3+3H_2SO_4 =Sb_2(SO_4)_3+3H_2S$ (balancing and checking off).

In the reaction between phosphoric acid, H_3PO_4, and sodium hydroxide, NaOH, if there were present enough of the base to replace one only of the three acid hydrogens, we could represent the action by the equation,

I $$NaOH+H_3PO_4=NaH_2PO_4+H_2O.$$

In the formula of the sodium dihydrogen phosphate, it will be noticed that the three bonds of the acid radical, PO_4, are held by a combination of three bonds, one from the sodium atom and two from the two hydrogen atoms.

Should there be sufficient sodium hydroxide to replace two of the three hydrogen atoms of phosphoric acid, the trial equation would be,

$$NaOH+H_3PO_4=Na_2HPO_4+H_2O.$$

It will be seen that the total number of sodium, oxygen, or hydrogen atoms on one side of the equation does not correspond or balance the atoms of these elements on the other side. Starting with the disodium hydrogen phosphate, which is the most complicated formula of the equation, its two sodium atoms require two sodium atoms in the left-hand or factor side of the equation, therefore, we take two molecules of sodium hydroxide. The equation then will be balanced, except its hydrogen and oxygen, which may be made equal on each side by making two molecules of water on the product side.

II. $$2NaOH+H_3PO_4=Na_2HPO_4+2H_2O.$$

When there is excess of sodium hydroxide, Na_3PO_4, would be formed and the equation would be,

III. $$3NaOH+H_3PO_4=Na_3PO_4+3H_2O.$$

Thus we find three different reactions represented by the three equations which are possible when sodium hydroxide is treated with phosphoric acid.

Calcium phosphate, $Ca_3''(PO_4)_2'''$, is used as a source of fertilizer. As it is very insoluble in water, in order to make it soluble and thereby quickly available as a plant food, it is treated with sulphuric acid, which changes the phosphate into a more soluble form. The following reactions may take place:

I. $Ca_3(PO_4)_2+3H_2SO_4=2H_3PO_4+3CaSO_4$,
II. $Ca_3(PO_4)_2+2H_2SO_4=CaH_4(PO_4)_2+2CaSO_4$,
III. $Ca_3(PO_4)_2+H_2SO_4=2CaH(PO_4)+CaSO_4$.

These equations should be read and the balancing of them checked.

CHAPTER III

ACIDS—BASES—SALTS—ANHYDRIDES—DISSOCIATION—NOMENCLATURE

21. Groups of Elements. The chemical elements may be roughly divided into three large groups:

(1) *Metals.* These are base-forming elements. There are somewhat more than a dozen of these elements that are important.

(2) *Non-metals.* These are acid-formers. The common acid-forming elements are oxygen, sulphur, nitrogen, carbon, silicon, boron, phosphorus, fluorine, chlorine, bromine, and iodine.

(3) *Metalloids.* Between the two groups (1) and (2) are a few intermediate elements which act either as acidic or basic, according as they are influenced by combination, on the one hand with strong basic elements, or on the other hand with strong acidic elements. These border-line elements thus are seen to be rather indifferent in their chemical affinities. The common metalloids are chromium, aluminium, manganese, arsenic, antimony, and tin.

22. Classes of Compounds. Most of the compounds of inorganic chemistry are included in one of the four classes—*acids, bases, salts, and anhydrides.* The properties and the composition of each of these classes must be studied carefully in order to gain a working knowledge of chemistry.

23. Acids. The most important acids are sulphuric, H_2SO_4; hydrochloric, HCl; nitric, HNO_3; phosphoric, H_3PO_4; and acetic, $HC_2H_3O_2$. If these or the score of other commonly-occurring acids should be examined, they all will be found to have the following characteristic properties:

(*a*) They are sour to the taste.

(*b*) They have the power of turning to a pink color paper that has been stained blue by an organic dye commonly called litmus.

(*c*) When in water solution, they attack such metals as zinc and magnesium, thereby being themselves broken up into hydrogen or some compound of hydrogen, as one of the decomposition products. Most frequently, this action may be observed by the bubbles of effervescing gas rising through the liquid acid solution.

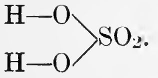
(*d*) They are soluble in water. They differ, however, in degree of solubility.

(*e*) They contain hydrogen, which is easily separated from the remainder of the acid when it acts chemically upon other substances.

(*f*) Acids react with *bases*, thereby neutralizing or destroying the characteristic properties of both acid and base.

(*g*) In respect to their composition, acids may be divided into two classes:

(1) *The Oxygen Acids.* These are composed of hydrogen which is bound by means of oxygen to a non-metallic element or radical. For example, hypochlorous acid, $HClO$, may be considered as $H—O—Cl$; nitric acid as $H—O—NO_2$; sulphuric acid as



$$\left.\begin{matrix} H—O \\ H—O \end{matrix}\right\rangle SO_2.$$

(2) *Hydrogen Acids.* These do not contain oxygen. The formula of the six common hydrogen acids are HCl, HBr, HF, HI, H_2S, HCN.

24. Bases. Some of the most common bases are sodium hydroxide, $NaOH$; potassium hydroxide, KOH; ammonium hydroxide, NH_4OH; calcium hydroxide, $Ca(OH)_2$; barium hydroxide, $Ba(OH)_2$. Bases have, generally, properties the opposite of those exhibited by acids.

(*a*) Bases that are soluble in water have an alkaline taste and feel soapy to the touch.

(*b*) When in water solution, bases turn back to a blue color litmus paper that has been made pink by the action of an acid.

(*c*) The stronger bases attack metals such as aluminium and zinc, producing thereby water as one of the products of the reaction.

(*d*) Generally they are insoluble in water. Those enumerated above are the only ones that will dissolve appreciably in water. The three first mentioned above are very soluble and are called the **alkalies.**

(*e*) Bases all contain the radical, hydroxyl, OH, the only other constituent being a metal. This hydroxyl is easily separated from the metal.

(*f*) Bases react easily with acids, the hydroxyl of the base uniting with the hydrogen of the acid, producing thereby water ($OH+H=H_2O$). This action takes away or neutralizes the characteristic properties of both acids and base.

(*g*) Bases are composed of a metal bound by means of oxygen to hydrogen. For example: silver hydroxide, $AgOH$; mercurous hydroxide, $HgOH$; copper hydroxide, $Cu(OH)_2$; iron hydroxide, $Fe(OH)_3$.

25. Salts. Salts have no characteristic properties defining them as a class. They may be best described by their methods of production and by their composition.

(*a*) When the acid hydrogen of an acid is replaced by a metal, the resulting compound is a salt. For example: Replacing the two hydrogens of sulphuric acid, H_2SO_4, by the bivalent metal zinc, a salt, zinc sulphate, $ZnSO_4$, is produced; replacing the hydrogen of nitric acid, HNO_3, by the univalent metal silver, a salt, silver nitrate, $AgNO_3$, is produced.

(*b*) When the hydroxyl of a base is replaced by a non-metal or by a non-metallic radical, the resulting compound is a salt. For example: When the hydroxyls of the base, zinc hydroxide, $Zn(OH)_2$, are replaced by the non-metallic or acid radical, SO_4, the result will be the salt, zinc sulphate, $ZnSO_4$; replacing the hydroxyl of sodium hydroxide by the non-metallic element, chlorine, the result will be a salt, sodium chloride, NaCl.

(*c*) When acids and bases react with each other, water is always produced by the union of the hydrogen of the acid with the hydroxyl of the base, $H+OH=H_2O$. What is left of the acid after its hydrogen is removed is *the acid radical.* For example: NO_3 from nitric acid, HNO_3. What is left of the base after its hydroxyl is removed is the metal: For example, K from the base potassium hydroxide, KOH. These remnants will unite and thereby form a salt; K and NO_3 produce the salt potassium nitrate, KNO_3.

There are four classes of salts:

(1) *Normal Salts.* These contain only the metal and the acid radical, such as sodium nitrate, $NaNO_3$, or potassium phosphate, K_3PO_4. They may be regarded as the salts in which all the hydrogen of the acid has been replaced by a metal.

(2) *Acid Salts.* In these one or more of the hydrogens of the acid from which the salt is derived has been retained. For example: sodium hydrogen sulphate, $NaHSO_4$, potassium hydrogen phosphate, $KHSO_4$. These generally are able to turn blue litmus to a pink color on account of the acid hydrogen left in them.

(3) *Basic Salts.* In these, some of the hydroxyl of the base from which the salt was derived has been retained. For example, basic bismuth nitrate, $Bi(OH)_2NO_3$. This is produced by substituting the acid radical NO_3 for one of the hydroxides of the base, $Bi(OH)_3$.

(4) *Neutral Salts.* These salts, when in water solution, do not change color in either blue or pink litmus paper.

26. Anhydrides. This word means *without water.* Anhydrides may be considered as either acids or bases from which water has been subtracted. They are quite generally oxides, that is, compounds in which oxygen is combined with one other element. There are two classes:

(1) *Acid Anhydrides.* For example: Sulphuric anhydride, SO_3, produced by subtracting water, H_2O, from sulphuric acid, H_2SO_4; nitric anhydride, N_2O_5, produced by subtracting water from two molecules of nitric acid, HNO_3.

(2) *Basic Anhydrides.* For example: Calcium oxide, CaO, produced by subtracting water from the base, calcium hydroxide, $Ca(OH)_2$; sodium oxide, Na_2O, produced by subtracting water from two molecules of the base $NaOH$.

27. Dissociation. If an acid or a base or a salt is dissolved in water and a current of electricity is passed through the solution, it will be found that the compound will tend to separate into two parts, one of which will accumulate at the + electrode, where the current *enters* the solution, while the other portion will condense about the − electrode, where the current *leaves* the solution. As opposite kinds of electric charges attract each the other, the portion attracted to the + electrode is called the *electro-negative part* of the compound, and the portion attracted towards the − electrode is called the *electro-positive portion* of the compound. These portions, because they *move* through the solution, are termed **ions.** In the case of acids it is found that the replaceable or acid hydrogen of the acid is condensed about the − electrode, and is therefore electro-positive, while the remainder of the acid, the acid radical portion, moves toward the + electrode, and is therefore electro-negative. These are some examples:

$$\overset{+}{H}\overset{-}{Cl},\quad \overset{+}{H}\overset{-}{(NO_3)},\quad \overset{+}{H}\overset{-}{(C_2H_3O_2)}.$$

When salts are thus electrolyzed, the metallic part of the salt is found to be electro-positive, and the acid radical part is electro-negative:

$$\overset{+}{Zn}\overset{-}{Cl_2},\quad \overset{+}{Pb}\overset{-}{S},\quad \overset{+}{Na_3}\overset{-}{(PO_4)},\quad \overset{+}{Na}\overset{-}{(H_2PO_4)},\quad \overset{+}{Na_2}\overset{-}{(HPO_4)}.$$

In the case of bases the metallic portion is electro-positive and the hydroxyl is electro-negative. This is indicated in the following formulas of bases:

$$\overset{+}{Na}\overset{-}{(OH)},\ \overset{+}{Ca}\overset{-}{(OH)}_2,\ \overset{+}{Fe}\overset{-}{(OH)}_3.$$

There are reasons for believing that when acids or bases or salts are dissolved in water, even when no electric current is passing through the solution, the compounds to some extent break up, or, as it is termed, *dissociate* into ions highly charged either positively or negatively. The ions with electro-negative charges are acid-forming. They are either the non-metallic elements or are radicals containing non-metals. According to the dissociation theory, acids are electro-negative elements or radicals united to hydrogen, and bases are electro-positive elements united to hydroxyl (OH), and salts are electro-positive elements united to electro-negative elements or radicals.

28. Nomenclature of Compounds. Names are given to most chemical compounds according to a few simple rules.

(1) *Nomenclature of Binary Compounds.* (*a*) Compounds composed of *two* elements have names ending in *ide.* This affix is attached to the abbreviated name of the non-metallic part of the compound. Thus oxygen forms *oxides,* as calcium oxide, CaO; sulphur forms *sulphides,* as lead sulphide, PbS; chlorine forms *chlorides,* as sodium chloride, $NaCl$. To indicate the number of atoms of the non-metallic element in the compounds, the prefixes *mono* for one, *di,* for two, *tri* for three, and *tetra* for four, are used; thus CO is carbon monoxide; SO_2 is sulphur dioxide; $AsCl_3$ is arsenious trichloride; CCl_4 is carbon tetrachloride.

(*b*) In case two compounds are made by the same two elements entering into combination in varying proportion, the name of the metallic element is modified by the terminations *ous* or *ic.* Thus $HgCl$ is called mercur*ous* chloride, and $HgCl_2$ is called mercur*ic* chloride. The compound in which there is the larger ratio of non-metallic component assumes the termination *ic*, while the compound having the smaller proportion of the non-metallic component has the termination *ous*. For example: FeO is ferr*ous* oxide; Fe_2O_3 is ferr*ic* oxide; SnS is stann*ous* sulphide; SnS_2 is stann*ic* sulphide.

(2) *Nomenclature of Acids.* The name of the acid-forming element to which is added the affix *ic* is assigned to the most common acid formed by that element: Thus sulphuric acid, H_2SO_4; phosphoric acid, H_3PO_4; chloric acid, $HClO_3$. When the elements form an acid which contains a *larger* amount of oxygen, the prefix *per* is used, as *per*sulphuric acid, $H_2S_4O_8$. In case the element forms an acid containing *less* oxygen than its *ic* acid, the termination *ous* is used, as sulphur*ous* acid, H_2SO_3. An acid with still less oxygen is designated by the prefix *hypo* as well as the affix *ous*; as H_2SO_2, *hypo*sulphur*ous* acid.

(3) *Nomenclature of Salts.* Names of those salts which contain more than two elements are determined from the names of the acids from which they are derived. Here are the two important cases:

The names of salts end in *ate* which are derived from acids ending in *ic*.

The names of salts end in *ite* which are derived from acids ending in *ous*.

Examples:

Sodium sulph*ate,* Na_2SO_4, formed from sulphur*ic* acid, H_2SO_4.

Silver nitr*ate,* $AgNO_3$, formed from nitr*ic* acid, HNO_3.

Sodium sulph*ite,* Na_2SO_3, formed from sulphur*ous* acid, H_2SO_3.

Sodium *hypo*sulph*ite,* Na_2SO_2, formed from *hypo*sulphur*ous* acid, H_2SO_2.

The following illustrate the series of chlorine acids and the salts derived from them:

$HClO_4$, *per*chlor*ic* acid: $KClO_4$, potassium *per*chlor*ate.*
$HClO_3$, chlor*ic* acid: $KClO_3$, potassium chlor*ate.*
$HClO_2$, chlor*ous* acid: $KClO_2$, potassium chlor*ite.*
$HClO$, *hypo*chlor*ous* acid: $KClO$, potassium *hypo*chlor*ite.*

Salts derived from the hydrogen acids, such as HCl, HBr, H_2S, contain but two elements and follow the rule in 1 (*a*) rather than that of 3; thus $CaCl_2$, from hydrochloric acid, is not called calcium hydrochlorate, but is termed calcium chloride.

CHAPTER IV

THE ELEMENTS NECESSARY FOR PLANT GROWTH—OXYGEN—HYDROGEN—CARBON—NITROGEN—PHOSPHORUS—SULPHUR—POTASSIUM—CALCIUM—MAGNESIUM—IRON

29. Oxygen. Oxygen is the most abundant of the elements. Upon it the life of plants as well as of animals directly depends. The greater part of the energy manifesting itself in the motion of objects about us is the result of the chemical activity of oxygen. Power for the purposes of commerce, energy which drives electric and steam cars, and the heat necessary for the sustenance of life and the maintenance of a temperature which makes life possible in other than tropical countries, all are derived from heat produced when oxygen combines with combustible substances.

Occurrence. In a free condition oxygen exists in vast quantities in the atmosphere, of which it is nearly 21 per cent by volume. In combination with other elements it is found in thousands of different compounds. Nearly nine-tenths of water is oxygen. It forms nearly one-half of the rocks composing the crust of the earth. It is rather difficult to find, in any of the common objects about us, a substance that is not combined with oxygen. Other than those substances that have been artificially produced by man and those that like carbon in coal are the product of vegetable life, almost the entire earth is composed of oxygen compounds.

Properties. When free, oxygen is an odorless gas without color or taste. It is a little heavier than air and is soluble in water at ordinary temperature to the extent of three volumes of the gas to one hundred volumes of the liquid. Fish and other marine life are dependent upon this oxygen dissolved in the water. With very few exceptions oxygen forms compounds with all the other elements; in this respect no other element can compare with oxygen.

The activity of oxygen in forming chemical combination is remarkably increased by raising its temperature. Many substances that resist any except very slow oxidation, when heated in the air, will unite with oxygen so rapidly that they suffer combustion. This is remarkably apparent when a building in conflagration is entirely consumed in a short time. Oxygen is absolutely essential in the building up of plant tissues. The carbohydrates, the proteids, and the fats, the constituents of plants that give to them their value as foods, are composed in large part of oxygen.

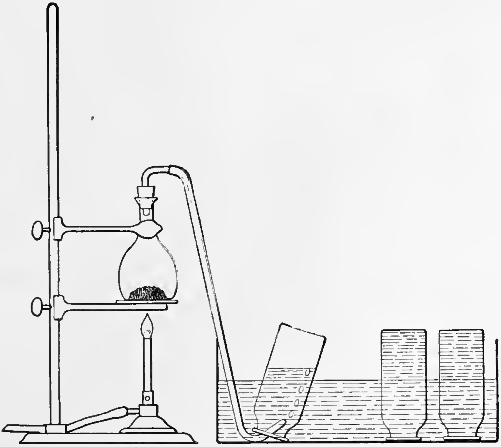


FIG. 6.—Preparation of oxygen in the laboratory.

In the process of decay and in the disposal of sewage, oxygen plays a beneficial role, decomposing germs that, if allowed to multiply, would produce epidemic diseases.

Preparation. Although oxygen exists at hand in enormous quantities in a free condition in the air, yet it is easier to obtain it by decomposing some of its compounds than to try to separate it from the nitrogen with which it is mixed in the atmosphere. In the chemical laboratory it may be produced by heating in a test-tube a little of the white salt, potassium chlorate ($KClO_3$). This melts at a comparatively low temperature (360° C.) and soon begins to boil, yielding an abundant supply of oxygen. This decomposition takes place at a still lower temperature (200° C.) when the black mineral, pyrolusite (manganese dioxide) is mixed with the potassium chlorate in the proportion of three parts of the chlorate to one part of the pyrolusite. The method of producing and of collecting the gas is shown in Fig. 6.

30. Hydrogen. The element hydrogen is a colorless gas. Very little is found in a free condition, although a small amount, estimated as one part in thirty thousand, exists in the air. It is not so active chemically as oxygen, forming compounds with comparatively few of the other elements.

Occurrence. Some of the compounds of hydrogen are of great importance. The principal source of hydrogen is water, of which it constitutes about 11 per cent. It is an essential ingredient of animal and plant structure. Organic substances, such as starch, sugar, albumen, and fat; bodies formed from organic matter, such as petroleum oil, bituminous coal, and coal tar, and the vast number of hydrocarbons, such as marsh gas, and acetylene, and the alcohols, all are made in part of hydrogen. All acids and all bases contain hydrogen as an essential ingredient. Ammonia and its compounds, which form an important food for plants, contain hydrogen.

Preparation. Hydrogen, as well as oxygen, may be obtained by the electrolysis resulting when an electric current is passed through water. In order that the electric current may pass through, the water is first mixed with a little sulphuric acid. The gases are most easily collected by means of an apparatus shown in Fig. 7. The volume of the hydrogen evolved is twice that of the oxygen.

Properties. Hydrogen will burn in air with a blue flame, yielding a quantity of heat greater than that produced by the combustion of the same weight of any other combustible. A quarter of a ton of hydrogen when burned will furnish as much heat as can be obtained from a ton of coal. For this reason coal gas, which is composed of about 50 per cent of hydrogen, is an economical fuel for cooking purposes.

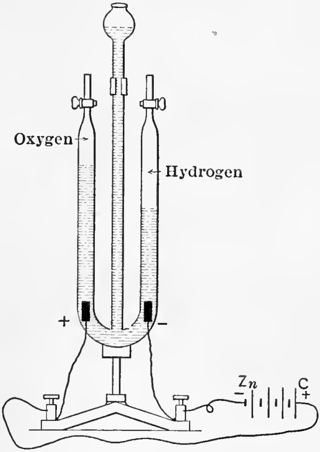


FIG. 7.—Electrolysis of water.

Hydrogen is the lightest known substance. Air is nearly $14\frac{1}{2}$ times as heavy as hydrogen gas, hence the latter is used for inflating balloons and for dirigibles. Hydrogen is a product of the decay of many organic bodies. When burned in air, it unites with oxygen and produces steam according to the equation

$$H_2 + O = H_2O.$$

31. Carbon. Next to oxygen carbon enters most abundantly into the composition of plants. It is a very important element, although not nearly so widely distributed as oxygen. It exists in the air in the form of the compound carbon dioxide gas, CO_2, constituting nearly four parts in ten thousand parts of air. Carbon exists in the soil as the carbonates of certain metallic elements such as calcium and magnesium. The diamond is a crystallized form of carbon. Most of anthracite, bituminous coal, and charcoal is carbon. Graphite is almost pure carbon.

The three compounds of carbon that interest us most from an agricultural view-point are carbon dioxide, the carbonates, and the carbohydrates. The soil water contains a certain amount of carbon dioxide, which is produced through the decay of organic matter in the earth. The higher the per cent of carbon dioxide in the water, the greater will be its solvent power. Thus, water percolating through the soil and absorbing carbon dioxide will dissolve mineral matter and become hard water.

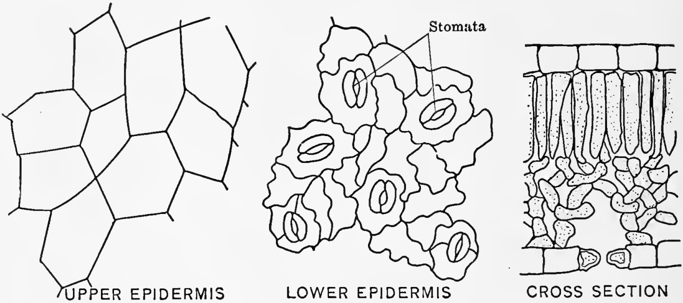


Fig. 8.—Structure of a leaf. The stomata are shown in the lower epidermis and in the cross-section.

The carbonates are compounds of carbon dioxide and a basic anhydride. Thus, $CaO+CO_2=CaCO_3$. Carbonate of lime, $CaCO_3$, is agriculturally the most important of the carbonates. The carbohydrates contain carbon and hydrogen and oxygen, the latter two being in the proportion of water, H_2O. The carbohydrates are formed in plants by the condensation of *formic aldehyde.* Formic aldehyde is formed in the green part of plants in the presence of sunlight, by the union of carbon dioxide, which enters through the stomata or breathing pores of the leaf of the plant, with water. During this process, oxygen is given off from the plant.

32. Nitrogen. When pure, nitrogen is a colorless, odorless, tasteless and very inactive gas. It combines directly with but few elements, although indirectly it enters into the formation of a large number of compounds possess-

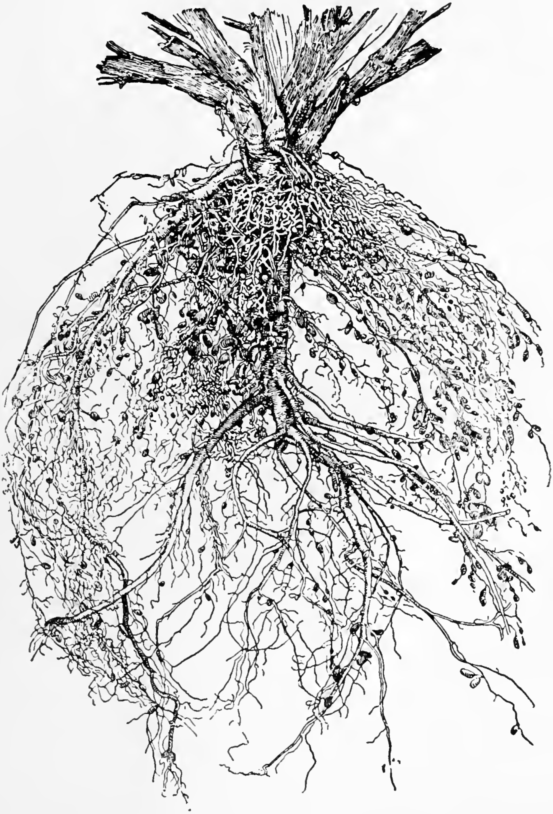


FIG 9.—Roots of red clover showing nodules by which nitrogen is secured for the plant.

ing very marked properties. Nitrogen, in the free state, forms about four-fifths by volume of the atmosphere; it exists in combination with other elements in important compounds, such as ammonium hydroxide (NH_4OH), one of the alkali bases; in nitric acid (HNO_3), one of the strongest acids; and in the ammonium form (NH_4), as a salt of many acids. It is present in combination in animal and in plant tissues. Nitrogen is available as plant or animal food only when it enters into some combination. It is the most expensive and at the same time the most elusive element with which the farmer has to deal.

While four-fifths, by volume, of the atmosphere is nitrogen, most plants are powerless to extract it from the air. A small amount of ammonia gas is formed in the atmosphere by electrical discharges and washed to the earth by rain water; in a similar way some of the oxides of nitrogen are formed. Certain bacteria that exist on decaying organic matter have the power of "fixing" atmospheric nitrogen in such combination that it will become available to the plants. A large amount of atmospheric nitrogen is "fixed" by means of bacteria that exist in so-called symbiotic union with leguminous plants. These bacteria form nodules on the roots of the plants which they infest, as shown in Fig. 9, the plants furnishing food for the bacteria, while the bacteria take nitrogen from the atmosphere and convert it into such a form that the plants can use it for the elaboration of their tissues. Peas, beans, vetches, clovers, alfalfa, peanuts, and beggarweeds are examples of legumes.

33. Phosphorus. Phosphorus is very easily oxidized, and, therefore, exists in nature in compounds only. It is quite widely distributed in combination with oxygen and calcium, as *phosphate rock*, which is largely calcium phosphate $Ca_3(PO_4)_2$. Phosphorus is often deficient in soils, and, as it is used rather plentifully for the development of both plants and animals, it is very often necessary to make applications of it in a commercial form. It is a necessary constituent of the bones of animals, which are composed in part of calcium phosphate. Phosphorus has an important part to play in the formation of the seeds of plants and in hastening their maturity. When freshly prepared and kept in the dark, the element phosphorus is an almost colorless or slightly yellow, waxlike solid. *It has a remarkably low kindling temperature, and therefore it is a very inflammable substance, and must be kept under water.* Phosphorus appears luminous in the dark, due to its slow oxidation to phosphorous trioxide (P_2O_3) when in contact with moist air. *Phosphorus fumes are very poisonous.* When yellow phosphorus is heated to 240°–250° Centigrade, it is changed to the red or amorphous form, which has a much higher kindling temperature than the yellow form. When heated to 260° C., it is again changed to the yellow form.

34. Sulphur. Sulphur occurs as yellow crystals, and also as opaque crystalline masses. It is found in nature in the free state, most frequently in volcanic regions. Compounds of sulphur with metals are known as *sulphides;* and when these compounds are more completely oxidized, they become *sulphates.* Compounds of sulphur are found widely distributed in both plants and animals. Small amounts of it occur in hair and in wool, while about 1 per cent of it is present in the albuminous substances which are present to a large extent in both plants and animals. Sulphur is mined in large quantities in Louisiana, where the supply of the United States is produced. It is also produced in Sicily and Japan. Most of our soils contain sufficient sulphur for plant growth.

35. Potassium. Potassium is rather abundant in nature, and especially so in soils that result from the decomposition of igneous rock. The minerals feldspar and mica contain potassium in large amounts. Granite rock contains over 3 per cent of potassium. Sea water contains

Fig. 10.—Obtaining sulphur at the Louisiana sulphur mine. (Reproduced by courtesy of F. H. Pough, Union Sulphur Co.)

some potassium in the form of sulphates and chlorides. Potassium chloride occurs in deposits in the vicinity of Stassfurt, Germany, where it is mined in large quantities. Some seaweeds contain a small percentage of potassium;

Fig. 11.—Masses of sulphur obtained from the Louisiana mine. (Reproduced by courtesy of F. H. Pough, Union Sulphur Co.)

wood ashes contain potash. Potassium has a tendency to lengthen the growing season of some crops.

36. Calcium. Compounds of calcium are widely distributed, but the element does not occur free in nature; it may be prepared by electrolysis. The most abundant compound of calcium is the carbonate. *Calcium carbonate* or " ground limestone rock " ($CaCO_3$) is of much agricultural importance, due to the fact that it corrects acidity in the soil. Calcium carbonate is a compound that is quite readily decomposed by other acids. Even the dilute acetic acid contained in vinegar will replace the carbonic acid of the calcium acetate.

No plant growth can take place without the presence of calcium. It has been shown that even the rather insoluble acid silicate of calcium may serve to furnish calcium to the plant. All normal soils have a supply of calcium compounds sufficient to furnish the calcium necessary for plant growth; but many soils are acid and, therefore, are benefited by applications of ground limestone to correct the acidity. These uses will be taken up later.

37. Magnesium. Magnesium ranks a little below calcium in its abundance in nature. It, too, never occurs in the free state in nature. Its compounds are quite abundant in the earth's crust, in rocks, in sea water, and in mineral water. It is also widely distributed in both animal and vegetable life. It exists in nature largely in the carbonate form, having the power to correct soil acidity, and being even more effective for this purpose per unit of weight than is calcium carbonate. If, however, magnesium is present in the soil in excess of about $1\frac{6}{10}$ per cent, it produces undesirable effects on vegetation.

38. Iron. Compounds of iron are widely distributed in nature in the form of brown or yellow oxides giving characteristic color to soils and as carbonate. These compounds form valuable deposits of iron ore. Iron sulphide in the form of pyrites or " fool's gold " is frequently found in coal-bearing strata and in other rocks. The hydrated oxide is iron rust

39. Summary. Of the ten elements necessary for plant growth, three—carbon, hydrogen, and oxygen—are exclusively derived from the atmosphere; one—nitrogen—partly from the atmosphere and partly from the soil; and six—phosphorus, potassium, sulphur, calcium, magnesium, and iron—are derived exclusively from the soil. From the standpoint of plant requirements only three are often deficient in soils—phosphorus, nitrogen, and potassium, and in many soils only one or two elements are deficient. The condition of the soil often warrants application of lime in some form.

CHAPTER V

WATER—SOLVENT ACTION OF WATER—DRINKING WATER—SPRINGS—SHALLOW WELLS—DEEP WELLS—TEMPORARY HARDNESS—PERMANENT HARDNESS—HOUSEHOLD WATER

40. Properties of Water. The two gaseous elements, hydrogen and oxygen, have a strong chemical attraction each for the other. They unite whenever possible in the proportions of two volumes of hydrogen to one volume of oxygen, and, by weight, in the proportion of one unit of hydrogen to eight units of oxygen, to form water, which is one of the most stable of compounds.

Water is possessed of remarkable physical and chemical properties. In common with most liquids, its volume changes with heating and cooling. When water is cooled, its maximum density is attained at the temperature of 4° Centigrade. This temperature is still 4° above the freezing temperature of water. At a lower temperature than 4°, water again expands, and at zero, when it freezes, it again expands suddenly. This latter expansion accounts for the disintegrating effects of freezing, the force being so powerful that it will split large rocks, and it also accounts for the fact that ice will float. This remarkable abnormal *expansion* of water, when the temperature falls from 4° C. to 0° C., results in the formation of ice at the surface of a cooling body rather than throughout its mass. When, by the radiation of heat into the air, the temperature at the surface of a body of water is cooled to 4° C., at which temperature it is densest, the cooled surface layers will continue to sink till the entire mass has reached the temperature of 4° C. Should the water grow still cooler, by exposure to the cold air above it, it will now remain at the surface supported by the heavier, though warmer, water beneath, and, finally, when the surface water lowers to zero, it will freeze. Ice, being a solid lighter than water, will float upon it and being a poor conductor of heat will prevent further radiation from the water and prevent its freezing more than to a limited extent. Were it not for this rather miraculous provision of nature, the lakes and

FIG. 12.—An attractive spring.

rivers, even in temperate zones, would freeze from bottom to top into masses of ice which no summer sun would have power to melt. Under these conditions the circulation of water would be prevented and our latitudes would be well-nigh uninhabitable.

When water under atmospheric pressure is heated to a temperature of 100° Centigrade, or 212° Fahrenheit, it assumes the gaseous form, and is known as *steam.*

41. Solvent Action of Water. Water is the most widely distributed, and also the most important of solvents. It not only dissolves plant food, but also serves as a medium for its transportation from the soil to the plants. All of the plant food that is derived from the soil is taken up from solution; hence the solubility of the materials determines their *availability* as plant food.

Water charged with carbonic acid gas is the most important natural solvent. In the decay of organic matter in the soil a great deal of carbonic acid and some nitric acid are liberated. This is one reason why it is desirable to incorporate a large amount of organic matter in soil. The nitric acid formed during the process of nitrification is a stronger solvent than carbon dioxide; but the quantity formed is comparatively small, hence the influence of the carbon dioxide as a solvent in the soil is believed to be greater than that of nitric acid. The nitric acid immediately reacts with the basic elements in the soils, such as calcium, sodium, potassium, magnesium, and ammonium, producing metallic nitrates, all of which are soluble. In this way, the plant may be furnished not only with nitrogen, but with potassium or calcium as well. Phosphoric acid and monocalcium phosphate are both soluble in pure water. Dicalcium phosphate, when present in soil, is insoluble in water, but it may be dissolved by treating it with neutral ammonium citrate of a specific gravity of 1.09. Tricalcium phosphate is insoluble in water; but it is soluble to some extent in the soil moisture when the soil is well supplied with decaying organic matter. It is probable that the carbonic acid in the soil solution is the most effective means for dissolving tricalcium phosphate, thus making it available as a plant food.

Table II shows the difference between the solvent action of water charged with carbon dioxide and of distilled water. The marked increase in the solvent power of water when carbonated is clearly indicated.

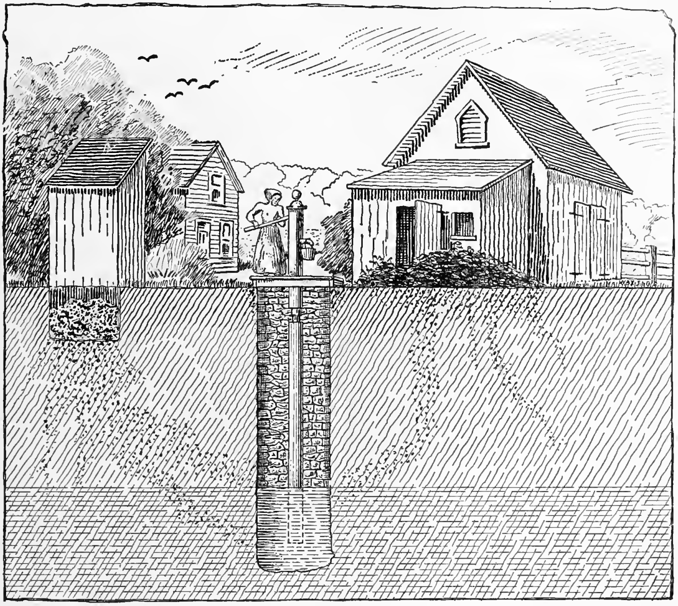


FIG. 13.—The shallow barnyard well, with privy vault and manure heaps near by. The water is likely to receive fluid from these any time. (From Smith's "Sewage Disposal on the Farm," Farmers' Bulletin, No. 43, U. S. Department of Agriculture.)

During the process of decomposition of organic matter, the nitrogen is changed in form. The organic compounds of nitrogen are changed by the ammonifying bacteria into

TABLE II.—THE SOLUBILITY OF CERTAIN MINERALS IN DISTILLED WATER AND IN CARBONATED WATER

Name of Mineral.	Composition.	Parts per Million Soluble in Distilled Water.	Parts per Million Soluble in Carbonated Water.
Calcite......	$CaCO_3$	34	980
Dolomite....	$CaCO_3MgCO_3$	25	325
Apatite.....	$Ca_3(PO_4)_2,CaCl_2CaF_2$	3	10
Gypsum.....	$CaSO_4 \cdot 2H_2O$	2390	4600
Feldspar....	$KAlSi_3O_8$	20	45
Mica........	$H_2KAl_3(SiO_4)_3$	5	8
Hematite....	Fe_2O_3	2	15
Quartz......	SiO_2	1	3

ammoniacal compounds. These compounds are oxidized by the activities of another group of bacteria into nitrous compounds, which are further oxidized by other bacteria into nitric compounds. The nitric acid thus produced forms, with the basic elements of the soil, soluble nitrate. Examples of these have already been mentioned. It should be remembered that *all nitrates are soluble in water.* The formation of nitric acid and its subsequent conversion of bases, formerly in insoluble compounds, into nitrates, which are soluble in water, and the increased solvent power of the soil water through carbonation, are examples of the natural solvents and their action. There are a number of organic acids both in the soil and in animal manures that have solvent powers; but the study of them requires a large mass of data which is as yet incomplete. It is sufficient to say that they exert marked activities in making available food for plants.

42. Factors Influencing Availability of Plant Food. Nature provides that the more the soil is worked, the more responsive it becomes and the more plant food becomes available. There are many factors influencing the availability of the plant food of the soil. We may mention warmth, moisture, decaying organic matter, cultivation, aeration, and freezing as the most important ones. An abundant supply of organic matter in a soil, its proper cultivation to allow an abundant circulation of air, an abundant supply of moisture, avoiding an excess, and warm weather are the conditions best suited for nitrification. The effects of frost and winds are mainly physical, and result in more finely divided soil particles, affording more surface area for the activities of the natural solvents.

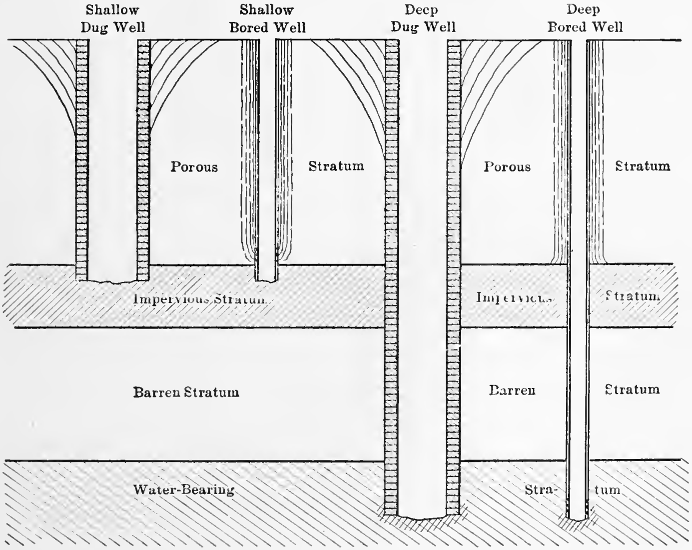


Fig. 14.—Driven and dug wells showing the relative danger of drainage contamination. (Farmers' Bulletin 549, U. S. Dept. Agr.)

43. Drinking Water. Impure water transmits many diseases, among which may be mentioned typhoid fever, dysentery, other diarrhœal affections, cholera, cholera infantum, animal parasitic diseases, enteric fever, tuberculosis, and scarlet fever. Typhoid fever may also be spread by milk, raw fruit, shell fish, or flies. Scarlet fever is more often spread by milk than by water; and cholera, dysentery, and cholera infantum are carried by milk to some extent. Enteric fever is carried by flies. Each of the above-mentioned diseases is spread by as pecific organism, and this organism must first get into the water for the water to become a carrier of the disease.

It has been estimated that approximately one-third of the water that falls runs off on the surface of the ground into streams. This water is termed the *run-off*. Two-thirds sinks into the soil, and of this, approximately one-half, or one-third of the total water, is lost by evaporation. This is termed the *fly-off*. The remainder, approximately one-third of the total rainfall, finds its way out in springs or through subterranean passages. This is termed the *cut-off*. The proportion of the run-off, fly-off and cut-off will vary with differing conditions, but the above estimate is generally approximately true. The cut-off is the water that interests us from the standpoint of sanitary water for rural homes.

Farm homes are usually supplied with water from one of three sources: springs, shallow wells, or deep wells.

(*a*) *Spring water* is contaminated, and may be infected, by coming in contact with filth of any kind; for this reason the water-shed of the spring should not have on it, draining toward the springs, any barnyards, pigsties, privies, slaughter houses, or graveyards. The spring should be well ditched around, so as to prevent its being overflowed, contaminated, and possibly infected. It is generally believed that the flowing of water through the soil purifies it, but this depends upon the character of the ground through which it flows. Under certain conditions (from a pathogenic standpoint) old water may be better than fresh water, because the germs have had time to die.

(*b*) *Shallow wells* have been used as a source of water-supply since Biblical times. They are likely to become infected through seepage and incomplete filtration. The open well and the chain and bucket should be discarded and a pump with a closely fitting well cover which does not leak, should be installed. Arrangements should be made for the removal of waste water and to prevent the seepage into the well of surface water. This can be accomplished, preferably, by the use of cement, or a brick and mortar structure may be employed. In both cases the foundation should be laid well below the surface of the ground, as in Fig. 15, and upon this foundation the well cover should be placed. The well which is to supply the family with drinking water should not be located in the barnyard or near any of the sources of possible infection already mentioned in connection with spring water. No drains or sewer pipes should run near the well for fear of pollution, contamination, or possible infection with disease organisms.

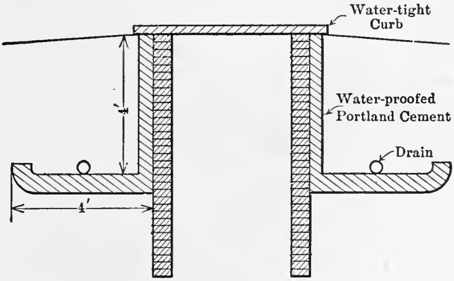


FIG. 15.—Proposed method of protection of dug wells. (Farmers' Bulletin 549, U. S. Dept. Agr.)

(*c*) *Deep Wells.* Where practicable, artesian wells, Fig. 16, furnish our best source of water-supply. These wells may vary in depth from one hundred to twenty-five hundred feet. Where a flowing well can be obtained it will usually prove to be the best and most economical water-supply.

After having seen to it that the drinking water-supply is as free as possible from infection, the factors that make for attractiveness of the water may be considered. These are taste, odor, color, turbidity, and sediment. The desirability of a good source and supply of water cannot be urged too strongly on the rural householder. It is an economic proposition, saving large sums in expense incident to sickness, and even more through increased efficiency. No man can work to best advantage when handicapped by poor health, which in many cases is the direct result of a poor water-supply.

Fig. 16.—Flowing well near Conway, S. C. (Photo by Prof. C. E. Chambliss.)

44. Hardness in Water. Hardness in water is caused by the presence of metallic salts, usually those of calcium or magnesium, dissolved in the water. When soap is added to such waters, the fatty acid radicals of the soap combine with the calcium and magnesium and produce an insoluble curdy precipitate. Until all of these calcium and magnesium salts are thus precipitated, no lather can be obtained with the soap and it is useless as a cleansing agent. Hardness in water is consequently easily determined by adding a standard soap solution to the water, which will produce a greasy precipitate with the calcium and magnesium salts in the water. Not till these salts are all precipitated can a permanent lather be formed on the surface of the water. The quantity of the soap solution needed to produce the lather will, therefore, measure the hardness of the water.

Hardness may be classified as *temporary hardness* and *permanent hardness.* Temporary hardness is usually caused by the presence of dissolved bicarbonates of calcium and magnesium. Permanent hardness is usually due to the chlorides and sulphates of these elements. Calcium and magnesium carbonates are insoluble, but if carbon dioxide is present in the water, they dissolve to some extent, forming the bicarbonates. Water having much hardness is objectionable for drinking purposes. For bathing and laundry purposes, it is expensive on account of the large amount of soap incident to its use.

Table III shows the relative efficiency of a number of soaps for the purpose of softening water as given by Whipple:

According to Alexander Smith, with water containing 35 grains of hardness per gallon (60 parts per 100,000), 6 pounds of soap are wasted per 100 gallons of water before the part of the soap that is to do the work of cleansing begins to dissolve.

When we consider that for each one part per million of hardness it requires ten dollars' worth of soap to soften one million gallons of water, it emphasizes the expense in the use of hard water as a detergent.

Temporary hardness may be removed:

(1) By heating the water to boiling, so as to expel carbon dioxide, in this way converting the soluble bicarbonate into an insoluble carbonate;

TABLE III.—EFFICIENCY OF SOAPS IN SOFTENING WATER

Hardness (Parts per Million).	Number of c.c. of Standard Soap Solution for 50 c.c. water.	Number of Grams of Standard Soap per Gallon of Water.	Number of Gallons of Water Softened by One Pound of									
			Standard Castile Soap.	Ivory Soap.	Babbitt's Laundry Soap.	Sapolio.	Bon Ami.	Gold Dust.	Pearline.	Pears' Hand Soap.	Colgate's Cerosa Toilet Soap.	Average (omitting the Standard Castile Soap).
20	2.1	1.11	409	196	138	102	143	165	167	187	225	167
25	2.4	1.27	358	174	121	90	125	145	147	164	206	147
40	3.6	1.91	238	115	80	59	83	96	98	109	137	97
50	4.3	2.28	200	96	67	50	70	81	82	92	115	82
75	6.1	3.24	140	67	47	35	49	57	58	64	80	57
80	6.4	3.49	140	70	44	33	45	52	53	60	75	54
100	7.8	4.13	110	53	37	27	38	44	45	50	63	45
125	9.5	5.04	90	43	30	25	31	36	37	41	52	37
150	11.1	5.89	77	37	26	19	27	31	32	35	44	31
175	12.7	6.74	67	32	23	17	23	27	28	31	38	27
200	14.3	7.59	60	29	20	15	21	24	25	27	34	24

(2) By treating the water with lye, sodium hydroxide,

$$CaH_2(CO_3)_2 + 2NaOH = CaCO_3 + Na_2CO_3 + 2H_2O;$$

(3) By treating with milk of lime,

$$CaH_2(CO_3)_2 + Ca(OH)_2 = 2CaCO_3 + 2H_2O.$$

Permanent hardness is removed by treating the water with sodium carbonate. The following equation may represent the reaction:

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

The calcium carbonate in all these cases, being insoluble, will be precipitated from the water, leaving in the water sodium salts, which are not particularly harmful.

Magnesium and iron salts react similarly to the calcium salts, though the iron precipitates as the hydroxide when sodium carbonate is the precipitant. Iron is objectionable in laundry work. Sodium carbonate is objectionable in water used in locomotive boilers, because it induces foaming; it is also objectionable in water for irrigation purposes, causing the accumulation of alkali in the soil. Permanently hard water affects the paper maker, the tanner, the bleacher, and the dyer.

45. Filtered Water. Thorough filtering makes water more attractive for household use, as color, odor, turbidity, sediment, and to some extent, hardness may be removed and an infected water may be made safer for drinking purposes. City water-supplies are often treated in this way and improved. Fig. 17 shows an effective sand filter. The bottom of the filter, *A*, consists of puddled clay 2 feet in thickness, built in with stones 8 inches in thickness; layer *B* consists of coarse, angular stones and is about 30 inches in thickness. The next layer, *C*, consists of 6 inches of smaller stones and over this is placed *D*, composed of

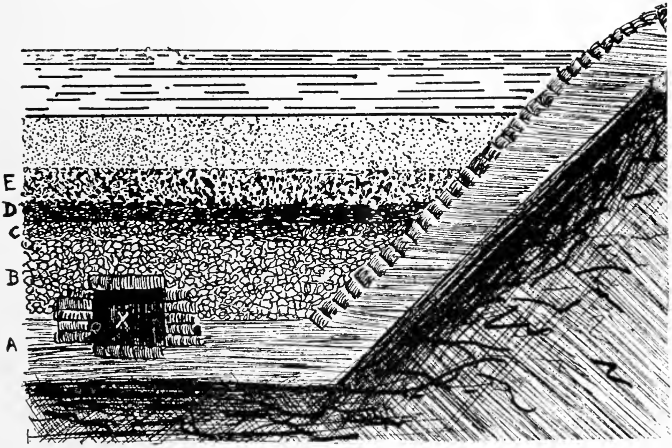


FIG. 17.—An effective sand filter. (Drawing by Mr. T. C. Hough.)

6 inches of coarse gravel, followed by *E*, 6 inches of fine gravel. The top layer consists of 30 inches of sand. Channels (shown at *X*) are used to collect the water; they are situated half in the bed of clay and half in the large rocks. The best size of sand to use is 0.5–1.0 millimeter in diameter, and the greater the uniformity obtained in the size of the sand the better the filtration obtained.

46. Boiled Water. Water is purified for drinking purposes by boiling. This method can easily be used and is quite inexpensive and effective.

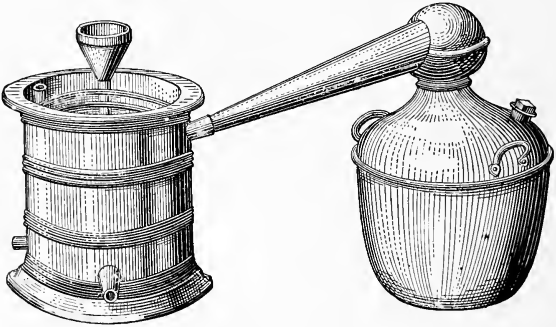


Fig. 18.—A simple apparatus for distilling water.

47. Distilled Water. Distilled water is pure, but it needs aeration to become palatable, as it has a flat taste. In Fig. 18 is shown an apparatus for distilling water.

48. Boiler Water. In limestone regions, we find hard water; in soils derived from sandstone and granite, soft water occurs. Water, however, does not always partake of the nature of the topsoil. Especially is this true when the sources of supply are wells, because the water may have come in contact with different strata below the surface. If possible, water to be used in boilers should be analyzed, and a suitable supply selected before installing the power plant; otherwise a hard crust or *scale* will deposit over the boiler tubes. Bicarbonates and sulphates of calcium and of magnesium dissolved in water make up, generally, at least 90 per cent of its hardness. The presence of the two bicarbonates constitutes what is known as temporary hardness, which is more easily handled than permanent hardness; the presence of calcium sulphate and of magnesium sulphate constitutes permanent hardness.

Fig. 19.—Scale removed from a boiler. (From *Power*, Dec. 22, 1914.)

The purification of boiler water may be accomplished by the methods given for household water, page 54. Temporary hardness may be removed by heating the supply in a tank before it enters the boiler, by means of waste steam or by any desirable method. This heating converts the rather soluble bicarbonate of calcium or of magnesium into the much less soluble normal carbonate, by expelling carbon dioxide, according to the following formula:

$$Ca_2H_2(CO_3)_3 + heat = 2CaCO_3 + H_2O + CO_2.$$

The normal calcium carbonate ($CaCO_3$) is soluble only to the extent of $2\frac{1}{10}$ grains per gallon. Magnesium bicarbonate, when heated, decomposes in the same way as calcium bicarbonate, although the normal magnesium carbonate is soluble to the extent of 14 grains per gallon.

As a second method, temporarily hard water may be softened by chemical means as already shown. Four pounds of quicklime will soften as much water as 80 pounds of soap, hence the use of the lime will be far more economical. Needless to say, this treatment must take place in a different receptacle from the boiler. The reaction is the same as that previously given for milk of lime.

Pure calcium carbonate does not produce a very hard scale at first, but it hardens with heating and drying. When it is heated rapidly, it deposits as mud; but when heated slowly it forms calcite, which will become a hard scale when baked. Magnesium carbonate behaves similarly to calcium carbonate.

Permanently hard water is less desirable as a boiler supply. Calcium sulphate is more troublesome than calcium carbonate, because it forms a hard and adhesive boiler incrustant, beneath which the iron is often corroded and overheated.

Boiler water may, also, be helped by filtration, although the suspended matter strained out by the filter as a rule does not cause a deposit of scale. One very simple precaution may save much trouble, *never empty a boiler while it is hot*, because the incrustation in that case will be baked on. Never blow out the boiler under steam pressure, because the incrustation, becoming dry, absorbs carbon dioxide from the air, which helps to fix the deposit more firmly.

CHAPTER VI

SOIL WATER

49. Water Requirements of Plants. No one factor has a more important bearing on crop production than the proper amount of the right kind of soil moisture. Table IV has been compiled by Warrington from data obtained by the investigators named to show the number of pounds of water transpired by growing plants for each pound of dry matter produced:

TABLE IV.—NUMBER OF POUNDS OF WATER EVAPORATED TO GROW CROPS ENUMERATED

Lawes and Gilbert, England.		Hellriegel, Germany.		Wollny Germany.		King, Wisconsin.	
Beans.....	214	Beans....	262	Maize....	233	Maize....	272
Wheat....	225	Wheat....	359	Millet....	416	Potatoes..	423
Peas......	235	Peas.....	292	Peas.....	479	Peas.....	447
Red clover.	249	Red clover	330	Rape.....	912	Red clover	453
Barley....	262	Barley....	310	Barley....	774	Barley....	393
		Oats.....	402	Oats.....	665	Oats.....	557
		Buckwheat	371	Buckwheat	664		
		Lupine...	373	Mustard..	843		
		Rye......	377	Sunflower.	490		

In general, it may be stated that from 200 to 500 pounds of water are required to produce 1 pound of dry matter of the ordinary field crops. The amount required is influenced by the climate, the soil type, and the preparation and cultural methods employed.

50. Soil Components. The soil is made up of three components, solid, liquid, and gaseous. The solid part consists of the inorganic and organic materials; the liquid part consists of water carrying more or less of mineral or of organic materials in solution; the gaseous part consists of air, mixed with carbon dioxide produced by the decomposition of organic matter, water vapor and other gases. The whole may be likened to an animal, the solid part forming the body, the skeleton of which represents the inorganic solids, while the flesh and muscles represent the organic solids; the soil water and its contents constituting the circulatory system of the animal, and the air and other gases the respiratory system.

51. Soil Water. All plant food that enters the plant from the soil is transferred to the plant in solution; therefore, we see that the plant food in the soil must become soluble in the soil water before the plant can use it for the building of its tissues. It is a wise provision of nature that the better treatment of the land accentuates the factors that promote solution, while poor methods of soil treatment make the plant food elements less soluble.

The rainfall of the different sections of the United States is variable, ranging from about 100 inches in the most humid areas to as low as from 2 to 5 inches in the most arid regions. The rainfall most desirable for maximum production is about 50 inches. When rainfall is less, there is more reason for greater efforts toward conservation of moisture.

There are three forms of water in the soil: Gravitational, capillary, and hygroscopic. The **gravitational or free water** moves under the force of gravity. Generally it is more harmful than helpful, because it leaches soluble plant food, excludes the air, hinders bacterial action, reduces surface tension, and dissolves cementing materials. It is helpful to the extent that it is converted into the capillary form. Also it may serve to wash some harmful bodies out of the soil.

The capillary moisture is the liquid film which surrounds soil particles. This form of moisture furnishes the plant with almost its entire supply of liquid food. When capillary action is promoted by favorable conditions of the soil, moisture may be drawn up from the water table some distance below, the amount of rise being determined by

Fig. 20.—Surface Washing. (Photographed by Dr. F. H. H. Calhoun.)

the cross-section area of the capillary spaces and by the strength of the liquid film at the upper surface of these spaces. The smaller the area of the capillaries the greater will be the distance through which the water will rise.

Every care should be exercised to increase the supply of moisture by the prevention of evaporation and percolation. The available moisture is increased and the surface washing is decreased by deeper preparation of the soil, which offers a larger reservoir for the retention of water. Then, too, surface washing can be greatly lessened by the practice of terracing, which is quite extensively used in the Southern States, and also by the use of rotations that do not have many clean-cultured crops in them. The evaporation can be greatly lessened by shallow cultivation, during the growing season, which serves to form a soil mulch, destroys the surface capillarity, and retains moisture very effectively. The retention of the largest possible amount of the moisture serves a two-fold purpose: It adds to the available moisture, which is often the limiting factor of production, and it lessens the surface washing. In no way are our clean-cultured, rolling lands depleted more than by surface washing, and its prevention is worthy of the close consideration of those who own or cultivate such lands.

For best soil conditions, the gravitational water should sink deep into the soil as rapidly as possible, in order that the capillary action may be at its best. Where the drainage is good, the gravitational water is no trouble. Deep fall plowing, the incorporation of organic matter, and comparatively shallow cultivation after each rain, in order to form a soil mulch, are the secrets of the conservation of moisture.

CHAPTER VII

AIR IN SOILS

52. Composition of the Atmosphere. The atmosphere consists mainly of a mixture of the two gases, nitrogen and oxygen, and contains in addition argon, variable quantities of aqueous vapor, and very small amounts of carbon dioxide, ammonia, hydrogen, and ozone. Under certain conditions other gases, certain salts, finely divided soil particles, and small particles of animal and vegetable matter may occur as incidental ingredients. Dry air contains about $75\frac{1}{2}$ per cent by weight of nitrogen, and about 23 per cent by weight of oxygen, the other elements and compounds mentioned being present in very small quantities in moisture-free air. Carbon dioxide is present on an average in the proportions of 4 parts of carbon dioxide to 10,000 parts of air. This seems insignificant, but the tremendous weight of the atmosphere can be realized when we consider that this minute proportion is equivalent to 28 tons of carbon dioxide in the atmosphere over one acre of land. The atmosphere is continuously moving, so that the air over an acre of land is renewed many times during the course of a day, thus tending to keep the air, although a mixture, approximately of definite composition. Growing crops rapidly use up carbon dioxide in the process of building up the plant structures, all of which are largely carbonaceous. The ratio between oxygen and carbon dioxide is kept constant, the amount of oxygen used up by combustion and life processes being restored by the decomposition of carbon dioxide by the chlorophyl of the growing plant and the discharge into the air of the oxygen thus produced.

The free nitrogen present in the air is inert and cannot be made use of by the plant directly for plant food. Certain parasitic micro-organisms living on the roots of plants have the power of converting the nitrogen of the air into a form which becomes available as plant food, as stated on page 38. There is another class of bacteria that live on decaying organic matter, which has the power of "fixing" atmospheric nitrogen in a form that may become available for plant growth. The bacteria that live on *decaying* organic matter are said to be *saprophytic.*

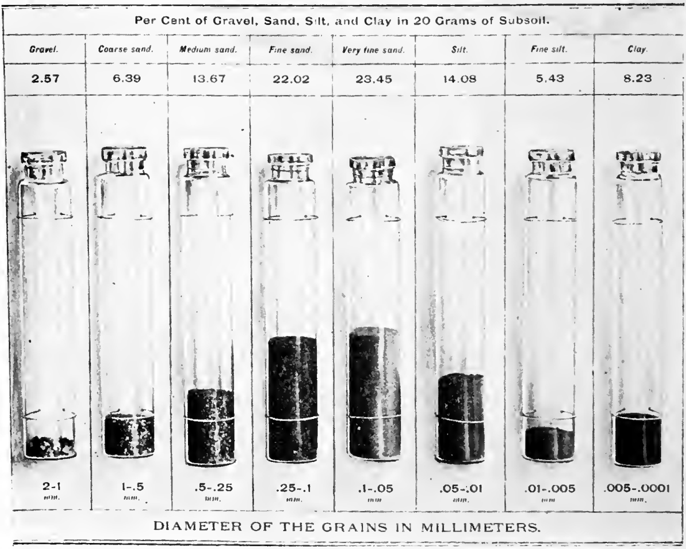


FIG. 21.—Texture of a typical bright tobacco land of Virginia and North Carolina. (U. S. Dept. Agr.)

53. Soil Air. The composition of the soil air depends upon the amount of organic matter present and the rapidity with which it is decaying. The composition of soil air differs considerably from that of the atmosphere. The volume of air contained in different soils is quite variable, and is affected by the soil structure, texture, organic matter and moisture content.

The greatest changes in the composition of soil air are found in the air of clayey soils when the particles are extremely small. Clay particles may be flocculated into masses, or flocculated clay may be granulated, thus considerably changing the pore space in the soil and the volume of air that it will contain.

The size of the soil particles, which determines texture, also affects the pore space and, consequently, the air content of the soil. Soil particles are of varying sizes, and under field conditions, the soils of fine texture generally possess large air space.

Organic matter is quite porous, and its effect in the soil is always to increase the volume of air. It is necessary to have a sufficient supply of air to promote the decay of organic matter. The main benefits of organic matter are gained through its decay.

The more completely the pore spaces in soils are filled with water, the smaller the amount of air that will be present. Water is held by capillary attraction more securely when the particles are small than when large, the capillarity being greater in a soil of comparatively fine texture. The volume of air increases and the capillary water diminishes when larger particles or granules are present. Because of this the flocculation of the clay soils of bottom lands by the use of lime permits of better drainage and more complete aeration, thus greatly improving this type of soil.

54. Effect of Carbon Dioxide on Decay. The very rapid decay of organic matter and the liberation of carbon dioxide in large volume might serve to decrease the rapidity of decay on account of the harmful effect of large percentages of carbon dioxide to certain of the organisms producing decay. The percentage of carbon dioxide liberated in the soil is proportional to the rapidity with which the organic matter decomposes; for carbon dioxide is one of the main products of the decay of organic matter. Decay goes on most rapidly during the warm months of the year, when the crop is being produced. At the time that soil moisture will be most highly charged with carbon dioxide and its solvent powers most increased, plant food is most needed. It has been proved that the plant roots absorb oxygen and give off carbon dioxide, which action has a tendency to increase the solvent power of the soil moisture in the immediate vicinity of the roots.

The formation of carbonates by the reaction between soil bases and carbonic acid may be beneficial to the soil, as in the case of carbonate of lime, and, in moderate quantities, carbonate of magnesium. On the other hand, large quantities of the carbonates of sodium and of potassium are deleterious, as is seen in the alkali lands of the West. There is a tendency for carbonates of sodium and of potassium to deflocculate the clay and, consequently, harmfully affect the tilth of the soil.

55. Oxygen Must be Present. The oxygen of the air is very important in its effects; the process of decay is in reality oxidation. Some mineral compounds are oxidized, and their solubilities changed. Most vegetable materials are oxidized during the process of decay, the ash elements contained being brought into solution so that they may be made use of by growing plants, and carbon dioxide is liberated, which, in turn, promotes the availability of insoluble plant food from the mineral materials. Oxygen is necessary for the germination of seeds, the growth of plant roots, and in combination with carbon as CO_2 for the formation of the carbohydrates stored up in plant structures.

56. Factors Affecting Soil Air. The air content of the soil is affected by several factors. In the first place, there is an exchange of air between the air above the soil and the air within the soil. They come together at the surface of the ground, and this exchange is brought about by diffusion, which is dependent upon the pore space within the soil.

Diffusion is the mingling of gases into each other. It may be measured by the passage of a gas through a porous partition. It has been demonstrated that the rate of diffusion of a gas is inversely proportional to the square root of the density of a gas. The rapidity of diffusion may be shown by the apparatus in Fig. 22. Hydrogen surrounding the unglazed porcelain cup and air within it each diffuse through the pores of the cup, but the air, being nearly sixteen times as dense as hydrogen, will diffuse one-fourth as rapidly. The hydrogen will penetrate to the interior of the cup more rapidly than the air can diffuse outward, consequently there will be increased pres-

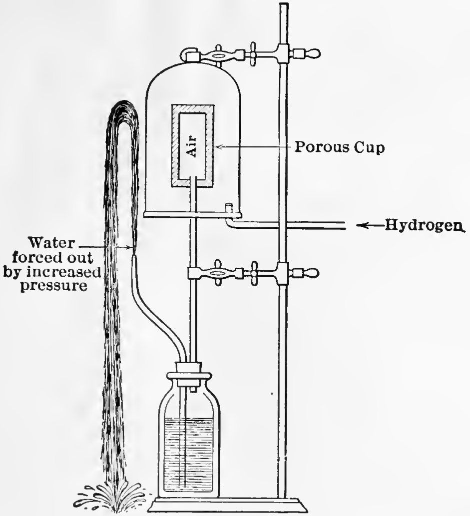


Fig. 22.—Diffusion of hydrogen through a porous cup.

sure within the cup, which will exert pressure upon the water in the connecting bottle, forcing it in a spray from the tube. Should the bell jar with its hydrogen atmosphere now be removed, the hydrogen which now is within the cup will diffuse rapidly into the outside air and the decreased pressure within the cup will be indicated by bubbles of air rising from the tube through the water in the bottle.

Thorough tillage enlarges the pore space and aids diffusion; packing a soil decreases the pore space and the diffusion. When rain falls, the water fills much of the pore space, excluding a certain volume of air; but, as the water sinks into the soil, the air is forced after it, because of the pressure of the atmosphere above, filling the space made vacant by the sinking of the water. The volume of a gas is *directly proportional to the temperature and inversely proportional to the pressure.* The warmer the temperature, the greater the volume of any gas, and the greater the pressure, the smaller will be the volume occupied by a given gas. Under climatic conditions, there are constant changes of both temperature and pressure, which bring about movement of the soil atmosphere.

57. Means of Producing a Change of Soil Air. The means at our disposal to produce change of soil air are *tillage*, *underdrainage*, *rotation*, *manures*, and *lime*.

Thorough tillage induces more exchange of air between the atmosphere above the surface and the air beneath the surface. Underdrainage removes superfluous water and increases the pore space that is filled by air, thus allowing a freer circulation within the soil. Irrigation induces change in soil air in the same manner that rain induces change. The influx of water to a large extent excludes the air from the soil, and, as the water sinks into the soil, the pore space is refilled with air. Rotation of crops aids in the proper aeration of a soil, because the root systems of the different crops grown in the rotation are confined to different soil strata, and, as old roots decay through the process already mentioned, air passages are formed in the soil. Animal manures exert an influence on the texture of the soil, which enlarges the pore space. Applications of lime affect the structures of certain soils very materially, causing a rearrangement of the soil particles in such a way as to open the soil to an appreciable extent.

CHAPTER VIII

THE ASSIMILATION OF PLANT FOOD

58. Source of Plant Food. The plant derives its food from two sources—the *atmosphere* and the *soil.* By far the greater portion is obtained from the atmosphere. Of the ten elements necessary for plant growth—carbon, hydrogen, oxygen, nitrogen, phosphorus, potassium, sulphur, iron, calcium, and magnesium—carbon, hydrogen, and oxygen compose about 95 per cent of all agricultural crops. These three elements are supplied from the atmosphere. Some of the nitrogen used by plants is also derived indirectly from the atmosphere, from which it is "fixed" by means of bacteria (see page 38). The soil elements necessary for plant growth are taken up by the plants from water solution. The root system of the plant constitutes the channels for taking up the solutions.

According to their root systems, plants may be divided into two main classes, *those that have tap roots and those that have a mass of lateral, fibrous roots.* The tap-rooted plants usually penetrate deeper into the soil. The main roots of the former class have smaller branches, and these, in turn, are covered with **root hairs** (Fig. 24) which are cells that act like syphons. They consist of cells which contain granular protoplasm and sap. These root hairs are widely distributed throughout the soil, and come in intimate contact with the soil particles. The soil particles are covered with capillary moisture containing certain amounts of plant food which has been dissolved from the particles. This moisture with its dissolved material is taken up by the root hairs and conveyed by *osmotic pressure* into the plant. The portion of the plant root that is covered with root hairs does not elongate. The root elongates from the growing tip.

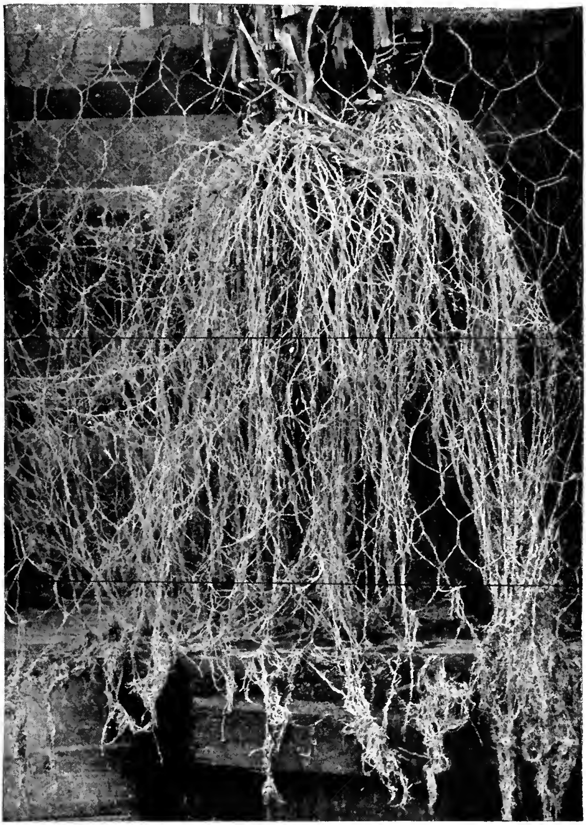


FIG. 23.—The root system of a corn plant to a depth of three feet. (From McCall's "Studies of Soils.")

59. Osmosis. When two solutions are separated by a membrane, the weaker solution will flow towards the stronger solution, because water readily passes through the membrane, while the solution containing the greater amount of material will flow more slowly, being obstructed by the membrane. The inflow of water into the plant is thought to be in response to the pressure thus generated, the cell wall of the root hair being the membrane and the sap within the cell being more concentrated than the soil solution. The diffusion of the plant food from cell to cell throughout the plant is considered to be due to the same cause.

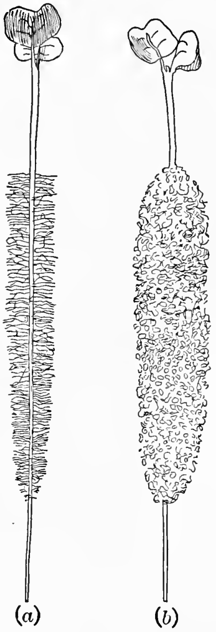


Fig. 24.—(*a*) Root hairs, (*b*) close contact of root hairs with soil particles.

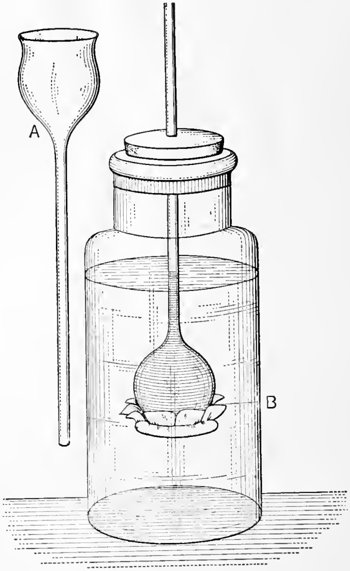


Fig. 25.—Osmosis shown with a bladder membrane.

Every element or compound in the soil solution has its specific relationship to osmosis and, in this way, the amount of each material imbibed is governed. Some excretions due to the slow passage of the denser liquid from the plant take place through the root hairs, but this is very small considering the amount taken in, the greater quantity going to the side of the stronger solution, i.e., *into* the plant. The solution containing the plant food finds its way through the stems of the plant to the leaves; there it comes into the " laboratory " of the plant, and in contact with the elements derived from the atmosphere.

60. Function of the Leaves of Plants. The water which serves as the carrier of plant food from the soil originally comes from the atmosphere in the form of rain water. Carbon dioxide comes from the atmosphere, and is taken into the plant through small openings in the leaf, known as the *stomata.* The stomata form the breathing pores of the plants. Through them carbon dioxide is taken into the plant and oxygen is given off. In the leaves of the plant, all of the various elements of plant food are brought together and are built up into the proximate constituents of the plant. This process is termed *photosynthesis.* Photosynthesis takes place only in plants which contain green coloring matter. The material that produces the green coloring of plants is known as *chlorophyl.*

The simplest photosynthesis is that in which formaldehyde is produced. This is made into carbohydrates. The process is accomplished in the leaves of the plants under the influence of chlorophyl, sunlight, and aqueous carbon dioxide. It may be expressed in chemical equation:

$$CO_2+H_2O=CH_2O+O_2,$$
$$6CH_2O=C_6H_{12}O_6.$$

Carbon dioxide and water yield formic aldehyde (CH_2O) and oxygen. The oxygen given off serves to replenish the atmosphere and aids in maintaining the balance between plant and animal life. Six molecules of formic aldehyde, by condensation, form sugar ($C_6H_{12}O_6$). The sugars are soluble, and it is in this form that the carbohydrates are transported to different parts of the plant, where they lose water, according to the reaction

$$C_6H_{12}O_6 = C_6H_{10}O_5 + H_2O.$$

The material is then stored in the form of insoluble starch ($C_6H_{10}O_5$).

The formation of the proteid compounds (nitrogenous) is more complex, but it, too, is carried on in the laboratory of the plant, the leaves. The rapidity of growth is dependent upon leaf area. This fact should be carefully considered, and too close clipping of grass in pastures should be avoided, because such cropping lessens the size of the factory that is building more grass.

61. Leaching. It has been shown that some of the plant food may be leached out of the plant into the soil by rains, and may possibly again be made use of by the same plant for the development of other parts of the plant. Hopkins gives the following tabular extracts from Le Clerc's lectures on this subject:

TABLE V.—PLANT FOOD REMOVED FROM PLANTS BY LEACHING WITH WATER ON BASIS OF PER CENT OF TOTAL CONTENT

Plants Leached.	Nitrogen.	Phosphorus.	Potassium.	Magnesium.	Calcium.	Sodium.	Chlorine.
Wheat, in early bloom	1	0	4	10	0	12	
Wheat, fairly ripe	7	33	54	46	34	41	60
Wheat, dead ripe	25	21	65	58	55	56	90
Oats, from 8 ins. in height to ripeness; total removed by repeated leaching	2	33	36	45	40	23	40
Potato vines	7	50	30	12	9	30	50

Similar experiments have been conducted by German investigators. These investigations show that little plant food is leached during the early stages of growth, but that there is considerable leaching as the ripening proceeds.

CHAPTER IX

THE FORMATION, COMPOSITION, AND FERTILITY OF SOILS

62. Formation of Soil. At one period in the history of the earth, its entire crust was igneous rock. Many agencies have been working through untold ages to develop the soil into its present condition. The weathering of rock has proceeded at different rates, being governed by the activities of the agencies involved. Weathering is brought about by chemical, physical, and biological means. The agencies of weathering are the atmosphere, water, heat, cold, gravitation, electrical discharges, and organisms.

The chief action of the atmosphere is chemical, brought about mainly through oxidation and the solvent effects of carbon dioxide in solution. The atmosphere also exerts physical influences that hasten rock decay. Winds blow particles against other particles, producing abrasion, and by blowing against trees and plants, cause them to act as levers, which press the soil particles against each other, thus causing them to grind and wear one another away.

Water, in addition to its solvent action, has a physical influence on the soil, in that rainfall causes the rubbing together of soil particles, thus producing some erosive effect. Surface water causes the wearing of soil particles against each other and thus increases their fineness. The erosion of the land tends to reduce the soil nearer to a base level.

Heat and cold have the same physical effects on rocks that they have on other substances, rocks expanding when heated and contracting on cooling. The units which go to make up rocks are *minerals*. Different minerals have different rates of expansion and contraction, consequently,

Fig. 26.—Soil formation on deeper rock layers.

when sudden changes of temperature occur, there is a tendency to break up the rock. The surface of the rock is subjected to more rapid changes, due to outside influence of heat and cold, and this influence tends to form flakes, cracks, and crevices, even on the outer surface of the same mineral. Water is retained in the cracks and crevices, and exerts its solvent influences. Then also, when water cools, it first contracts, becoming densest at 4° Centigrade, then expands till the temperature falls to zero. These changes of volume tend to break up rocks. When the water freezes, there is a sudden expansion by which such enormous pressure may be exerted as to shatter the strongest rocks.

After soil is formed in the crevices of rocks, plants grow, and the roots of these plants have a solvent effect on the rock, due to the excretion of sap. Later, when more soil has formed, trees may grow between the rock masses, exerting a powerful force tending to separate the masses. In addition to this action of plants and trees in separating masses of rock, minute plant organisms, such as lichens and mosses, grow on rock surfaces and form soil which is either washed off or deepens until it furnishes a home for higher orders of plants, which in turn are followed by trees. These growing trees and plants get their plant food from deep down in the soil, and drop their leaves on the surface of the ground. The decay of these leaves impregnates the soil moisture with carbon dioxide, in which condition it has a much greater solvent effect on the mineral portion of the soil underneath. The soil layer is thus continuously deepened through additional deposits above and the continued solution of the rock beneath.

Glaciers have exerted in past ages a powerful influence on soil formation. These vast ice fields crept slowly southward, grinding the rocks beneath them to a condition of great fineness. Some of the richest soils of the world are of glacial origin.

Rivers emptying into the ocean, on account of the checking of the current and the action of the salts in the sea water, deposit the materials carried in suspension. These materials gradually accumulate on shallow bottoms until marsh lands are formed, and the building is continued through the action of winds, waves, tides, and plants until soil is gradually formed. There are many organisms in the ocean, such as coral polyps and shell-fish, that build up islands. The sea bottom is the seat of many soil-forming activities, and vast areas of sea bottom have been elevated to form some of our most fertile soils. Sandstones, shales, and marls are formed at the bottom of the ocean.

FIG. 27.—Residual soil, Piedmont region. (By permission F. G. Tarbox, S. C. Exp. Station.)

63. Composition of Soils. About ninety-eight per cent of the earth's solid crust consists of the eight elements: oxygen, silicon, aluminium, iron, calcium, potassium, sodium, and magnesium, here arranged in the order of their abundance. These elements make up the common minerals, which, in turn, make up the common rocks.

The difference in the chemical composition of different soils is due to the differing compositions of the rocks from

FIG. 28.—Coastal plain soil. (Photo by Director J. N. Harper, S. C. Exp. Station.

which the soils are derived, the method of rock decay, and the conditions under which it has existed since its formation. The soils that have remained where they were originally formed are of two kinds, *residual* and *cumulose*, the latter being the result of the accumulations of plant residues. The residual soil is the result of rock decay, and represents the portions of the products that remain on the parent rock. This consists, in a large measure, of the elements most insoluble, which, however, represent but a small part of the original rock. There is very little carbonate of lime in residual soils; even those derived from limestone rock are often deficient in calcium carbonate, the soil itself being simply the remains of the impurities in the original limestone rock. The carbonate of lime has been converted into soluble calcium bicarbonate, when it has come in contact with water containing carbon dioxide, and then it is leached out of the rock. Soils derived from granite or gneiss are generally of a clayey nature. Soils from marine formations are often sandy. Both classes grade into clay loam or sandy loam as the case may be.

The transported soils are formed from the products of rock decay mixed with a certain amount of organic matter. These materials have been transported from the place where they were formed by such agencies as water, ice, wind, and gravity. Their composition will vary to a considerable degree.

Soils that have been transported by water are classified as *marine*, *alluvial*, and *lacustrine*. Marine soil is formed by the deposits in the ocean beds, which are subsequently elevated. Alluvial soils are formed by the deposition of material along the shores of streams, and are very variable in composition. Lacustrine soils are formed in the beds of lakes or ponds which are subsequently drained.

The wind-borne, or *aeolian*, soils are rather extensively represented by the loess soils of the central parts of the United States. This wind-deposited soil covers to varying depths parts of the Mississippi basin. The loess deposits extend from Illinois and Iowa as far south as some parts of Mississippi.

FIG. 29.—Saprophytic plants called "frog stools" indicate that decay has begun. (Farmers' Bulletin 468, U. S. Dept. Agr.)

The gravity-moved soils are termed *colluvial,* and are not very extensive.

64. Gain and Loss of Plant Food. Two sets of factors affect the fertility of soil, both of which may be modified by artificial means. One set of factors tends to impoverish the soil; the other set is constructive. It is necessary to distinguish those factors which exhaust the soil from those which build it up, and to know how to minimize the former and to magnify the latter. In the natural state, there usually is a process of enrichment due to the accumulation of plant food elements in the surface soil. These elements are left in the residues of decaying organic matter. In the process of decay, the organic matter furnishes food for myriads of bacteria, some of which have the power of fixing the nitrogen of the atmosphere in a form that plants can make use of for their growth. These organisms must not be confused with the bacteria that exist in symbiotic union with legumes, and fix nitrogen in such a form that either the legume or a companion crop may make use of it. The bacteria on legumes grow on living plants, and may be termed *parasitic* in their mode of life, while the bacteria that live on dead tissues may be termed *saprophytic.* There is a point reached in the accumulation of plant food in the soil from the plant residues at which the increase and the loss in plant food about balance, due to loss through leaching.

65. Importance of the Rotation of Crops. When land is planted to clean-cultured crops, two sets of losses to the soil are operative; one, due to the amount of plant food removed in the crop, and the other due to the increased rapidity of nitrification brought about by cultivation, and consequently, increased losses through leaching.

There are advantages incidental to rotation. It is a well-established fact that some plants take up greater amounts of some elements than do others; that some plants possess the power of taking their food from compounds that others are powerless to use. Some plants have a longer growing season than others, and although they may take as much food from the soil, yet the drain is lighter, owing to the longer growing season. The root systems of plants differ considerably, and the area occupied by the root system limits the area from which the plants feed. The cultivation of crops differs, and the influences of the cultivation of a previous crop must be considered when we plan a rotation.

The practice of the proper systems of rotation makes it possible to maintain, at low cost, the supply of organic matter in the soil. Organic matter may be supplied in the form of animal manures, but this source of supply is very limited when we consider the total area in cultivation. Some organic matter is also accumulated in pastures and in woodland, but these methods of incorporating organic matter are quite slow. The incorporation of residues from field crops, especially the leguminous crops, is the best method for increasing the amount of organic matter in the soil.

Fig. 30.—Field of Cowpeas ready to plow under. (Farmers' Bulletin 278, U. S. Dept. Agr.)

TABLE VI.—THE CONTENT IN PLANT FOOD OF CERTAIN AIR-DRIED LEGUMINOUS CROPS

	Percentage Composition.		
	Nitrogen (N).	Phosphoric Acid (P_2O_5).	Potash (K_2O).
Red clover, medium	2.07	0.38	2.20
Red clover, mammoth	2.23	0.55	1.22
Alsike clover	2.34	0.67	2.23
White clover	2.75	0.52	1.81
Crimson clover	2.05	0.40	1.31
Alfalfa	2.19	0.51	1.68
Cowpea	2.50	0.52	1.47
Bean	1.91	0.40	1.32
Vetch	2.80	0.75	2.30

TABLE VII.—COMPOSITION OF VARIOUS CROP RESIDUES

	Percentage Composition.		
	Nitrogen (N).	Phosphoric Acid (P_2O_5).	Potash (K_2O).
Corn stalks	0.80	0.18	1.04
Wheat straw	0.59	0.12	0.51
Oat straw	0.62	0.20	1.24
Cotton bolls	1.36	0.40	2.90
Cotton leaves	2.37	0.46	0.83
Cotton stems	0.83	0.22	0.92
Cotton roots	0.17	0.24	0.86
Cowpea vines	2.50	0.52	1.47
Alfalfa	2.19	0.51	1.68
Soy bean straw	1.75	0.40	1.32
Red clover, medium	2.07	0.38	2.20
Red clover, mammoth	2.23	0.55	1.22
Alsike clover	2.34	0.67	2.23
White clover	2.75	0.52	1.81
Crimson clover	2.05	0.40	1.31
Pasture grasses (mixed)	0.91	0.23	0.75
Timothy	0.48	0.26	0.76
Orchard grass	0.43	0.16	0.76
Sorghum	0.23	0.09	0.23
S. potato vines	2.00	0.28	2.81

Rotation encourages diversified farming, which, when properly carried on, greatly aids in keeping the land in good condition. When the single-crop system is employed, if that crop is a clean-cultured one, as is usually the case, the organic matter of the soil becomes depleted, the soil erodes more easily and, consequently, " gullying " sets in. When land once begins to wash, it is difficult to keep the most valuable part of the soil from being lost. The topsoil is the most active in furnishing plant food and in promoting plant growth. When this soil is washed away, the land becomes unproductive and it takes many years of careful building to restore it to its former fertility. The rebuilding of soil is time-consuming and expensive, therefore care should be exercised to prevent erosion. Erosion may be prevented by the incorporation of organic matter, deep plowing, and, in some cases, by terracing.

FIG. 31.—A cover crop on corn land. (Permission F. G. Tarbox, S. C. Exp. Station.)

66. Proper Sequence of Crops. In arranging rotations, the endeavor should be to avoid having a crop that feeds heavily on a particular element, followed by another crop that feeds heavily on the same element; nor is a crop that requires a large amount of any particular element adapted to a soil that does not contain a fair amount of that element. Shallow-rooted crops should be followed by deep-rooted crops; clean-cultured crops as much as possible by crops that will leave much organic matter to be incorporated in the soil. Leguminous crops should be used frequently in rotations, in order that the largest amount of the expensive element, nitrogen, may be obtained from the supply that exists in the atmosphere. It is only when a high-priced crop is being grown that a farmer can afford not to rotate his crops.

67. Use of Manures. When manure is intelligently conserved, a profit can be made by feeding leguminous crops to stock and, while obtaining profit on the increase in flesh, recovering most of the fertilizing elements in the manure, in a better state of mechanical division than it was as plant tissue. It does not follow necessarily, however, that the plant food will be more available in manure than in the plant tissues. The question for the farmer to decide is, whether or not it is more economical for him to feed the crops to animals, conserve the manure and apply it to his soil, or to incorporate the organic matter from the crops directly in the soil. Hopkins, in his "Soil Fertility and Permanent Agriculture," gives the table on page 88, showing that a large part of the organic matter during the processes of digestion and assimilation is decomposed into carbon dioxide and water, and that little over 25 per cent of the dry matter is recovered in the manure.

Doubtless, the best practice for the farmer to follow will depend upon the money value of the crop that he grows. If, for example, a valuable crop is to be grown for market, it will pay to grow a previous crop and incorporate it in the soil, provided the increased yields of suc-

TABLE VIII.—THE AVERAGE DIGESTIBILITY OF SOME COMMON FOOD STUFFS

Food Stuffs.	Percent Digested of Total in Food.		Dry Matter of Food: Recovered in Manure.	
	Dry Matter.	Nitrogen.	Percent.	Pounds per Ton.
Pasture grasses	71	70	29	580
Red clover, green	66	67	34	680
Alfalfa, green	67	81	33	660
Mixed meadow hay	61	57	39	780
Red clover hay	61	62	39	780
Alfalfa hay	60	74	40	800
Oat straw	48	30	52	1040
Wheat straw	43	11	57	1140
Corn stover	60	45	40	800
Shock corn	63	42	37	740
Corn-and-cob meal	79	52	21	420
Corn ensilage	64	49	36	720
Oats	70	78	30	600
Corn	91	76	9	180
Wheat bran	61	79	39	780

ceeding crops will more than repay for the value of the crop returned to the soil. If, on the other hand, the crops grown will not fulfill the above requirements, it will pay to use the plants for feed, and to carefully conserve the manure. However, it has been shown that there is a considerable loss in organic matter, due to the exhalation of carbon dioxide by the animals to which the material is fed. There is a further loss of nitrogen due to the formation of muscle and sinew, which contain a large percentage of this element; and of phosphorus and potassium due to the formation of bone. From the foregoing statements, it

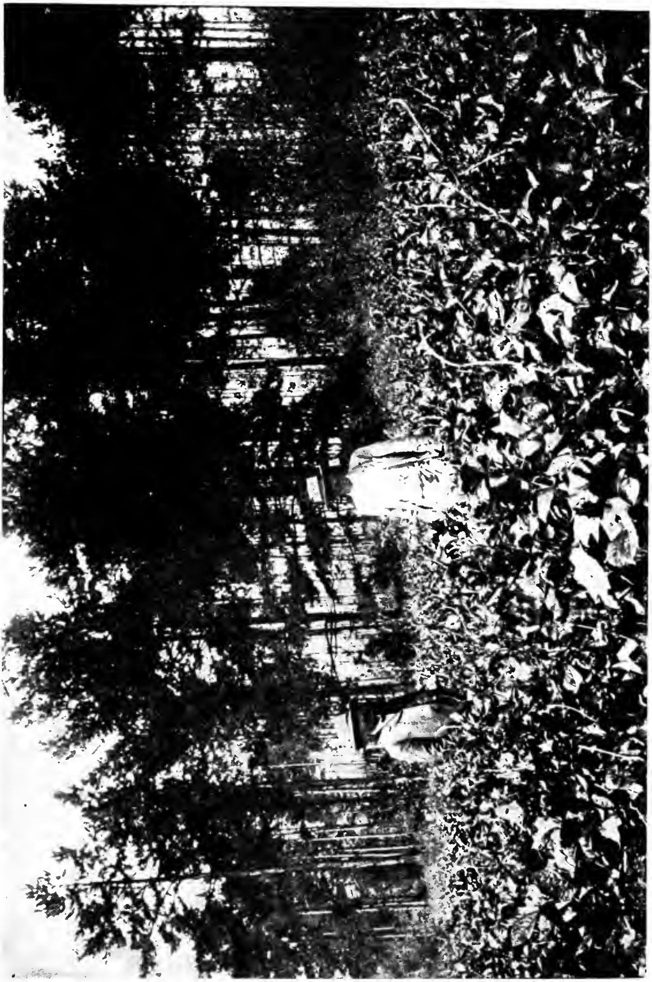


FIG. 32.—A catch crop grown on residual soil. (By permission Director J. N. Harper, S. C. Exp. Station.)

can readily be seen that a young and growing animal will remove considerably more plant food and use it in the elaboration of tissue than will a mature animal. Another factor influencing the composition of the manure will be the composition of the feed. The third factor, which is probably the most important of all, is the care of the manure. If, after carefully considering his own conditions, the farmer decides that it is more profitable for him to feed the crop and return the manure to the land, which is usually the decision reached in diversified farming, there are several factors still to be considered; these will be discussed in the following chapter.

68. Keeping the Land Covered. Under the prevailing methods of crop growth, the land is allowed to lie bare a part of the year. During this time, especially if the weather is warm, there is some nitrification going on, and much plant food is lost through leaching. It is good practice to keep a growing crop on the land as much as possible, to take up the plant food as it becomes available and convert it into an organic form. If such a crop is planted as a winter protection to the soil, it is known as a *cover crop.* The cover crop is a material aid in the prevention of washing, because it fills the soil with fibrous roots which tend to hold the soil together. When a crop is planted between two other crops, it is known as a *catch crop.* An example is the planting of cowpeas or soy beans after grain has been harvested and before another grain crop is planted.

When leguminous plants can be used for cover or catch crops, or in connection with other crops used for this purpose, they serve another purpose; that of collecting nitrogen from the atmosphere and storing it in such a form that it is available as plant food. A more general use of cover crops and catch crops, especially of the legumes, will mark a great step forward in our agricultural development. For cover crops, clovers, vetch, oats, and rye are excellent. For Southern conditions, soy beans and cowpeas for summer crops, and vetch, oats, and rye for winter, are most easily grown, though crimson clover, red clover, and burr clover are excellent when established. At the North, the clovers are favorites, because they may be included in the regular rotations.

CHAPTER X

ANIMAL MANURES

69. Quality. The quality of animal manure depends largely upon three factors: The composition of the feed, the age of the animal fed, and the handling to which the manure is subjected. The causes which account for the influence of the age of the animal have already been discussed in Sec. 67, and they show the importance of feeding mature animals as much as practicable, where the composition of the manure is a consideration. The use of feeds rich in nitrogen, phosphoric acid, and potash, where the price of such feeds permits, produces the most valuable manures. Cottonseed meal, a feed rich in the elements named, sells for a reasonable price, and can be fed in moderation to advantage to all farm animals except hogs. It is the cheapest source of protein on the market. In buying feeds and in compounding rations, the plant food content of the feed should receive consideration.

70. Liquid Manures. It is very important that an abundant supply of absorbent litter be used in the stables, to take up the liquid manure. It is best to use a litter that readily nitrifies and that carries as high per cent of plant food as possible. Table IX gives the compositions of some materials suitable for bedding. Some of the materials, corn stalks for example, should be shredded before being used.

Table X emphasizes the fact that most of the nitrogen and potash is voided in the liquid manure, and it further shows that an abundant supply of absorbent litter should be used to conserve properly the liquid manure. The manure furnishes an excellent medium for bacteria, and, consequently, hastens the availability of the plant food in the litter.

TABLE IX.—MATERIALS SUITABLE FOR BEDDING

	Phos. Acid, Per Cent.	Nitrogen, Per Cent.	Potash, Per Cent.
Corn stalks	0.30	0.70	1.40
Wheat straw	0.12	0.59	1.51
Oat straw	0.20	0.62	1.24
Rye straw	0.28	0.46	0.79
Marsh hay	0.36	0.97	1.46
Sweet potato vines	0.28	2.00	2.81
Cotton bolls	0.40	1.36	2.90
Cotton leaves	0.46	2.37	0.83
Cotton stems	0.22	0.83	0.92
Long-leaf pine straw	0.24	1.00	0.41
Short-leaf pine straw	0.15	0.77	0.21

TABLE X.—THE CONTENT OF PLANT FOOD PRESENT IN SOLID AND LIQUID MANURE, ACCORDING TO VIVIAN

	Nitrogen, Per Cent.		Phosphoric Acid, Per Cent.		Soda and Potash, Per Cent.	
	Solid.	Liquid.	Solid.	Liquid.	Solid.	Liquid.
Horses	0.50	1.20	0.35	trace	0.30	1.50
Cows	0.30	0.80	0.25	trace	0.10	1.40
Swine	0.60	0.30	0.45	0.125	0.50	0.20
Sheep	0.75	1.40	0.60	0.05	0.30	2.00

TABLE XI.—NITROGEN, PHOSPHORIC ACID AND POTASH PRESENT IN ROTTED MANURES

	Per Cent Phos. Acid (P_2O_5).	Per Cent Nitrogen (N).	Per Cent Potash (K_2O).
Horse manure, rotted	0.40	0.50	0.50
Cow manure, rotted	0.30	0.50	0.45
Sheep manure, rotted	0.80	0.65	0.60
Hog manure, rotted	0.80	0.60	0.30
Hen manure	0.25	1.30	0.20

71. Rotted Manures. Table XI shows that rotted sheep manure has a higher nitrogen content than any other

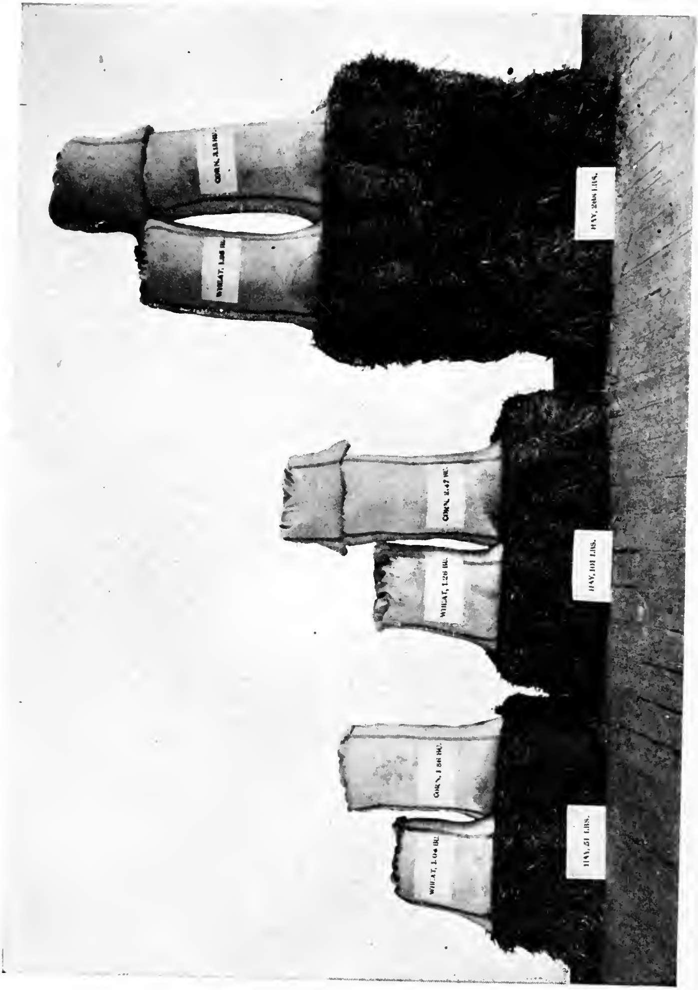


FIG. 33.—Produced by one ton of manure. (Bulletin 180, Ohio Exp. station.)

rotted manure, and next to this comes hog manure. The nitrogen content of horse and of cow manure when rotted is nearly the same. The horse and the cow manure contain more potash than the manure from hogs. On the other hand sheep and hog manures run higher in phosphoric acid. An explanation of this can probably be found in the fact that the horse and the cow largely make use of different sources of feed than those consumed by hogs and sheep.

Horse manure ferments very rapidly under certain conditions, and the best method for the farmer to pursue is to haul the manure to the field frequently and apply it to a growing crop; but such method is often impracticable, due to the extra labor entailed, inclemency of the weather, and the fact that there is not always a growing crop available. Where horse manure is kept in a pile for some time, it must be packed down sufficiently to prevent violent nitrification, followed by denitrification, which is known as *firefanging*. This latter condition results in the loss of much of the nitrogen, and the material is just as truly ashed in the firefanged spots as though it had been in the fire. When manures firefang, they heat and liberate gases both injurious and uncomfortable to the animals. There is little danger of firefanging of cow manure because this manure will not heat.

72. Effect of Exposure to the Weather. In handling dairy cattle, it is absolutely necessary that the stalls be kept scrupulously clean. In such a case it may be advisable that the manure be hauled out every day, if possible, and spread upon the land that has, or is soon to have, a growing crop. Preferably the manure should be plowed in as soon as possible. It has been shown at the Maryland Experiment Station that, when 80 tons of manure were exposed to the weather for a period of one year, the weight was reduced to 27 tons. At the Experiment Station of the Dominion of Canada, when 2 tons of manure, containing 1938 pounds of dry matter, were exposed for four summer months, the dry matter was reduced to 655 pounds through the agencies of fermentation and decay. During the same time, the nitrogen content was reduced from 48.1 pounds to 27.7 pounds. These experiments, as well as many more that could be cited, show the importance of applying the manure and incorporating it into the soil as soon as possible.

73. Rate of Application. The rate of application of animal manures should vary considerably. It depends upon two factors: The supply of manure and the section of the country. The reason that the supply is a factor, is that manure is a good medium for the growth of bacteria, in addition to the plant food content; therefore it should be spread over as much land as practicable to furnish bacteria flora to the soil. Conditions affecting nitrification differ in various sections of the country. Thus the conditions prevalent in the southeastern part of the United States favor rapid nitrification; in fact, very noticeable results have been obtained in South Carolina from the use of only 2 tons of manure per acre, applied to cotton. On the other hand, the conditions existing further north favor slower nitrification; consequently, heavier applications are necessary, but heavy applications under these conditions are more lasting in their influence. For general farm crops in the South, it is advisable to apply about 6 tons of manure per acre, while in some Northern sections of the United States, from 12 to 20 ton applications frequently are made.

CHAPTER XI

AGRICULTURAL LIME

74. Sources of Lime. Lime is found in limestone (mainly $CaCO_3$) which is widely distributed over the United States, principally as calcite, dolomite, marl, chalk, and deposits of the shells of mollusks or other marine animals. Limestone, when burned, yields calcium oxide, called *quick lime*, which, when slaked with water and mixed with sand, is made into mortar. Dolomite is rock composed mainly of the carbonates of calcium and magnesium. Marl consists of calcium carbonate mixed with clay, or peat in varying proportions. Its calcium carbonate content ranges from 5 to 90 per cent.

75. Effects of Lime on the Soil. Lime is beneficial to the soil on account of its chemical, physical, and biological effects. Lime also acts as a direct plant food; for calcium is one of the ten elements necessary for plant growth, although it is used by plants in less amount than is potassium or magnesium. Any of the soluble salts of calcium may serve to furnish the element calcium for plant food. However, only three forms—calcium oxide (quick lime), calcium hydroxide (slaked lime), and calcium carbonate (limestone)—serve to correct acidity of the soil. The correction of acidity has an important influence on the development of the bacterial flora, and it also assists nitrification by furnishing a basic material to combine with the nitric acid which is formed when the nitrogen of the air becomes " fixed " or oxidized.

The different compounds of calcium vary in their chemical action upon soil. Calcium oxide, or quick lime, being a caustic, is very active chemically. It decomposes organic matter, corrects acidity, furnishes the element calcium, and by means of its chemical activity reacts with other bases in the soil. An example of this last effect is found in the reaction between lime and the zeolites of the soil, which are the double silicates of aluminium and some other base, the base being changed by substitution of calcium due to the action of lime. In this way, lime may serve to liberate potassium, which must be present in available form in a fertile soil. Lime may also bring about reactions with the phosphates of iron or aluminium, the product being a phosphate of lime, which is more soluble and therefore more available for plant food than the phosphates of iron or aluminium.

Calcium hydroxide is produced by the action of water upon quicklime and is similar in its action to calcium oxide. When applied to the soil, calcium oxide is quickly converted into calcium hydroxide by moisture

$$CaO + H_2O = Ca(OH)_2,$$

which, in turn, is rapidly converted by the carbon dioxide of the air into calcium carbonate

$$Ca(OH)_2 + CO_2 = CaCO_3 + H_2O.$$

Calcium carbonate is not caustic, and consequently it is much less drastic in its effects than is the oxide or hydroxide. Carbonates are easily decomposed by acids, therefore the application of ground limestone serves to correct acidity in soils. In humid regions probably it is rapidly converted into calcium silicate. Calcium carbonate fulfills most of the functions performed by calcium oxide and calcium hydroxide, but it acts in a much milder manner. Calcium silicate ($CaSiO_3$) and calcium sulphate (Ca_2SO_4) or "land plaster," serve most of the functions of the other forms of lime except the correction of acidity, the effectiveness of the salts varying with their solubilities.

Lime modifies the physical structure of soils. It tends to flocculate clay, permitting a freer circulation of capillary water. It also serves to bind together sandy soils, making them more compact. The action of caustic lime on muck or peat soils is usually very beneficial: first, because it brings about the rapid destruction of organic matter, accompanied by the liberation of considerable amounts of soluble plant food; second, because it promotes the decomposition of the excess of organic matter, resulting in improved structure of the soil. When caustic lime is applied, there

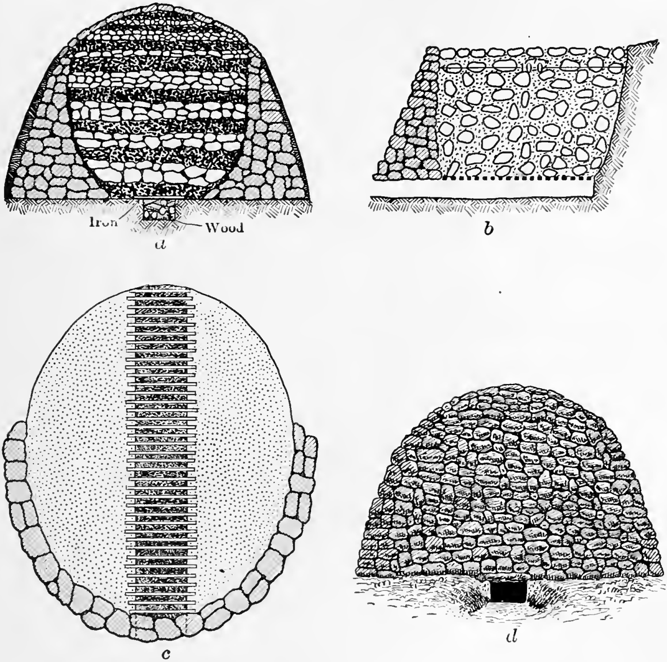


FIG. 34.—Burning lime on the farm. Details of construction of a farm limekiln. *a*, Cross-section, showing layers of rock and coal; *b*, longitudinal section, showing side hill used as back wall; *c*, ground plan, showing trench and grate; *d*, completed kiln, walled in and plastered with mud. (Farmers' Bulletin 435, U. S. Dept. Agr.)

is danger of depleting the organic matter in soils which are not well supplied with it, but this does not hold true for applications of calcium carbonate. In soils moderately well supplied with organic matter, the use of heavy applications of caustic lime may lead to the liberation of more available nitrogen than the plants can use. In this case some plant food, especially nitrogen, will be lost. Excessive applications of caustic lime, even to clay soils, may lead to the flocculation of the clay to such an extent that percolation will be too rapid. The flocculating power of lime may be illustrated by adding lime water or milk of lime to water containing clay in suspension, when it will be observed that the clay particles rapidly settle out.

Caustic lime, when applied excessively, may exert a harmful effect on the soil bacteria, and temporarily arrest to some extent the useful functions performed by these agents; but this form of lime, when applied in moderate amounts, is usually quickly changed to a neutral salt, either calcium carbonate or calcium silicate. The former salt is still effective to correct acidity, but calcium silicate does not exert such an influence.

The fact that continuous liming without manure makes land less productive than it formerly was, has led many people to object to the use of lime altogether. The initial application of lime produces such marked results, due to its influence on the stored plant food in the soil, that the fact that its effects are indirect is not recognized and there is a temptation to continue its use at the expense of the potential fertility of the soil. It is very unusual for the soil to contain such an insufficient supply of lime that lack of calcium becomes a limiting factor in plant growth.

76. Shipping Lime. The main forms of lime marketed for agricultural purposes are " quick lime " (CaO), " water-slaked lime " ($Ca(OH)_2$) and " air-slaked lime " ($CaCO_3$). To ship agricultural lime a long distance involves large expense, due to freight charges. A ton of water-slaked lime, or calcium hydroxide, contains only 1513 pounds of calcium oxide, the remaining 487 pounds consisting of water, and a ton of air-slaked lime, or calcium carbonate, contains only 1120 pounds of calcium oxide, the remaining 880 pounds being composed of carbon dioxide, while quicklime should be pure calcium oxide. On this basis of comparison, we see that it is much more expensive to freight a given amount of calcium in the carbonate or hydroxide form than in the oxide form. In shipping, it is necessary that the quicklime and water-slaked lime be barreled or sacked, because by exposure to moisture and air both of these materials are transformed into air-slaked lime, and also on account of the difficulty of loading and unloading these caustic materials. The air-slaked lime, or ground limestone rock, which are each calcium carbonate, and not caustic, may be handled without containers.

The same condition holds for hauling the different forms of lime from the railroad station to the farm that held in the freight charges. It is most economical to haul the quicklime, the water-slaked costing somewhat more, and the carbonate of lime is most expensive for cartage, though the carbonate is the most easily handled. A smaller application of caustic lime will produce more marked effects than will a larger application of carbonate of lime, although the latter is more lasting in its influences. The amounts of other forms of lime which are equivalent to a ton of quicklime are given in Table XII.

TABLE XII

Quicklime, Pounds.	Water-slaked Lime, Pounds.	Air-slaked Lime, Pounds.
2000	2643	3571

77. Applying Lime to the Soil. Some difficulty attends the distribution of quicklime on the soil, for it is necessary to slake it before it can be spread. This is often accomplished by putting the material in small piles at regular intervals over the field and covering the piles with moist earth, which promptly water-slakes the lime, making it into a powdered condition in which it may easily be spread from the piles.

Fig. 35.—Effect of liming spinach. (R. I. Exp. Station.)

A number of State Experiment Stations have investigated the use of lime, in various forms, with the general conclusion that best results are obtained from the use of calcium carbonate. Results at the Pennsylvania Station, covering a period of over sixteen years, indicate that on plots to which caustic lime ($Ca(OH)_2$) was applied as compared with the application of twice the quantity of ground limestone ($CaCO_3$) there was a loss from the caustic lime, during that period, of 375 pounds of nitrogen, without a corresponding increase in yield.

At the Rhode Island Station, it was found that Kentucky blue grass, timothy, awnless brome grass, meadow oat grass, tall fescue, and orchard grass were benefited, while red top and Rhode Island bent did well without lime. Beets and spinach showed marked effects from liming, less marked effects being shown on rye, carrots, and crimson clover. The following plants were improved, due to application of lime: Strawberries, asparagus, rhubarb, white mustard, leeks, endive, mangel wurzels, muskmelons, dwarf brown corn, sweet peas, and poppies. Watermelons are greatly injured by applications of lime, and should not be planted on limed soil until three or four years have elapsed

FIG. 36.—Distributing lime with a lime spreader. (Bulletin 159, Ohio Exp. Station.)

since the application. Parsley and chicory show little benefits from liming.

It is advisable to apply lime in autumn, preferably after a large amount of vegetable material has been turned under. The lime may be applied by means of machines especially constructed for the purpose, and should be spread as evenly over the surface of the soil as possible, and disk-harrowed in to the depth of about two inches.

78. Machine for Applying Lime. The Ohio Station makes the following recommendation for constructing a home-made machine for the application of ground limestone.

Make a hopper similar to that of an ordinary grain drill, measuring inside 8¼ feet or 11 feet long with sides about 21 inches wide and about 20 inches apart at the top. The sides may be trussed with ⅜-inch iron rods running from the bottom at the middle to the top at the ends of the hopper. Let the bottom be 5 inches wide in the clear, and cut in it crosswise a row of diamond-shaped holes, 2 inches wide, 2½ inches long, and 4 inches apart (6 inches between centers). Make a second bottom with holes in it of the same size and shape as those of the main bottom, and so shaped that they will register. Let this second bottom slide loosely under the first, moving upon supports made by leaving a space for it above bands of strap iron 12 inches apart, which should be carried from one side to the other under the hopper to strengthen it. The upper bottom piece may be made of about 8-inch sheet steel, and the lower one may be smooth, seasoned hard wood, about 1 inch thick and 7 inches wide, reinforced with strap iron if necessary, and well oiled or painted. To this under strip attach a V-shaped arm, extending an inch in front of the hopper, with a half-inch hole in the point of the V, in which drop the end of a strong lever, bolting the lever loosely but securely to the side of the hopper, and fasten to the top of the hopper a guide of strap iron, in which the lever may move freely back and forth. The object of this lever is to regulate the size of the openings by moving the bottom board. Make a frame for the hopper, with a tongue to it, similar to the frame of an ordinary grain drill.

Get a pair of old mowing-machine wheels with strong ratchets in the hubs, and with pieces of round axle of sufficient length to pass through the frame and into the ends of the hopper, which are to be welded to a square bar of iron about 1⅜ inches in diameter and the length of the inside of the hopper. The axles should be fitted with journals, bolted to the under side of the frame.

Make a reel to work inside of the hopper by securing to the axle, 12 inches apart, short arms of $\frac{3}{8}$-inch by 1-inch iron, and fastening to these arms four beaters of $\frac{5}{8}$-inch square iron, about an inch shorter than the inside of the hopper, the reel being so adjusted that the beaters will almost scrape the bottom of the hopper, but will revolve freely between the sides. The arms may be made of two pairs of pieces, bent so as to fit around the axle on opposite sides, and secured by small bolts passing through the ends and through the beater, which is held between them. The diameter of the completed reel is about 5 inches, and it serves as a force feed.

Two pieces of oilcloth may be tacked to the bottom of the hopper, one in front and one behind, of sufficient width to reach nearly to the ground, in order to reduce the annoyance of the flying dust to man and team. Another piece may be buttoned across the top of the hopper in windy weather, if desired; but the dust of limestone or of natural phosphate is certainly no worse than the dust of the field.

A sort of second force feed has been evolved from the extensive experience of Illinois farmers in building home-made machines: Two pieces of sheet steel, each about 6 inches wide and the length of the machine, are used as a V-shaped bottom for the hopper, forming nearly a right angle at the lowest point. One piece is stationary and the other is given an endwise motion back and forth by means of a small wheel with a heavy rim waving in and out horizontally and running through a slotted piece firmly attached to the movable sheet steel. Two very small wheels forming the sides of the slot serve to reduce the friction, and a lever is arranged to throw this mechanism out of gear. One of the pieces of sheet steel is provided with an adjustment by means of which a crack is opened of any desired width, the entire length of the bottom. Thus the stone falls, not through holes or in streaks, but in a perfect broadcast. Several of these home-made machines are in use. The draft is more than with the reel alone, but they are undoubtedly more satisfactory than anything on the market.

The cash expense for such a machine, aside from the mower wheels with axle and ratchets, has varied from less than \$10 to more than \$20, depending on the cost of material and labor. Farmers with some mechanical skill hire only the necessary blacksmithing.

79. Gypsum. Many soils, especially in the Southeastern part of the United States, have received by the application of superphosphate fertilizer, a large quantity of gypsum (calcium sulphate). To make superphosphate, the ground phosphate rock is treated with sulphuric acid, the result of this action being a soluble calcium acid phosphate and gypsum in the proportion shown by the equation,

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

Rock phosphate contains other calcium salts than phosphate, such as the fluoride and carbonate, and these also appear as calcium sulphate after the action of the sulphuric acid. Considerably over one-half, often 70 per cent, of superphosphate is gypsum. This, however, is no disadvantage, for gypsum, when applied to leguminous crops for the calcium sulphate, releases potassium present in an insoluble condition in clay soils formed by the decomposition of feldspar rocks.

CHAPTER XII

PHOSPHORUS

80. Presence in the Soil. Of all minerals necessary for plant growth the compounds containing phosphorus are most liable to be deficient. The average of many analyses of the earth's crust shows the presence of only $\frac{9}{100}$ of 1 per cent of phosphorus, while many of our best arable soils contain considerably less than that amount. The phosphorus present in the soil is usually in the form of a calcium phosphate. Calcium, with its valence of two, and the phosphate radical, with its valence of three, unite in accordance with the *criss-cross* rule stated previously, so as to form normal calcium phosphate with the formula $Ca_3(PO)_2$. This is known in the trade as *rock* or *bone phosphate.* There are also two acid phosphates, the dicalcium phosphate $Ca_2H_2(PO_4)_2$, known as *reverted phosphoric acid,* and the mono-calcium phosphate, $CaH_4(PO_4)_2$, which, when mixed with calcium sulphate, is known as the *superphosphate of lime.* The reaction with sulphuric acid by which the insoluble rock phosphate is converted into the soluble superphosphate is as follows:

$$Ca_3(PO_4)_2 + 2H_2SO_4 = CaH_4(PO_4)_2 + 2CaSO_4.$$

Should there not be enough sulphuric acid to complete this reaction, or, in other words, should there be excess of rock phosphate, the following reaction may take place:

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

Thus, there will be formed the reverted phosphate, which is insoluble in water.

The inorganic phosphorus present in the soil is generally in the form of the normal calcium phosphate combined with fluorine and chlorine ($Ca_3(PO_4)_2CaFCl$), although some of it is found as the phosphates of iron or aluminium. Aluminium phosphate is a normal constituent of rock phosphate, but phosphates containing iron, even in very small amounts, are rejected, as the iron has the power in the soil, even after the treatment with sulphuric acid, to take away phosphoric acid from acid phosphates and render them insoluble. A small amount of the total phosphorus of the soil is found combined in organic compounds and is liberated by the decay of organic matter.

Experimental results have indicated that 1 per cent of the total phosphorus present in the soil is available during the course of a year. Obviously this availability will depend upon several factors, the form of combination of the phosphorus, the amount of soil moisture, the content of decaying organic matter, and the influence of added fertilizers on the solubility of the material present. It must be kept in mind that, in explanation of the low phosphorus content of normal soils, a large per cent of the phosphorus used is stored in the seed of the plant, which is generally the product sold off the farm. Assuming $\frac{5}{100}$ of one per cent of phosphorus and 2,000,000 pounds of soil in the surface area per acre, a total of only 1000 pounds of phosphorus will be present, of which perhaps 1 per cent will become available, furnishing 10 pounds of phosphorus combined in soluble compounds. Ten pounds of soluble phosphorus, providing that none leached out, would furnish per acre phosphorus sufficient to make 43 bushels of corn, or 62 bushels of oats, or 31 bushels of wheat, or cotton sufficient to amount to 375 pounds of lint. As a matter of fact, many soils do not contain as much as $\frac{5}{100}$ of 1 per cent of phosphorus, and some of the available phosphorus is lost through leaching.

81. Commercial Sources. The farmer has at his dis-

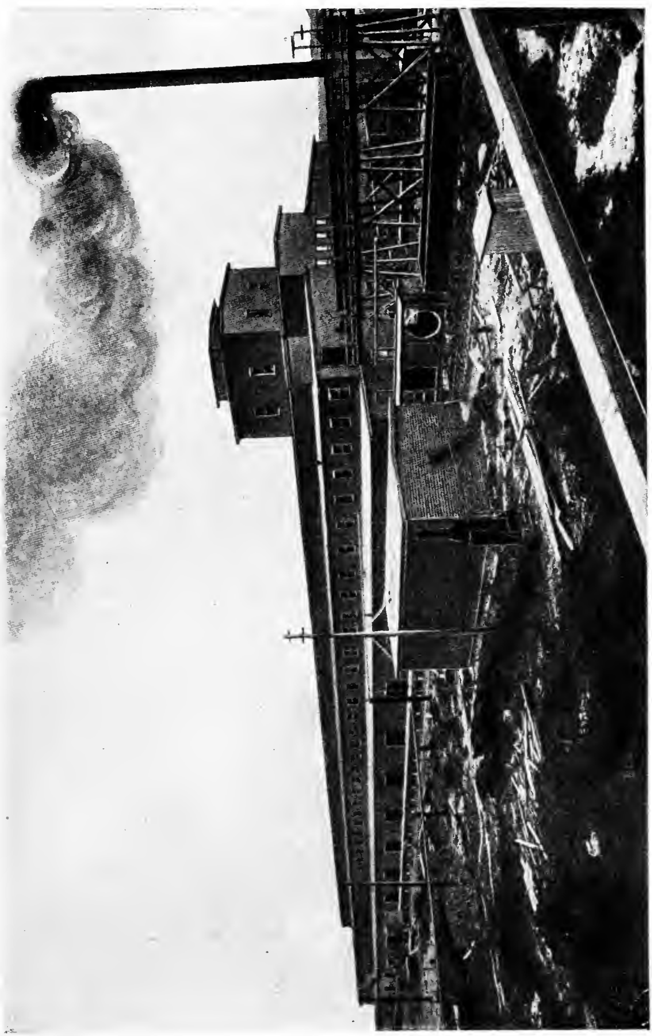


FIG. 37.—In this building phosphate rock is made into acid phosphate.

posal a number of phosphorus-bearing materials to supply a deficiency of phosphorus in the soil. The materials derived from farm lands are animal manures, bones, and some vegetable products, such as cottonseed meal, which, while valued mainly for its nitrogen, contains a considerable amount of phosphorus. But the phosphorus in these materials all came originally from the soil; so, by merely returning it, we cannot hope to keep up the normal supply. Animal manures do not contain enough phosphorus to make them a balanced fertilizer, hence it is desirable to add a certain amount of a phosphatic fertilizer. The same is true for cottonseed meal, rapeseed meal, and castor pomace, all of vegetable origin, when used in fertilizer. The most important commercial sources of phosphorus whereby the normal content of the soil may be maintained are phosphate rock, superphosphate, bone, Thomas slag, mineral phosphate, and guano.

82. Phosphate Rock. This is obtained from mineral deposits in the earth that are directly traceable to organic origin. The United States fortunately has large deposits of this rock. Those in Florida, Alabama, South Carolina, Tennessee, and Arkansas have produced enormous quantities of the rock. There are extensive deposits in Idaho, Utah and Wyoming which are not yet developed. Within the last decade considerable attention has been devoted to the use of finely ground phosphate rock as a source of phosphorus. Experiments have proved that this ground rock may profitably be used in connection with animal manures or an abundant supply of decaying organic matter derived from any source. When ground phosphate rock is purchased, it should be specified that 90 per cent of the material shall pass through a sieve having 100 meshes to the linear inch. It has been shown that when 50 to 100 pounds of these "floats" are mixed with each ton of animal manure, good results follow. It is advisable to get floats which are ground from unburned rock, for the burn-

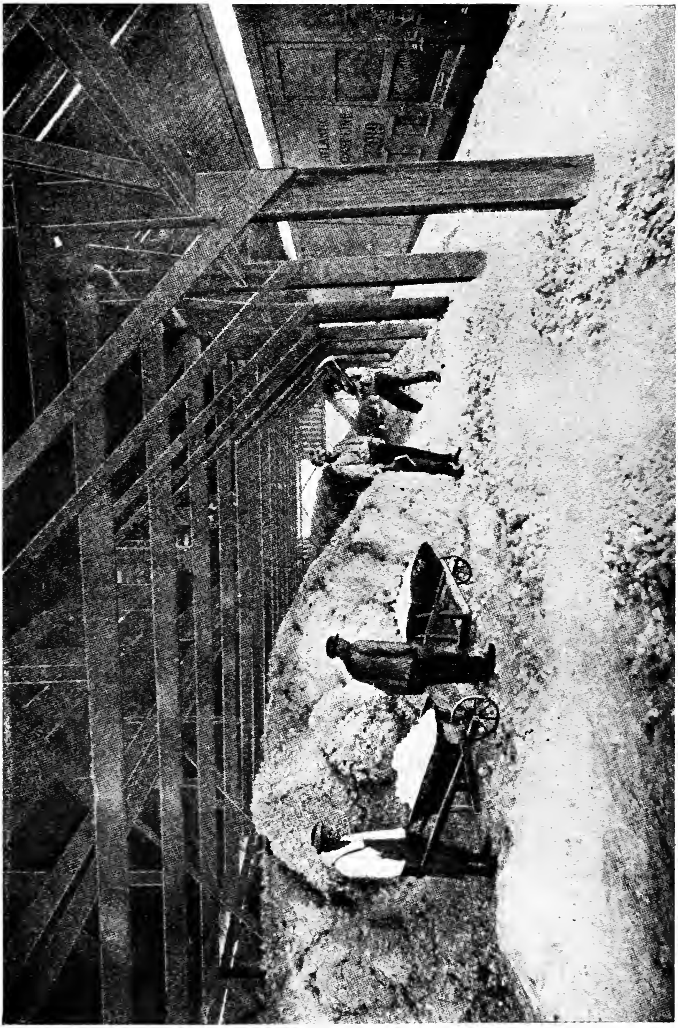


FIG. 38.—A shed of burnt rock being shipped to the factory for conversion into acid phosphate.

ing drives off the combined water and makes the material less soluble.

83. Acid Phosphate or Superphosphate. This is the form of phosphorus most used as a fertilizer. The reaction given on page 23 by which the insoluble phosphate rock is made soluble was discovered by Baron Liebig and was applied by him to the treatment of bones. About 1845, Lawes made use of this reaction for the treatment of the newly discovered mineral source of phosphorus, *coprolite*, and from this beginning the manufacture of phosphates has grown into an immense industry. Superphosphate should not be mixed with rock phosphate, lime, Thomas phosphate, cyanamid, or basic calcium nitrate, because the calcium contained in these materials would "revert" the acid salts of calcium phosphate into the insoluble dicalcium phosphate, in this way neutralizing the advantages of the acid treatment. A soluble phosphate, when applied to the soil, goes into solution in the soil water and is diffused throughout the soil. When it comes in contact with a basic material, it is precipitated in fine solid condition on the surface of the soil particles. In this way, the added phosphate is widely distributed, and the exudation from root hairs of the plant, coming in contact with it, dissolves the phosphate, which then by osmosis is taken into the plant structure.

Acid phosphate applied together with fertilizer containing nitrogen and potash gives the best results, the proper proportions for each case varying with the soil and the crop to be grown. In many cases, superphosphate, when applied alone, is advantageous, especially on land well supplied with organic matter. The fact that superphosphate carries with it much sulphate of lime or land plaster should always be remembered in connection with the use of this phosphate as a fertilizer. Land plaster has the property of aiding in the breaking down of organic matter in the soil and of liberating potash and phosphorus from

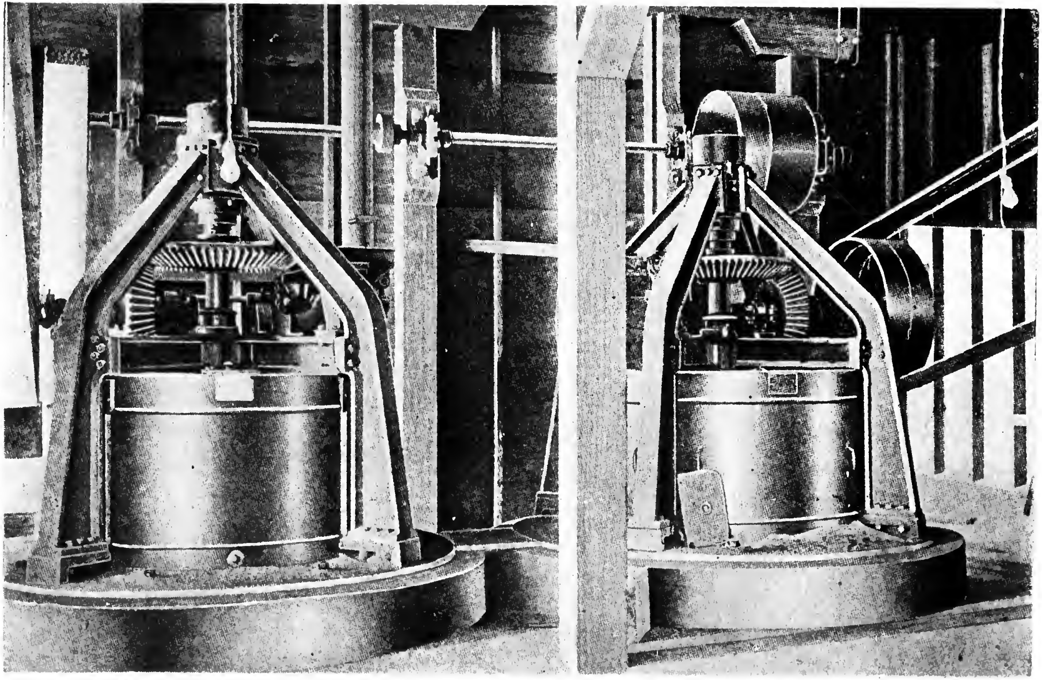


Fig. 39.—These pulverizers reduce the rock to fine dust.

insoluble compounds in the soil, in this way depleting in time the local supply. Land plaster acts similarly to lime, in that it may furnish calcium, an essential plant food element. It also assists in liberating nitrogen from organic compounds and also frees insoluble potash and phosphorus, but it does not correct acidity.

84. Thomas Phosphate or Basic Slag. In the manufacture of steel, various processes are resorted to for the purpose of removing the phosphorus from the pig-iron from which the steel is manufactured. Essentially all processes consist of lining the furnaces with dolomite, a calcium magnesium limestone, before the pig-iron is put in. The mass is subjected to a high heat, and the magnesium limestone slags off the phosphorus as calcium phosphate, which rises to the surface. This slag is drawn off from the converter, cooled, broken, finely ground and placed on the market. It is stated that slag consists of tricalcium phosphate and calcium silicate in proportions shown by the formula $(CaO)_5P_2O_5SiO_2$. This material may contain some free lime, and more lime may become soluble by repeated washings. Thomas slag gives good results on sour lands that contain organic matter, on lands rich in humus, and on lands deficient in lime. It must not be mixed with any material containing salts of ammonia—for example, sulphate of ammonia—because the free lime will liberate the ammonia as a gas, which will be lost.

85. Bone. Among the sources of phosphorus, both raw and steamed bone have held an important place. Raw bone contains 3 to 4 per cent of nitrogen in the form of organic matter, and from 20 to 25 per cent of phosphoric acid. About half of this phosphoric acid is available, more becoming available as the bone decays. The composition of the bone varies with the age of the animal, the bones of old animals usually containing more phosphorus and less nitrogen.

Bones are steamed for the purpose of removing the gelatine and glue. In this process, much of the nitrogenous material is removed; but, as the phosphoric acid is not removed to any extent, the decrease in weight of the bones caused by the materials extracted brings about a corresponding increase of the percentage of phosphoric acid. The process of extraction also removes the greases and fats which interfere with the decomposition of the raw bone in the soil. Experiments show that steamed bone acts more quickly and is more valuable as a source of phosphorus than raw bone. Raw bone is especially prized as a source of phosphorus and nitrogen for fruit trees, where a slowly available supply of these elements is desired.

FIG. 40.—Corn grown without the use of special fertilizer.

86. Mineral Phosphate. Deposits of mineral phosphates which are not derived directly from organic sources are widely distributed in rocks of igneous origin. A typical mineral phosphate is apatite, a double phosphate, and fluoride of calcium with the formula $Ca_3(PO_4)_2 \cdot Ca_2FPO_4$. Formerly large quantities of this mineral were imported from Canada for manufacture into fertilizer. The expense of mining and transportation does not permit this mineral to enter into competition with rock phosphate as a fertilizer.

Fig. 41.—Corn grown on the same area and soil as that of Fig. 40, with the addition of 500 lbs. acid phosphate and 188 lbs. dried blood per acre.

87. Guano. This material has been a rich source of phosphorus as well as of nitrogen. The standard Peruvian guano contains nearly 40 per cent of bone phosphate, corresponding to about 18 per cent of phosphoric acid (P_2O_5). Certain small, rocky islands of Peru, owing to the abundance of fish found in the waters of these coasts, have been the habitat for untold ages of enormous numbers of sea birds. Rain seldom falls in these regions and the excrement (Spanish Guano) has collected in thick deposits.

Fig. 42.—Corn grown under the same conditions as that of Fig. 40, but with 160 lbs. of muriate of potash added per acre.

From one group of these small islands, the Chincha, guano to the value of $1,000,000,000 has been taken. As a source of phosphorus guano is much more expensive than is rock phosphate and the supply is being exhausted.

88. Purchase and Application of Phosphorus. The selection of the source of phosphorus to use is largely an economic problem to be determined by the costs of the materials delivered on the farm. Lower prices for fertilizing materials are secured by buying them in car-load lots from the manufacturer or wholesaler. The author has known as great a difference as 60 per cent in cost between buying in car-load lots from the wholesaler and in buying in small quantities from the retailer.

Experiments have been conducted to determine which source of phosphorus is most effective for the different crops on different soils, taking into account the cost of the material carrying the phosphorus. The results of these experiments agree that ground phosphate rock is the most economical source of phosphorus on the market. It has an additional advantage in that its content of phosphorus is higher than that of any other commercial source, thus enabling the purchaser to transport a large number of pounds of phosphorus in a ton of material. Its chief disadvantage lies in the fact that it is the most unavailable source of commercial plant food.

Ground phosphate rock can be used to advantage under two sets of conditions:

(*a*) For sprinkling in stalls or barnyards where animal manures are accumulating. This addition of ground phosphate rock should be made at intervals so that it will become thoroughly incorporated with the manure. It is advisable to add ground phosphate rock at the rate of from 50 to 100 pounds for each ton of manure accumulated, the quantity within these limits depending upon the total amount of manure to be applied per acre. If applications of more than 12 tons of manure per acre are to be made, 50 pounds of ground phosphate rock per ton should suffice; if lighter applications of manure are to be made, 100 pounds per ton would be preferable. The thorough incorporation of the finely ground phosphate in the animal manure will subject a large surface area of that material to the action of the acids present in the manure, causing some of it to be converted into the more available forms. After the manure is applied to the field, the processes of nitrification will cause further reactions to take place which gradually render the phosphorus available.

(*b*) Ground phosphate rock can be used to advantage in a rotation which assures an abundant supply of decaying organic matter. Decaying organic matter is the key to profitable farming; few farmers realize when their soil has an abundance of this material. It is the general opinion that merely following a rotation will assure an abundance of organic matter; as a matter of fact, it is necessary that large crops be grown so that the crop residues will be large.

CHAPTER XIII

NITROGEN

89. Importance of Nitrogen. The need of nitrogen in crop production cannot be over-emphasized. The lack of a plentiful supply of this element in the organic form will inevitably make land infertile. In the formation of the earth's crust, the addition of nitrogen must have been very gradual, the first probably being due to the oxidation of atmospheric nitrogen by electrical disturbances. This operation is still effective, and oxides of nitrogen and ammonia gas (NH_3) in small amounts are washed down by rain water. Nitrogen from this source must have nourished the earliest forms of plant life, and the organic remains of these lower plant forms must have supplied the basis for our supply of organic nitrogen in the soil. Necessarily the accumulation of this supply required very long periods of time.

When enough organic matter had accumulated to make possible the growth of legumes, the accumulation of nitrogen probably became much more rapid, as these plants bear round their roots nodules which are the homes of colonies of a species of bacterium that have the power of causing the nitrogen and oxygen of the air to unite, thereby "fixing" the nitrogen. There are to-day many wild legumes still adding to the supply of nitrogen in an organic form. Therefore, the cultivation of domestic legumes, such as the clovers, cowpeas, vetches, alfalfa, field peas, beans, lupines, and peanuts cannot be urged too strongly. Certain sections of the United States make successful use of these crops in rotation, to furnish their nitrogen supply. For specialized crops, such as cotton, tobacco, sugar cane,

FIG. 43.—Compare with Fig. 44. Alfalfa. Difference in growth due to fixation of nitrogen. (R. I. Bulletin 152.)

sugar beets, and truck, it is necessary to make additional use of nitrogen derived from a commercial source. However, it is recommended that the annual legumes be used as catch crops and cover crops to supplement the artificial supply.

It is an interesting fact, established experimentally by Lipman of New Jersey, that a non-leguminous crop grown as a companion crop with a legume may derive nitrogen from the supply of atmospheric nitrogen fixed by the legume. The experiment was conducted as follows: A small glazed pot was placed in a large pot to serve as a check, while a small non-glazed pot was placed in another pot for the determination. All pots were filled with earth and a legume was planted in the outer pot in each case, and the non-legume in the inner pots. Where the non-porous inner pot was used, the non-legume made much poorer growth than where the porous inner pot was used, because the soluble nitrogen could go through the walls of the porous inner pot to serve to nourish the non-legume.

90. Commercial Nitrogen Profitable. After supplying all nitrogen that it is practicable to secure by means of leguminous crops, it is still generally advisable to apply nitrogen in the commercial form to specialized, high-priced crops. The grower of early truck can afford to purchase a large amount of high-priced fertilizer if it will improve the quality, yield, and early maturity of his product. The same will hold true to a less extent with tobacco, sugar cane, sugar beets, and cotton.

91. Selection of Source of Nitrogen. In purchasing nitrogen in its various forms, great care must be taken in the selection of the source to assure high agricultural value. As nitrogen is the highest priced element of commercial fertilizers, there are more attempts to palm off an inferior kind of nitrogenous fertilizer than in the cases of phosphorus or potassium. It is usually unwise to buy low-grade fertilizers at any price; the best are cheapest in

FIG. 44.—Alfalfa. Difference in growth due to the fixation of nitrogen. (R. I. Bulletin 152.)

the end, and the reduction in price of the inferior sources is usually not great.

The crop grown and the character of the soil should be the determining factors in the selection of the sources of nitrogen. Light sandy soils are leachy, and do not easily retain soluble plant food, therefore it is often advisable to make use of organic sources with such soils. Some crops have to be forced and require a large amount of rapidly available fertilizer; but these crops are usually so valuable that the grower can afford a certain amount of loss through leaching.

92. Inorganic Sources of Nitrogen. The sources of nitrogen may be divided into two classes—organic and inorganic. The inorganic sources of the nitrogen found in commerce in large quantities are potassium nitrate, (KNO_3), sodium nitrate ($NaNO_3$), calcium nitrate ($Ca(NO_3)_2$) and sulphate of ammonia ($(NH_4)_2SO_4$). These are all easily soluble in water. The nitrates remain soluble under all conditions until they are either used as plant food, leached out, or, as occurs under very unusual conditions, lost through denitrification. The nitrates are so soluble that they may be considered the most thoroughly predigested nitrogenous plant food and, therefore, are most efficacious when applied to a growing crop as a topdressing. Sulphate of ammonia reacts with certain soil compounds which render the ammonium radical (NH_4) less soluble in water and, consequently, more slowly available. This reaction is supposed to take place between the ammonia salts and compounds in the soils called *zeolites*. The zeolites are double hydrated silicates of aluminium with some other base which is interchangeable. Examples of zeolites are Thomsonite, $CaAl_2Si_2O_8$, and natronite, $Na_2Al_2Si_3O_{10}$. The bases that may be substituted in the zeolites are calcium, sodium, potassium, and ammonium. Sodium will displace calcium in the zeolitic compounds, while potassium will displace sodium or calcium, and ammonium will displace potassium, sodium, or calcium. Ammonia salts are constantly forming in the soil; thus nature has furnished a means for their conservation if the nitrification is not rapid enough to take up the ammonia formed. The fact that the four basic materials enumerated above are held in the relative order of their agricultural value is significant.

FIG. 45.*—Blasting a test hole in caliche to obtain nitrate of soda.

There is another action which may cause calcium to liberate sodium, potassium, or ammonium; sodium to

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* Figs. 45–50 are furnished by The Nitrate of Soda Propaganda, William S Myers, Director.

liberate potassium or ammonium; and potassium to liberate ammonium; the converse of the above. This is termed *mass action.* When heavy applications of lime are made, mass action ensues and much stored-up plant food is liberated.

Certain salts have the power of absorbing water from the atmosphere. This property is termed *deliquescence.* A very deliquescent material may be hard to preserve in a good mechanical condition, as it may absorb enough moisture to become sticky or even to dissolve in the water taken in.

FIG. 46.—Opening up a trench after blasting; extraction of caliche by piece work.

93. Potassium Nitrate, "Niter," "Saltpeter." This salt is the least deliquescent of the three common commercial nitrates. It contains nitrogen and potassium both in comparatively large percentages. The pure salt, KNO_3, contains nearly 14 per cent of nitrogen, and over 41 per cent of potassium oxide. In commerce, the percentages run 1 or 2 per cent lower than these figures. Potassium nitrate is extensively mined in India; but there is a large demand for it in the arts, especially for the manufacture of gunpowder, consequently the cost is so high that little finds its way into the fertilizer trade. Potash salts from the Stassfurt deposits in Germany have been the chief sources of potassium, but other compounds containing nitrogen are much cheaper sources of that element than is potassium nitrate.

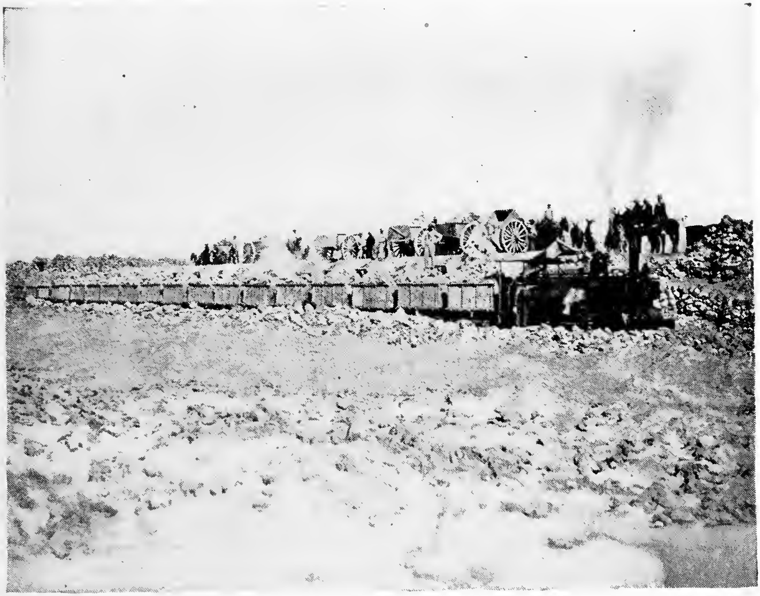

Fig. 47.—Loading caliche on railway trucks.

94. Sodium Nitrate, "Chili Saltpeter," "Soda Saltpeter." Deposits of sodium nitrate ($NaNO_3$) are found generally in the soils of arid or semi-arid regions, but only in a few regions is there a percentage high enough to warrant their leaching and purification. Very extensive deposits are located on the western coast of South America, principally in Chili, whose government derives a large income from this source. The deposit is called *caliche,* and occurs at depths ranging from 10 inches to 16 feet from the surface of the soil. The layers containing the sodium nitrate vary in thickness from 6 inches to 3 feet. This material is generally covered with a kind of conglomerate rock called *costra.* These beds are from 15 to 90 miles distant from the sea-coast and extend 220 miles in length and in some places 2 miles in breadth. It is believed that

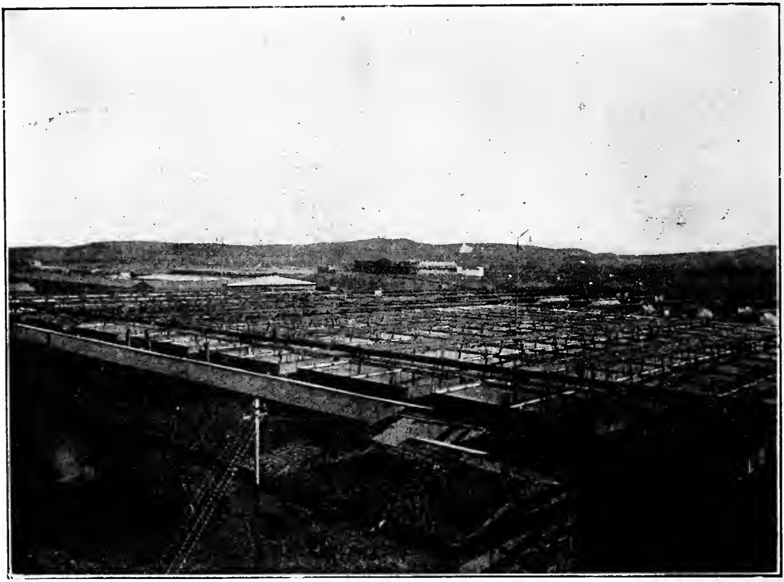

Fig. 48.—General view of crystallizing pans for obtaining nitrate of soda. Each pan has about 500 cu. ft. capacity and 225 sq. ft. cooling surface.

they were formed comparatively recently and are due to the nitrification of marine vegetation; that continued leachings from soils accumulated in great lakes in which much vegetable material grew and accumulated; and that finally these lakes became isolated, and evaporation and rapid nitrification took place. The presence of iodine in the caliche would seem to support the theory of marine formation. There are a number of impurities in the natural sodium nitrate, among which are organic matter, common salt, calcium sulphate, and insoluble silica.

Fig. 49.—Deposit of nitrate crystals in the pans of Fig. 48 after the liquor is run off.

Some niter deposits have been found in California, though these are not of so high grade as those of Chili. An average of more than a hundred analyses of these California claims shows a sodium nitrate content of about 9½ per cent. The low niter content and poor transportation facilities have prevented the development of these deposits. About 1,750,000 tons of nitrate of soda, containing about 15½ per cent nitrogen, are annually shipped out of Chili, about one-tenth of which comes direct to the United States. Some of the European supply is also reshipped to this country.

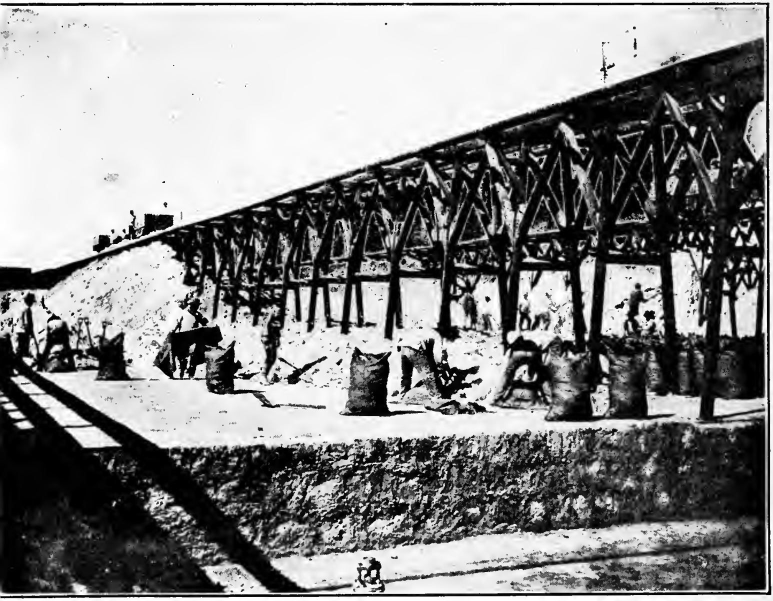

FIG. 50.—Drying floors and bagging of nitrate of soda.

95. Calcium Nitrate. After many unsuccessful attempts the compound, calcium nitrate, is now manufactured commercially in this country and abroad from nitrogen of the atmosphere by electrolytic means. In Notodden, Norway, where the large water-power is utilized to produce electric energy, three factories have been established, where, in 1911, there was manufactured calcium nitrate to the value of \$350,000. Air at the rate of 25,000 liters per minute is sent through the electric arcs spread by powerful electro magnet. About 1 per cent of the total volume of gas is oxidized to nitric oxide (NO). This oxide leaves the apparatus through a tube kept at a temperature of 500–700° Centigrade; the gases are then rapidly cooled to 50–60° C., a temperature favorable to the further oxidation of the nitric oxide to nitrogen tetroxide (NO_2). This product reacts with water to produce nitric and nitrous acids. The equation expressing this reaction is

$$2NO_2+H_2O=HNO_3+HNO_2.$$

The nitric products that fail to be absorbed in the water are caught in a milk of lime trap as calcium nitrate and calcium nitrite. The latter is liberated as nitrous oxide by treating with nitric acid. The reaction is

$$Ca(NO_2)_2+2HNO_3=2HNO_2+Ca(NO_3)_2.$$

The nitrous oxide is again put through the process of conversion into nitric acid. At least 95 per cent of the oxide of nitrogen formed is transformed into nitric acid of 50 per cent strength. The nitric acid is converted into nitrate of lime by adding it to the correct quantity of calcium carbonate, according to the reaction

$$2HNO_3+CaCO_3=Ca(NO_3)_2+CO_2+H_2O.$$

The nitrate of lime formed is 75 to 80 per cent pure, and contains about 13 per cent of nitrogen. This material must be shipped in casks on account of its deliquescence. The deliquescence of normal calcium nitrate has led to the manufacture of some basic nitrate of lime, which is accomplished by the addition of the proper amount of quicklime to the hot solution. The equation is

$$CaO+Ca(NO_3)_2=Ca_2O(NO_3)_2.$$

Basic calcium nitrate contains about 10 per cent of nitrogen.

96. Ammonium Sulphate. This material is a by-product of the gas-works, bone distilleries, and coke-ovens. It contains about 24 per cent of ammonia, and is soluble in water. Its action in the soil has already been discussed. It is a good source of nitrogen for plant food, but it is higher in price than is nitrate of soda.

97. Organic Sources of Nitrogen. The organic compounds containing nitrogen vary greatly in their agricultural value.

Animal Sources: (*a*) *Dried blood* is a by-product of the slaughter-houses. It is carefully saved, because of its high value as a source of nitrogen. The fresh blood contains about 2½ per cent of nitrogen, but, after drying, the product contains from 12 to 14 per cent. Blood is an excellent quickly available source of nitrogen for use on sandy land, and is highly prized as a source of nitrogen for sugar cane and tobacco. It nitrifies much more rapidly than the other organic forms of nitrogen.

(*b*) *Dried ground fish* is an important source and contains from 7 to 10 per cent of nitrogen, and usually from 6 to 9 per cent. of total phosphoric acid. This material is obtained as a mixture of refuse and whole fish from the herring, pilchard, and mackerel fisheries. Fish has long been used as a fertilizer. The first colonists found the Indians using it as a fertilizer for corn. Fish is more slowly available than blood, and consequently more lasting in its effects. This fact enforces the importance of using at least two sources of nitrogen on farm crops having a long growing season.

(*c*) *Tankage.* This term, variously modified, is employed to designate quite a range of fertilizing materials, and the modifying words should be carefully noted. There is a great difference between first-class slaughter tankage, consisting of the waste products of slaughter-houses, such as blood, flesh, and bone, and leather tankage which may consist of leather scraps which have not been chemically treated to render them available. Considering the fact that, in the manufacture of leather, the hide is chemically treated to make it resistant to decomposition, it can readily be seen that untreated leather will be one of the last materials to nitrify. Leather tankage is useless without treatment with sulphuric acid, but where so treated its nitrogen is available. Great care should be exercised to ascertain its value to the soil before purchasing any kind of leather tankage.

(*d*) *Peruvian guano* consists of the excrement and carcasses of sea-fowls. It contains high percentages of both phosphoric acid and nitrogen, as well as some potash; but its chief value is due to its nitrogen content. Its source was noted when it was considered as a source of phosphorus. It needs no treatment before applying. Fresh guano collected from some islands of the Pacific Ocean contains a considerable amount of ammonium carbonate and must be treated with sulphuric acid to fix this ammonia in the form of a sulphate, because the carbonate is very volatile.

(*e*) *Hoof meal* should be classed apart from hides, horns, hair, and feathers. Hoof meal runs to about 14 or 15 per cent of nitrogen, and it gives good results in field tests. The chemical methods for determining availability as plant food do not, as a rule, show the real value of this material.

(*f*) *Hides, horns, hair,* and *feathers* are very resistant to nitrification, and hence they are of low agricultural value unless treatment with sulphuric acid is used to render the nitrogen available. These materials all run high in nitrogen content, but their use, when they cost much, is unadvisable.

(*g*) *Wool* contains about 17 per cent of nitrogen. In uncleaned wool there is a fatty material known as *suint,* which contains a large per cent of potash salts, mainly in the carbonate form, although some chloride and sulphate are present. In the wool of British sheep there is about 10 per cent of potash salts. Wool is, also, very resistant to nitrification.

(*h*) *Bone.* Raw and steamed bone have been discussed under sources of phosphorus.

98. Vegetable Sources. (*a*) *Cottonseed meal* is the most important source of nitrogen of vegetable origin. It is very highly prized as a feed for animals on account of its high protein content, and can be used to greater advantage as a feed than as a fertilizer, provided that the manure is carefully conserved. It is much used in mixed fertilizers, not only on account of the plant food that it contains, but on account of the fact that it is an excellent material to keep moisture from salts which might absorb it. Cottonseed meal contains about 2 per cent of available phosphoric acid, 6 per cent of nitrogen, and 1½ per cent of water-soluble potash.

(*b*) *Rape meal* is sometimes used as a fertilizer. It contains about 5 per cent of nitrogen and 1$\frac{6}{10}$ per cent of phosphoric acid. This meal is the product left after the removal of the oil from rape seed. It is finely ground before being marketed.

(*c*) *Linseed meal* is a by-product of the manufacture of oil from flaxseed. The old process linseed meal is the residue left after pressing the oil out of the crushed flaxseed, either when cold or when warm. The linseed meal manufactured by the new process consists of the residue left after extracting the oil with naphtha. Linseed meal obtained by either process contains about 5¼ per cent of nitrogen, 1$\frac{6}{10}$ per cent of phosphoric acid, and 1¼ per cent potash. Linseed meal is mainly used as a feed for cattle.

(*d*) *Castor pomace* is the residue left from the extraction of castor oil from the castor bean. It cannot be used as a stock feed on account of poisonous properties; but it has value as a fertilizer. It contains about 5½ per cent nitrogen, $1\frac{3}{4}$ per cent phosphoric acid, and 1 per cent potash.

(*e*) *Calcium cyanamide* is a manufactured organic source of nitrogen. It is a dark crystalline powder which, when exposed to the air, increases in weight, due to the slaking of the lime. This results in a lessening of the per cent of nitrogen that it contains, not by losing its nitrogen, but because of the increased weight of the product.

Calcium cyanamide is manufactured by heating a mixture of limestone and coke in an electric furnace to a temperature of 1100° C. At this temperature calcium and carbon unite to form carbide (CaC_2). The finely powdered calcium carbide has purified nitrogen gas passed over it when it is at a white heat and under these conditions it will take up two atoms of nitrogen according to the following formula:

$$CaC_2 + N_2 = CaCN_2 + C.$$

The nitrogen of the air is purified either by passing it over red-hot metallic copper or by the fractional distillation of liquid air. The manufactured product contains as impurities carbon, quicklime, silica, iron oxide, and calcium sulphide, phosphide and carbonate. It contains about 20 per cent nitrogen, which is equivalent to 57 per cent of calcium cyanamide.

The impurities in cyanamide, consisting of small quantities of sulphides, carbides, and phosphides, are decomposed by the soil moisture when applied, and, unless sufficient time elapses for the escape of these products of decomposition that are harmful, the germination of seed is affected. The American Cyanamide Company claims that they have an improved process whereby the injurious impurities are removed. Their product is known as " Improved Cyanamide," and the nitrogen is present partly as the cyanamides of calcium and sodium, and partly as nitrate of soda. The American Fertilizer Handbook of

1910 gives a proximate analysis of this material, which shows 3.39 per cent nitrogen in the form of nitrate, and 13.62 per cent of nitrogen in the cyanamide form.

Experiments show that cyanamides do not give as good results as a fertilizer as does sulphate of ammonia, on soils containing an abundant supply of calcium carbonate. On acid soils, the lime content of the cyanamide should exert a good influence.

CHAPTER XIV

SOURCES AND USE OF POTASH SALTS

99. Occurrence. Potassium is one of the ten elements absolutely essential to plant growth. Some crops are especially heavy feeders on this element, prominent among them being the legumes, the root crops, the sugar-producing crops, and tobacco. Any crop is particularly sensitive to a deficiency of potash.

The main commercial sources of potash salts are the Stassfurt deposits. These deposits are located in Saxony, Germany, and extend eastward from the Harz Mountains to the Elbe River about 60 miles, and from the city of Magdeburg southward to the town of Bernburg about 20 miles. The deposits of these salts in this region are amply sufficient to supply the world for many centuries.

These deposits are the result of the evaporation of an ancient inland sea which became isolated from the ocean. During the time of this evaporation, the climate of the section in question is supposed to have been tropical. As the evaporation continued, various salts crystallized out in the order of their insolubility. The lowest stratum consists of sulphate of lime, $CaSO_4$; the next stratum consists of rock salt, which in places reaches a thickness of 3000 feet; the third stratum is the mineral, which consists of sulphate of lime, potash, and magnesia. Above this stratum comes the kieserit region, where there is a layer of sulphate of magnesia, and upon it rests a deposit of *carnallite*, which is a mixture of potassium chloride and magnesium chloride. The carnallite deposit varies in thickness from 50 to 130 feet. This deposit yields most of the crude potash from which the more concentrated salts are produced. *Kainit* and *sylvinit* are found in adjacent deposits. The kainit consists mainly of potassium

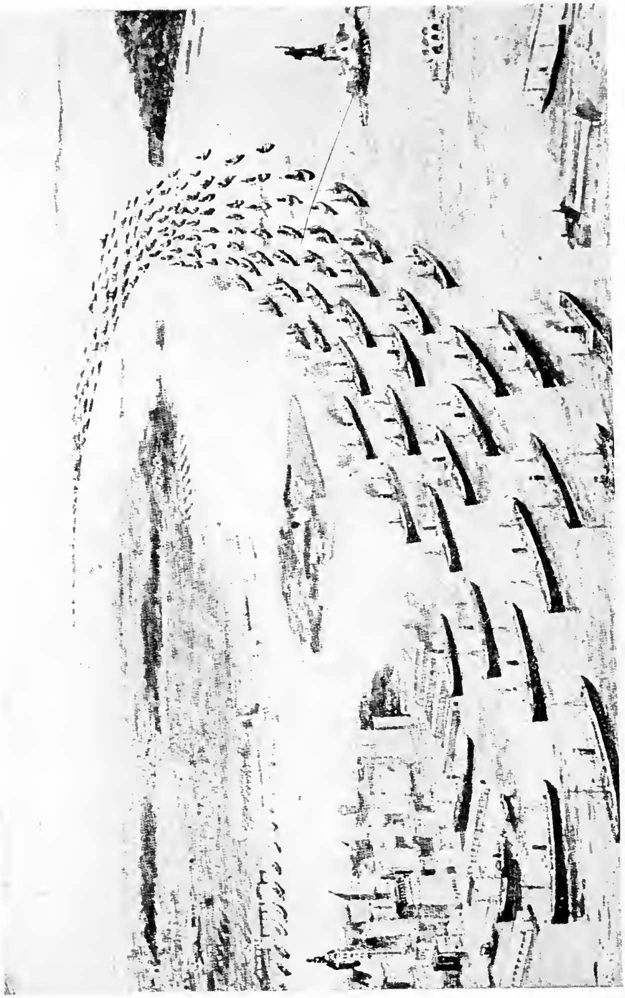

Fig. 51.—Fleet of 258 vessels, each carrying 4000 tons, required to ship the 1,032,127 tons potash salts used by the United States of America and Hawaii in 1911.

sulphate, magnesium sulphate, magnesium chloride, and sodium chloride, along with small quantities of potassium

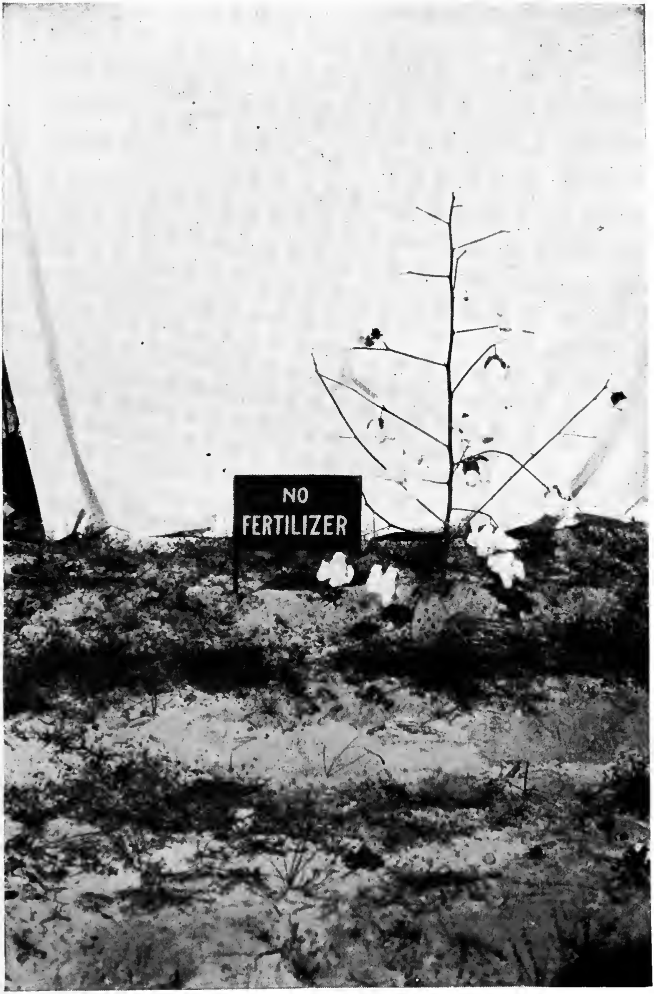

FIG. 52.—Individual cotton stalk grown without special fertilizer.

chloride and calcium sulphate. Sylvinit consists mainly of potassium chloride and sodium chloride. Overlying the potash region is a layer of impervious clay, which has served to keep out water and prevent the loss of these salts by leaching. Above this clay are the following strata: anhydrite, gypsum, clay, sand, and limestone.

The value of these salts was discovered about 1860, the potash salts having formerly been bored through and discarded as worthless, while the rock salt below was mined. Since the discovery of the value of these salts, the mining of them has been regulated by the German Government, which derives a large income from the export tax which is imposed.

100. Wood Ashes. Before the discovery of the Stassfurt potash deposits, the main source of potash was wood ashes. The potash content of these ashes is in the carbonate and sulphate forms. Ashes also contain a considerable percentage of lime, and a small percentage of phosphorus. Ashes from hardwood trees are higher in their potash content than other ashes. In conserving ashes for their potash content, they should be stored in a covered pit with impervious sides and floor, for the potash is readily leached out.

101. Organic Sources of Potash. Some organic materials contain appreciable amounts of potash. Tobacco stalks and stems contain from 4 to 8 per cent of potash. Cottonseed and flaxseed each contain some potash. Cottonseed contains about 1¼ per cent of potash, cottonseed meal about 1½ per cent, cottonseed hulls about 1 per cent, and cottonseed hull ashes about 24 per cent. Linseed meal contains about 1¾ per cent potash.

The pomace obtained from the fermenting of wine contains some potash and some nitrogen.

102. Minor Sources. Another source of potash is kelp, the ashes of seaweeds. Kelp contains from 4 to 20 per cent of potash, depending upon the seaweed burned.

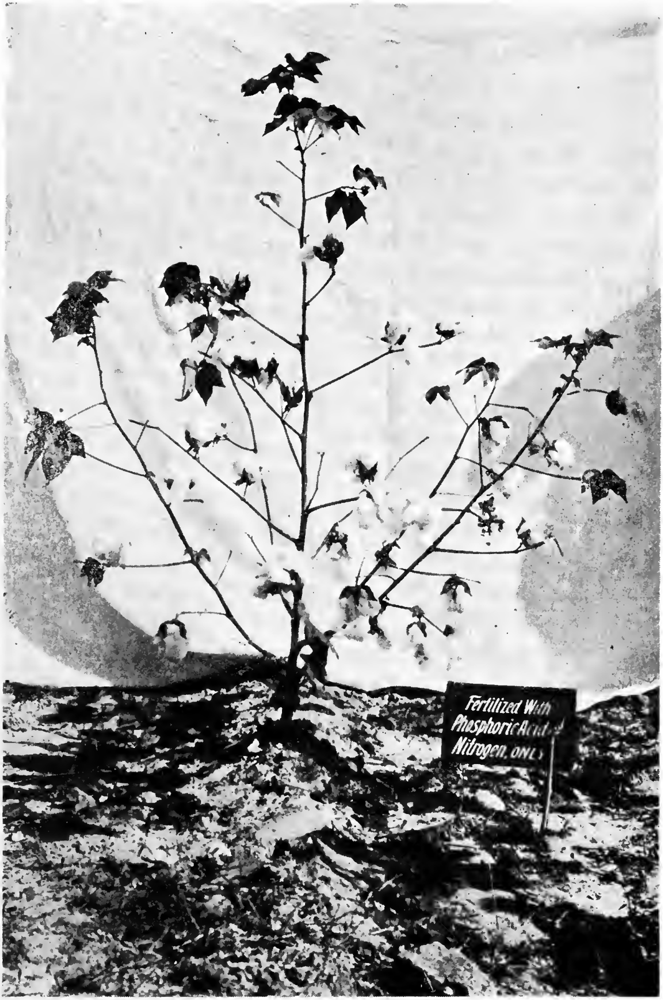

Fig. 53.—Cotton stalk grown in same soil as that of Fig. 52, fertilized with phosphoric acid and nitrogen.

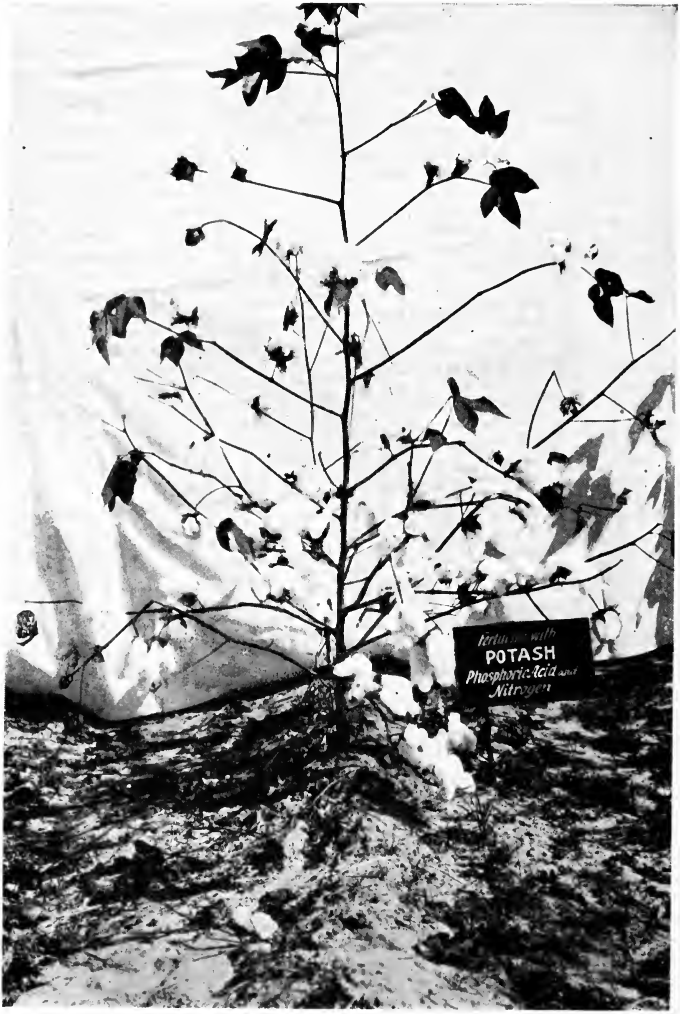

FIG. 54.—Cotton stalk grown in same soil as that of Fig. 52, fertilized with phosphoric acid, nitrogen and potash.

An inorganic source of potash that seems to offer some possibilities is the mineral alunite, which exists in large deposits in some of our western States. This material contains aluminium sulphate and potassium sulphate, and, when burned, the aluminium sulphate is decomposed, leaving alumina, which is insoluble in hot water, while potassium sulphate is quite soluble and can be removed by lixiviation.

Fig. 55.—Sweet potatoes grown without fertilizer.

At the prices that have formerly prevailed, the Stassfurt salts have crowded the other sources out of the general market.

103. Commercial Salts of Potash. Two of these salts, kainit and sylvinit, already mentioned in Sec. 99, are exported and sold in the crude state. Kainit is a crystalline gray material with some red and yellow particles.

It contains, as a rule, between 12 and 13 per cent of potash (K_2O). Sylvinit is similar in appearance to kainit; but it is redder in color. It is someties sold as kainit, and contains a slightly higher percentage of potash, ranging from 12½ to 15 per cent of potassium oxide (K_2O). The disadvantage in the use of these salts is that they are more expensive per pound of potash delivered on the farm than the purified salts. This is due to the fact that the transportation charges on a pound of potash in the form of kainit are four times those on the same amount of potash in the form of muriate of potash, because kainit contains 12 to 13 per cent potash, while muriate contains from 48 to 52 per cent.

Fig. 56.—Sweet potatoes grown on same soil as those of Fig. 55 but fertilized with phosphoric acid and nitrogen.

The purified potash salts on our market are muriate of potash, sulphate of potash, double sulphate of potassium and magnesium, double manure salts, and potassium-magnesium carbonate.

104. The Functions of Potash. Potash in the soil favors the formation of the carbohydrates, such as starches, sugars, and cellulose in the plant. It is very beneficial to such root crops as mangolds, sugar-beets, Irish potatoes, and sweet potatoes. It produces marked influences on the growth of leguminous crops, not only with respect to yield, but also with respect to the relative proportion of the legume to the other herbage. Potash induces the healthy development of the leaf and the stalk, and is especially beneficial to grasses. When applied in large quantities, potash lengthens the growing season of the

FIG. 57.—Sweet potatoes grown on the same soil as those of Fig. 55 but fertilized with potash, phosphoric acid and nitrogen.

plant. It also seems to promote a more economical use of the soil moisture.

105. The Use of Potash on Different Soils. The potash content of soils is very variable, ranging from $\frac{1}{10}$ of 1 per cent on very light sandy soils, to as much as 2 per cent on very heavy clay soils.

The muck soils are very deficient in potash. Truck crops and practically all crops grown on light sandy and muck soils are improved by applications of potash salts. This is true to a very marked extent with cotton. On muck soils, the yields of corn are largely increased by the use of potash salts. In fertilizing general farm crops, unless there is some special reason that makes it objectionable, the use of muriate of potash is quite satisfactory and most economical.

Heavy clay soils contain a sufficient supply of potash for general farm crops, and, if these soils are properly farmed so that the conditions for bringing stored up plant food into availability are accentuated, there should be such an abundant supply of potash that it will not become a limiting factor of plant growth. In fact, field tests show that large amounts of money are expended unnecessarily each year for the application of potash to such soils.

Table XIII shows the effect of the use of potash on grass lands. The yield of hay is greatly increased and the growth of leguminous plants stimulated while the percentage of weeds is markedly decreased through the use of a complete mineral manure as compared with results obtained with a fertilizer not containing potash or with no fertilizer at all.

106. Selection of the Source of Potash. The cheapest form of potash for sale in the United States is the muriate (KCl). This is manufactured by the purification of crude salts, most of the impurities being removed. While muriate of potash is a cheap and effective source for general farm crops, the use of a potash salt containing chlorine injures the burning qualities of tobacco, lowers the starch content of Irish and sweet potatoes, and hinders the crystallization

FIG. 58.—Peach trees grown without special fertilizer.

TABLE XIII.—INFLUENCE OF POTASH ON GRASS LANDS. (HALL)

Plot.	Manuring.	Dry Hay.		Composition of Herbage in 1902.		
		1856 to 1902	1893 to 1902	Grasses.	Leguminous Plants.	Weeds.
		Cwts.	Cwts.	Per Cent.	Per Ct.	Per Ct.
7	Complete mineral manure	38.8	36.5	20.3	55.3	24.4
8	Complete mineral manure without potash	28.1	21.6	28.8	22.1	49.1
4	Superphosphate only	23.3	17.8	54.4	15.4	30.2
3	Unmanured	21.9	15.9	34.3	7.5	58.2

of the sugar contained in sugar beets. Sulphate of potash, double sulphate of potassium and magnesium, or potassium-magnesium carbonate should be used for the crops named. Truckers observe that when potatoes are fertilized with potassium sulphate, they are smoother than when fertilized with a salt of potash carrying chlorine. It has been shown at the South Carolina Experiment Station that the water content of sweet potatoes is higher when fertilized with muriate of potash than when fertilized with sulphate of potash.

Double sulphate of potassium and magnesium is not extensively used in the United States. It contains about 26 per cent of potash, and may be used as a substitute for sulphate of potash.

Double manure salts contain from 20 to 30 per cent of potash. It is used to some extent in the United States. The potash is mainly in the form of a chloride, and sells, usually, for more than does an equal amount of potash in kainit or in muriate of potash.

Potassium-magnesium carbonate is a dry, white material containing from 20 to 25 per cent of potash combined as a carbonate. It is highly prized by growers of tobacco and

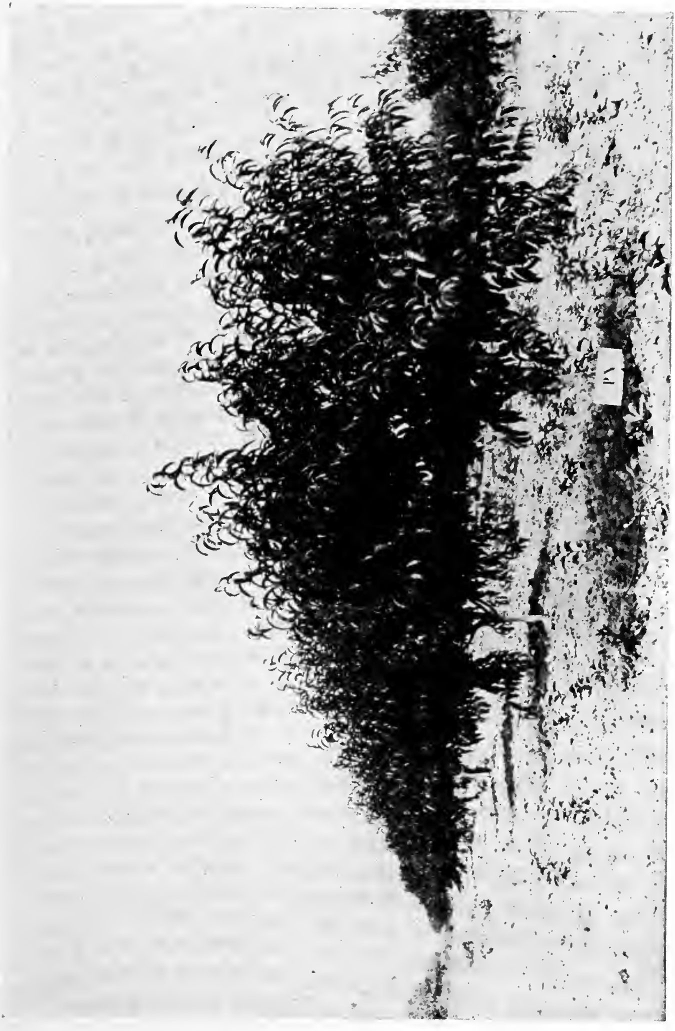

FIG. 59.—Peach trees fertilized with phosphoric acid and nitrogen.

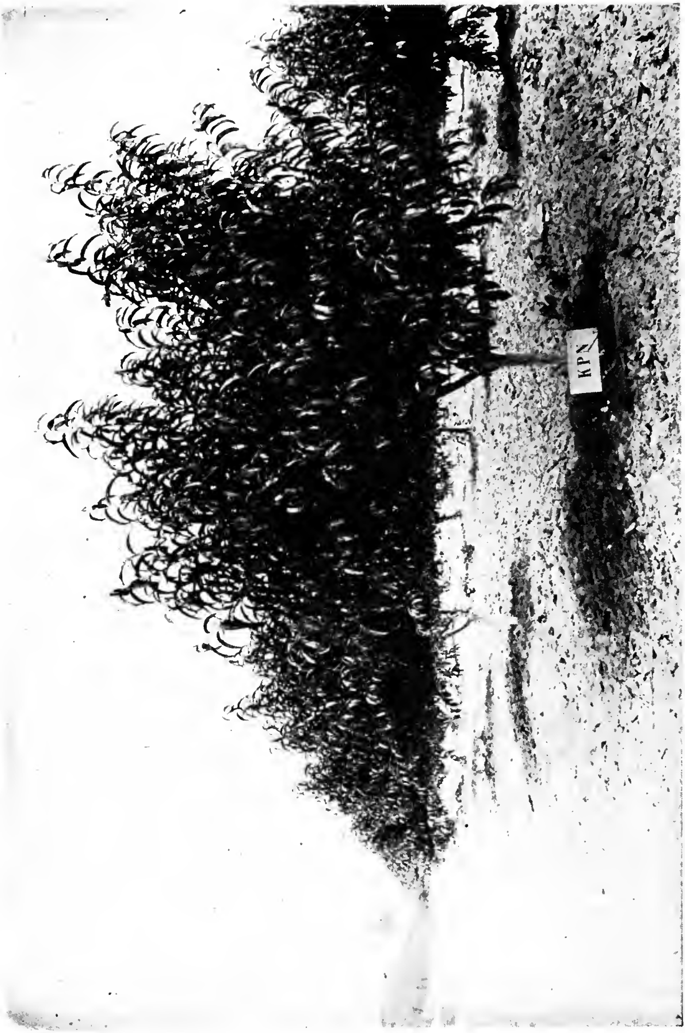

Fig. 60.—Peach trees grown with potash, phosphoric acid and nitrogen as fertilizers.

oranges. It is not deliquescent and, hence, is easily distributed.

In connection with the use of commercial potash salts it is interesting to note that plants take up a large part of their food, especially in the form of potassium and phosphorus, and store it in the early stages of development; while nitrogen is taken up, and carbonaceous material, such as starches and sugars, is for the most part formed in the later stages of the plants' development. This emphasizes the importance of applying the potash salts and the phosphorus-bearing fertilizers before planting the crop, and the soluble nitrogen as a topdressing.

107. Tendency to use too much Potash. It is also interesting to remember that most of the potash is stored in the leaves and the stalks of the plant, and, if these materials are incorporated in the soil or fed on the farm and the manure carefully conserved and returned to the soil, there will be comparatively a small loss of potash from the soil, although the plant makes use of more of it than of any other ash element. This fact, and the high content of potash present in most soils, shows that in many sections the application of commercial potash is largely over-done. To judge his potash needs accurately the farmer must thoroughly understand the functions of potash, the composition and condition of his soil, and the requirements of the crops that he is growing. There is no element that pays so handsomely when needed or is so valueless when unnecessarily applied.

CHAPTER XV

MEASURING PLANT FOOD REQUIREMENTS

108. Forms of Plant Food. There are two forms of each element of plant food present in every soil: the insoluble, or unavailable; and the soluble, or available. The former may be termed the potential plant food, and the latter the kinetic. The amount of *available* plant food is the limiting factor of plant growth, however much potential plant food may be present. The unavailable plant food is by natural processes slowly changed chemically so as to become soluble and these changes may be hastened by appropriate treatment. The depletion of the total food content of the soil must be avoided by application of fertilizer.

109. Soil Analyses. The plant food in the soil is present in salts, minerals, and organic matter, which vary to a marked extent in their solubility in different solvents. The fact that solvents in the soil vary in their composition and therefore in their solvent power makes it extremely difficult to select a chemical solvent that truly represents the solvent power of the soil solvents; hence it is practically impossible to determine accurately by chemical means the absolute amount of available plant food in any soil. Soil analyses can only determine what elements are present, in what form and in what amount. They are suggestive of the treatment that should be given the soil and, therefore, in many ways are of value; but it should be remembered that soil analyses do not afford definite data of the amounts of various kinds of food plants may obtain.

Hopkins' "Soil Fertility and Permanent Agriculture" estimates that, by the most approved agricultural methods, 2 per cent of the total nitrogen content, 1 per cent of the phosphorus content, and one-fourth of 1 per cent of the potash content of the soil generally can be made available in one year. If we have an analysis of the soil, we can readily calculate the number of pounds of each element of plant food that would become available, and if the composition of the crop to be grown is known, the limiting factors of crop raising can be determined with some degree of accuracy, provided that the premises are correct and that unusual seasons do not exercise undue influence.

110. Methods of Soil Analysis. (*a*) *Collecting and Preparing Samples for Analysis.* A soil sample is collected by taking fifteen or twenty borings at different and apparently representative places on the soil. The borings should be dried, pulverized if necessary, and thoroughly mixed and rolled on a large piece of wrapping paper or enamel cloth; then by means of a spatula or wooden paddle, quarter the mass into four approximately equal parts, discard two-quarters that are diagonal to each other and continue the mixing, quartering and discarding until the residue amounts to about a pint. This residue should be an accurate sample of the field. A 2-inch auger with a long stem makes a good implement for collecting soil samples. Taken to a depth of 6⅔ inches, an average soil weighs 2,000,000 pounds per acre, and taking the sample to this depth facilitates calculations.

After air-drying, the sample is pulverized to pass through a sieve with round holes 1 millimeter or $\frac{1}{25}$ of an inch in diameter. The gravel particles which are too large to pass through are weighed to determine the per cent present and then discarded. The sample is thoroughly mixed and placed in an air-tight container for analysis. The obtaining of a sample which fairly represents the soil is of the utmost importance, and time and care in this process are necessary.

(*b*) *Acidity* or *Alkalinity.* Ten grams of soil are shaken with 100 cubic centimeters of distilled water in a suitable flask and allowed to stand over night. The liquid is then decanted through a filter paper and 50 cubic centimeters are placed in a beaker, 2 or 3 drops of phenolphthalein added, the beaker covered with a watch-glass and boiled to a volume of 5 cubic centimeters unless a pink color appears before that degree of concentration. If no color appears the soil is neutral or acid, while if a pink color appears it is evidence that the soil is alkaline.

A very simple test for the reaction of a soil may be made by placing a strip of blue litmus paper and a strip of red litmus paper in the bottom of a tumbler, adding the soil to be tested to a depth of about 1 inch in the tumbler and then moistening the soil with either distilled water or rain water. At the end of an hour examine the paper by looking at the bottom of the tumbler. If both papers are red, the soil is acid; if both are blue, it is alkaline, and, if unchanged, the soil is neutral.

(*c*) *Phosphorus.* The following provisional method for determining the phosphorus present is given together with some explanation on page 234, Bulletin 107 (revised) Bureau of Chemistry. Weigh 10 grams of sodium peroxide into an iron or porcelain crucible and thoroughly mix with it 5 grams of the soil. If the soil is very low in organic matter, add a little starch to hasten the oxidation action. Heat the mixture carefully by applying the flame of a Bunsen burner directly upon the surface of the charge and the sides of the crucible until the action starts. Quickly cover the crucible until the reaction is over and keep at a low red heat for fifteen minutes. Do not allow fusion to take place. By means of a large funnel and a stream of hot water, transfer the charge now free from organic matter to a 500 cubic centimeter graduated flask. Acidify with hydrochloric acid and boil. Let cool and make up to the mark with distilled water. If the action has taken place properly, there should be no particles of undecomposed or colored soil in the bottom of the flask. Allow the silica to settle and draw off 200 cubic centimeters of the clear solution.

Precipitate the iron, alumina, and phosphorus with ammonium hydroxide added in slight excess to the warm solution, heat, stir, filter and wash several times with hot water, discarding the filtrate. Return the precipitate to the beaker with a stream of hot water, holding the inverted funnel over the beaker, retaining the filter paper in the funnel, and dissolve the precipitate in hot hydrochloric acid, pouring acid upon the filter to dissolve any precipitate remaining and add this acid washing to the dissolved precipitate. Evaporate the solution and washings to complete dryness on a water bath to dehydrate the silica. Take up with dilute hydrochloric acid, heating if necessary, and filter out the silica. Evaporate the filtrate and washings to about 10 cubic centimeters, add 2 cubic centimeters of concentrated nitric acid, and just neutralize with ammonium hydroxide. Clear up with nitric acid, avoiding an excess. Heat at 40 to 50° on a water bath, add 15 cubic centimeters of molybdic solution, keeping at this temperature for from one to two hours. The molybdic solution is made as follows: Dissolve 100 grams of molybdic acid in 417 cubic centimeters of ammonia sp. gr. .96 and pour the solution slowly into 1250 cubic centimeters of nitric acid sp. gr. 1.20, keep the mixture in warm place for several days or until a portion heated to 40° C. deposits no yellow precipitate. Decant the solution for any sediment. Let stand over night. filter, and wash free of acid with a $\frac{1}{10}$ per cent solution of ammonium nitrate and, finally, once or twice with cold water. Transfer the filter to a beaker, and dissolve in standard potassium hydroxide (1 cubic centimeter–0.2 milligram P), titrate the excess of potassium hydroxide with standard nitric acid of the same concentration as the KOH solution, using 0.5 cubic centimeter of phenolphthalein as indicator. Subtract the number of cubic centimeters of acid used from the cubic centimeters of KOH used, and multiply the remainder by .0002 and the result will be the grams of phosphorus present in 200 cubic centimeters of the soil solution. Determine the amount present in 500 cubic centimeters, and dividing by the weight of soil taken for analysis (5), multiplying by 100 will give the per cent of phosphorus present.

(*d*) *Nitrogen.* Seven grams of soil are weighed into a large Kjeldahl flask, 0.7 gram of mercuric oxide is added, and to this is added about 20 cubic centimeters of conc. sulphuric acid. The contents of the flask are boiled and digested until colorless. Finely powdered potassium permanganate is added while the contents of the flask are hot, until a green solution furnishes assurance that the oxidation is complete. After cooling, about 250 cubic centimeters of water are cautiously added, then enough potassium sulfide solution to precipitate out the mercury, and some zinc filings to lessen the bumping on boiling. Enough strong alkali is then added to neutralize the acid and leave the solution strongly alkaline. The flask is immediately connected to a still and the ammonia distilled off into a standard solution of sulphuric acid. The excess of acid is titrated with standard sodium hydroxide solution of the same concentration as the sulphuric acid, using an alcoholic extract of cochineal as an indicator. Determine the number of cubic centimeters of acid neutralized by the ammonia and multiply this by the nitrogen factor of the acid. In case the acid is Fifth Normal this factor will be .0028. Divide the grams of nitrogen by the weight of the sample and multiply by 100 and the result will be percentage of nitrogen.

(*e*) *Total Potassium.* This test is carried out as given on page 147, Bulletin 105, Bureau of Chemistry, Department of Agriculture. One gram of soil, very finely pulverized, 1 gram of ammonium chloride, and 8 grams of calcium carbonate thoroughly ground in an agate mortar are fused as directed in Fresenius' "Quantitative Analysis," Vol. 2, page 1175, and by Hillebrand in Bulletin 305 of the United States Geological Survey, where an illustration of the apparatus is given. The fused mass is transferred to a porcelain dish, slaked with hot water, finely ground with an agate pestle and transferred to a filter. After washing with about 600 cubic centimeters of hot water, the filtrate and washings are run to dryness in a Jena beaker, taken up with hot water and again filtered, acidified with hydrochloric acid, concentrated to about 10 cubic centimeters, and $1\frac{1}{2}$ cubic centimeters of

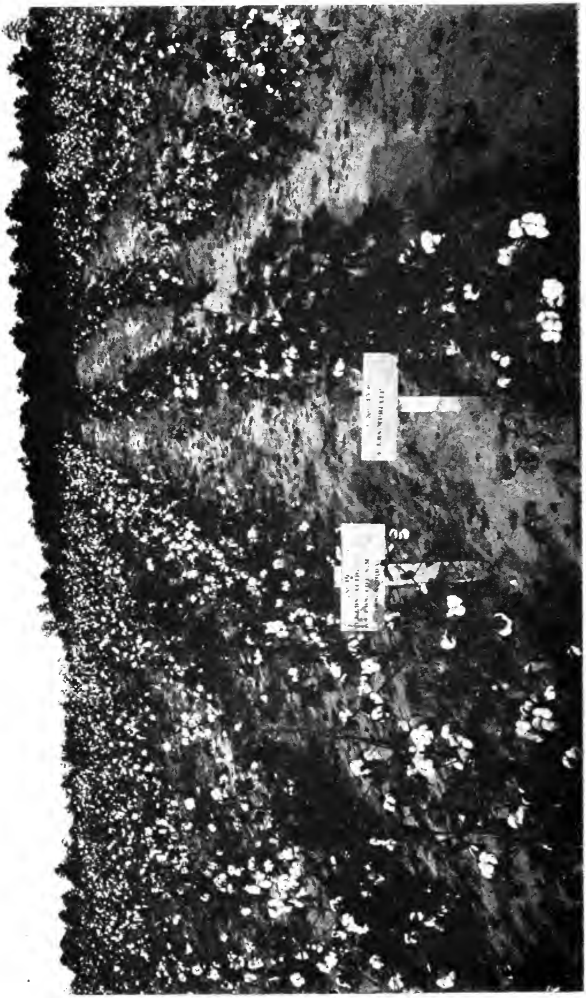

FIG. 61.—Plot tests of the production of cotton. (Permission Director J. N. Harper, S. C. Exp. Station.)

a platinum chloride solution (10 cubic centimeters containing 1 gram platinum) added. This is then evaporated to a sirupy consistency, taken up and washed about fifteen times with 80 per cent alcohol, three times with ammonium chloride solution, and again fifteen times with alcohol. The precipitate is then washed through the filter with hot water into a platinum dish, evaporated on the steam bath to dryness and heated in an air oven at 110° C. for an hour, cooled in a desiccator, and weighed as K_2PtCl_6. Duplicate samples should not differ more than 1.5 milligrams in the final weight. The weight of K_2O can be determined by multiplying the weight of the K_2PtCl_6 by the factor .1941.

A correction must be made for the amount of potassium in the reagents, which is found by making a blank determination, using no soil.

(Ammonium chloride solution is made by dissolving 200 grams NH_4Cl in 1000 cubic centimeters water and saturating with K_2PtCl_6.)

(*f*) *Calcium.* Calcium may be determined as described by Hopkins in his Soil Fertility and Permanent Agriculture, page 632. Five grams of soil (or less if high in calcium) are decomposed by heating 10 grams of sodium peroxide in an iron crucible. This is then taken up with water and hydrochloric acid and made up to 500 cubic centimeters, as in the phosphorus determination. After being allowed to settle over night, 200 cubic centimeters of the supernatant solution are heated to boiling and precipitated from the hot solution with ammonia. The precipitate is filtered out on a 15-centimeter filter and washed with hot water until but a slight test for chlorides is given with silver nitrate. The filtrate is again evaporated to dryness and heated (to dehydrate any remaining silica), taken up with water and hydrochloric acid, brought to a boil, and ammonia added to precipitate any remaining aluminum. The precipitate is filtered out on a small filter and washed with hot water. It should not be washed more than necessary to remove the chlorides, as the wash water carries aluminum through into the filtrate. On heating this filtrate and allowing it to stand overnight, more aluminum may be found to precipitate out. All of the aluminum must be removed by repeated precipitations. The solution is then made slightly alkaline with ammonia, brought to a boil, and to it is added slowly, while it is being stirred, enough concentrated ammonium oxalate solution to precipitate the calcium and to change the magnesium to the oxalate. After boiling until the precipitate has a granular appearance, it is allowed to stand three hours or longer, decanted into a filter, and washed twice by decantation. The precipitate in the beaker is then dissolved with a few drops of hydrochloric acid, a little water added, and the calcium reprecipitated, boiling hot, by adding ammonium hydroxide to slight alkalinity. A little ammonium oxalate is added, the solution allowed to stand as before, and filtered through the same filter, washed free from chlorides with hot water, the filter burned and the precipitate ignited in a blast until it ceases to lose weight, and weighed as calcium oxide (CaO). This weight multiplied by the factor of calcium in calcium oxide (7129) will give the weight of calcium from which the percentage may be obtained by dividing by weight of the sample taken for analysis.

111. Field Tests. The best measure of the amount of available plant food in a soil, and of food deficiencies, is obtained by *actual field tests* extending over a number of years to eliminate varying seasonal conditions and using as many crops as possible to test out crop peculiarities. On account of the expensive nature of such experiments they must usually be left to the State Experiment Stations, and those interested in soil chemistry will do well to study what has been done by various States as published in State Bulletins. It would be of great value if test farms could be maintained on every large and distinct soil type. The crops that are generally grown on this distinct type should be tested in order that the information might be definite, and this information should be available to the farmers living within the area tested in order that they might apply the knowledge thus gained in their own farming.

The simplest effective form of field test consists in a number of plots on which may be tested the value of each single element to a given crop; then of every possible combination of two elements; and, finally of all elements. It is best to provide as many duplicate plots as there are years in the rotation employed, and, in this way to produce *every crop, every year,* thus eliminating varying seasonal conditions. These elementary tests may be enlarged to include a comparison of the different sources of each element of plant food, varying relative proportions of the three most important elements, nitrogen, potassium and phosphorus, and different cultural methods used in connection with fertilizing. A combination of two sources of nitrogen is often most effective.

Fig. 62.—Plot tests of oats. Two-foot dividing space between plots.

Table XIV shows an effective three-year test, using the common three-year rotation so much advised for Southern conditions.

TABLE NO. XIV.—AN ELEMENTARY FERTILIZER TEST IN CONNECTION WITH A THREE-YEAR ROTATION

Corn and Cowpeas, Followed by Oats or Oats and Vetch, Followed by Cowpeas, Followed by a Cover Crop, Preferably a Legume Followed by Cotton, Followed by a Cover.

Nitrogen.	Phosphorus.	Potassium.	No Fertilizer.	Nitrogen and Phosphorus.	Nitrogen and Potassium.	Phosphorus and Potassium.	Nitrogen, Phosphorus and Potassium.

Oats or Oats and Vetch Followed by Cowpeas, Followed by a Cover Crop, Preferably a Legume, Followed by Cotton, Followed by a Cover Crop, Followed by Corn and Cowpeas.

Nitrogen.	Phosphorus.	Potassium.	No Fertilizer.	Nitrogen and Phosphorus.	Nitrogen and Potassium.	Phosphorus and Potassium.	Nitrogen, Phosphorus and Potassium.

TABLE NO. XIV.—*Continued.*

COTTON FOLLOWED BY A COVER CROP, FOLLOWED BY CORN AND COWPEAS, FOLLOWED BY OATS OR OATS AND VETCH, FOLLOWED BY COWPEAS, FOLLOWED BY A COVER CROP.

Nitrogen.	Phosphorus.	Potassium.	No Fertilizer.	Nitrogen and Phosphorus.	Nitrogen and Potassium.	Phosphorus and Potassium.	Nitrogen, Phosphorus and Potassium.

The plan as outlined serves to show a simple fertilizer test in connection with a three-year rotation; it may be enlarged or modified to cover any desired scope or condition, or it may be used simply to test a single crop. In making fertilizer tests, the most approved agricultural methods for maintaining fertility should be followed, unless the object of the experiment is to determine the plant food requirements under a one-crop system.

The individual farmer should avail himself of all the data issued by his own and neighboring Experiment Stations, and it will often prove profitable for him to conduct simple tests himself. He should be familiar with the plant food content of his various soil types, procured by soil analyses, for this shows the amount of potential plant food in his soil, and he has at his command the various agencies already discussed for bringing this food into availability.

CHAPTER XVI

MIXING OF FERTILIZERS

112. Advantages of Home-Mixing. Phosphorus, nitrogen and potassium are the three elements most usually found necessary to be supplied to a soil to keep up its fertility. The sources of these elements have been discussed. The next consideration is how to apply most economically these purchased plant foods.

Fertilizer factories are equipped with machinery that will mix thoroughly the raw materials, provided their work is well done. That this work is not always thoroughly done and that the materials are not always compounded so as to approximate the desired mixture, is readily seen by examining any of the many Fertilizer Control Reports issued from the various Experimental Stations. When fertilizing materials are mixed, it is extremely difficult to determine with any degree of exactness the kind and proportion of all of the raw materials used. Due to this fact, a small amount of cheap and unavailable plant food, especially low-priced nitrogen, can be, and often is, worked into the mixture. The fertilizer manufacturers charge for mixing from $3 to $7 per ton. There are a number of formulas that farmers have become accustomed to buy of which some are very low grade. In mixing such formulas, the manufacturer must necessarily add some " make-weight " to his high-grade materials to bring the mixture to the desired percentage. This " make-weight " is known as the *filler*.

The transportation and hauling of filler is a heavy and unnecessary expense that can be avoided by the purchase and home-mixing of high-grade materials. The greatest advantage to be gained by the home-mixing of commercial fertilizers lies in the fact that the sources from which the phosphorus, nitrogen, and potash are derived are then known. A thorough knowledge of the relative availabilities of the different sources of commercial fertilizers, and of their actions under different crops, will enable the farmer to select wisely materials the fertilizing values of which are known.

113. Fertilizers may be Thoroughly Mixed on the Farm. The mixing of fertilizers can be thoroughly done on any farm, as has been shown by the South Carolina Experiment Station. When practicable, an out-building with a tight floor is preferable for the mixing, because the work can be done when weather conditions would prevent outside work. If no tight floor is available, one may be made, preferably under a shed, by taking straight-edged boards about 1 inch in thickness, laying them on a level place and keying them up tight. A floor 8 feet wide and 12 feet long, surrounded on three sides by upright boards 12 inches wide, will suffice for the mixing.

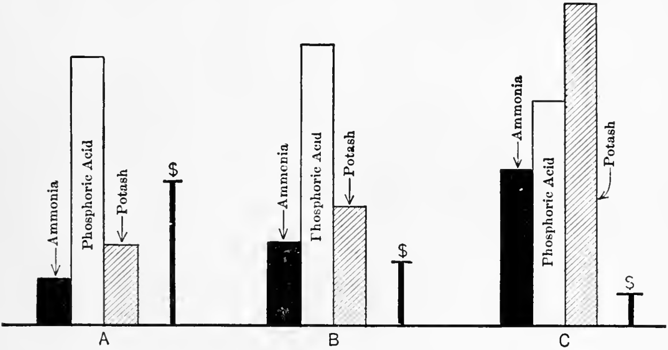

FIG. 63.—Diagram showing relative composition and value of fertilizers: *A*, low grade; *B*, medium grade; *C*, high grade. (Farmers' Bulletin 457, U. S. Dept. Agr.)

The raw materials are generally purchased in sacks. If a sufficient quantity is mixed to warrant the purchase in car-load bulk shipments, it will usually be advisable to buy a machine for mixing. The formula having been worked out, and knowing that 1000 pounds makes a good quantity for two men to manipulate, one-half of the materials necessary to make a ton of fertilizer is poured in the middle of the floor in alternate layers, beginning preferably with the acid phosphate. Two men can perform the mixing most advantageously, one mixing with a hoe, and the other with a spade or shovel. In the case of the mixture made at the Station referred to, the mass was hoed and shoveled first to one corner, then to the other corner, and once diagonally across the 8 by 12 floor. Samples were taken of the unmixed materials and of the mixed materials. Table XV may be taken as a typical analysis of the result of such mixing.

TABLE XV.—AN EXAMPLE OF THE THOROUGHNESS OF HOME-MIXING OF FERTILIZERS

	Lbs. of Total Phosphoric Acid (P_2O_5).	Lbs. of Nitrogen (N) Equivalent to Ammonia (NH_3).	Lbs. of Water-soluble Potash (K_2O)
800 lbs. 17.28% (P_2O_5) acid phosphate contains...............	138.2		
400 lbs. 8.14% (NH_3) 2.91% (P_2O_5) 1.70% (K_2O) cottonseed meal contains................	11.6	32.6	6.8
65 lbs. 48.06% (K_2) muriate of potash contains..............	....	....	31.2
1265 lbs.......................	149.8	32.6	38.0
Mixture contained theoretically..	11.84	2.58	3.00
Mixture analyzed...............	11.77	2.76	3.01

In making a home-mixture, it is very desirable to use some material that acts as a good dryer. Cottonseed meal is a most excellent dryer. Rape meal, linseed meal, and muck are also good dryers.

In the mixture mentioned, it was found that two men can mix from 6 to 8 tons per day, weighing out the materials when fractions of a sack are used and assuming the weight on the sack as accurate when full sacks were used. In the formula noted, only the muriate of potash was weighed. The mixed material was replaced in the sacks from which the raw materials were removed. The cost of mixing each ton can be computed by dividing the wages of the men by the number of tons mixed. It will usually amount to less than 50 cents per ton.

114. Educational Influence. An advantage of the home-mixing of fertilizers, not often considered, is that it necessitates a more thorough knowledge of fertilizing materials and it is a strong incentive to study, for fertilizing materials cannot be indiscriminately mixed. However, the incompatibilities are few and easily explained. The chart, Fig. 64, shows the materials that may be mixed advantageously, and the materials that should not be mixed. This chart, which had its beginning in a German publication, has been modified from time to time as data have been secured. It is modified from the chart given in Bulletin 388 of the Office of Experiment Stations, because it has been shown at the South Carolina Experiment Station that the potash content both of muriate of potash and kainit is rendered partly insoluble by mixing with basic slag or Thomas phosphate; and the chart has been made to conform to this fact.

115. The Calculation of Formulas. Six forms of calculations are commonly met with in connection with the home-mixing of fertilizers.

1. Given the percentage and weights of materials; calculate the formula.

2. Given the materials and their analyses and the composition of the formula desired; calculate the weight of each material required.

3. Given the materials too low in composition for making a formula of high percentage composition; overcome the difficulty.

4. Given the high-grade materials; reduce to the proportion of a low-grade formula and avoid the use of a filler.

5. To determine the amount and composition of a fertilizer when a portion is used under the crop and the remainder as a side application or topdressing.

6. To convert a fertilizer from one formula to another.

Examples of each form of calculation are given as types of the work involved.

In the fertilizer trade, the term *unit* is often used. A unit is 1 per cent of a ton, or 20 pounds. In making these calculations, it must be remembered that per cent means pounds in a hundred pounds of material.

(1) *The percentage and weight of material being given, calculate the formula.*

PROBLEM: Given, 1000 pounds of 16 per cent available acid phosphate (P_2O_5), 100 pounds of muriate of potash, 48 per cent water-soluble potash (K_2O) and 900 pounds of cottonseed meal that will analyze nitrogen equivalent to 7 per cent ammonia (NH_3), 2 per cent phosphoric acid (P_2O_5) and 1.5 per cent of water-soluble potash (K_2O).

A good way to outline this calculation is as follows:

Lbs. of Material.	Percentage, Composition, and Source of Material.	Lbs. of Nitrogen (N) equivalent to Ammonia (NH_3).	Lbs. of Phosphoric Acid (P_2O_5).	Lbs. of Water-Soluble Potash (K_2O).
1000	16% P_2O_5 acid phosphate will furnish..........................		160.0	
900	7% NH_3—2% P_2O_5—1.5% K_2O C.S. meal will furnish...............	63.0	18.0	13.5
100	48% K_2O muriate of potash will furnish.......................	......	......	48.0
2000		63.0	178.0	61.5
	Formula..................	3.15%	8.9%	3.08%

The formula is obtained by dividing the content in pounds of each constituent by twenty, the number of hundred pounds in the mixture, and the result is the number of pounds of the constituent in 100 pounds of material, or the percentage composition.

(2) *Given, the materials and their analyses and the composition of the formula desired; calculate the weight of each material required.*

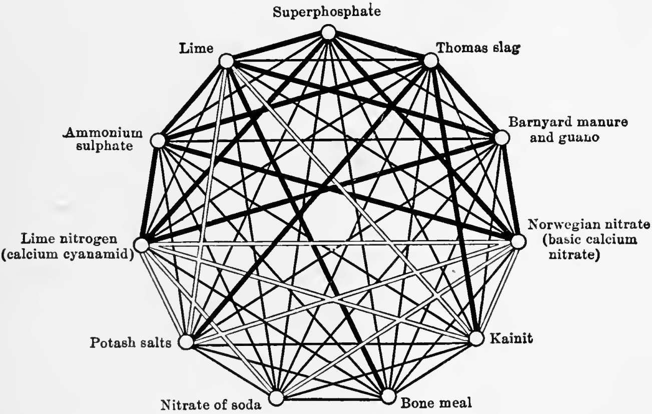

FIG. 64.—Diagram indicating what fertilizer materials may and may not be safely mixed. The dark lines unite materials which should never be mixed, the double lines those which should be applied immediately after mixing, and the single lines those which may be mixed at any time.

PROBLEM: Make a fertilizer analyzing nitrogen equivalent to 4 per cent of ammonia, 8 per cent phosphoric acid, and 4 per cent water-soluble potash. Use 150 pounds of nitrate of soda as a source for a part of the nitrogen and derive the balance of the nitrogen from that contained in ground fish scrap. The ground fish scrap contains nitrogen equivalent to 10 per cent of ammonia, and, in addition, 6 per cent of phosphoric acid. The potash is to be derived from muriate of potash. The phosphoric acid is to be derived from 16 per cent acid phosphate.

This calculation should be handled as follows: The number of pounds of plant food required for a ton of this material is nitrogen equivalent to 80 pounds of ammonia, 160 pounds of actual phosphoric anhydride (P_2O_5), and 80 pounds of water-soluble potash. There is a specified amount of one material to be used as a source of nitrogen, 150 pounds of nitrate of soda which will contain nitrogen equivalent to 18 per cent of ammonia or 27 pounds in the 150 pounds of material. Nitrogen equivalent to 80 pounds of ammonia is required; so 27 pounds furnished by the nitrate of soda must be deducted, leaving 53 pounds to be furnished by ground fish scrap which contains nitrogen equivalent to 10 per cent of ammonia; hence it will require 530 pounds of ground fish scrap to furnish the remainder of the nitrogen. In addition to the nitrogen content of the fish scrap, this material carries 6 per cent of phosphoric acid, which is equivalent to 31.8 pounds of phosphoric acid. The amount of phosphoric acid required is 160 pounds, less 32 pounds derived from the ground fish scrap, leaving 128 pounds of actual phosphoric anhydride to be furnished by 16 per cent acid phosphate. The number of hundred pounds of acid phosphate required can be determined by dividing the number of pounds required, 128, by the number of pounds of phosphoric anhydride contained in 100 pounds of acid phosphate, 16, in this case. The number of hundred pounds of muriate of potash to use is determined by dividing 80, the number of pounds of actual potash, by 48, the number of pounds of potash contained in 100 pounds; $80 \div 48 = 1.666$, or 167 pounds. This form of calculation is the one most used by fertilizer manipulators in calculating their formulas.

Tabulating, we have the following:

Lbs. of Material.	Source and Composition of Material.	Lbs. of Nitrogen (N) equivalent to Ammonia (NH_3).	Lbs. of Phosphoric Acid (P_2O_5).	Lbs. of Water-Soluble Potash (K_2O).
150	18% (NH_3) nitrate of soda........	27.0		
530	10% (NH_3) and 6% (P_2O_5) ground fish..........................	53.0	32.0	
800	16% (P_2O_5) acid phosphate........	......	128.0	
157	48% (K_2O) muriate of potash.....	......	......	80
353	Make-weight filler...............			
2000		80.0	160.0	80
	Formula.................	4.0%	8.0%	4.0%

(3) *Given, material too low in composition to make a formula of high percentage composition; overcome the difficulty.*

PROBLEM: To apply 1000 pounds of a fertilizer per acre for truck, analyzing nitrogen equivalent to 5 per cent ammonia, 8 per cent phosphoric anhydride, and 8 per cent potash. Source of phosphoric acid, 14 per cent acid phosphate; source of nitrogen, ground fish scrap containing nitrogen equivalent to 10 per cent ammonia and 6 per cent available phosphoric acid; source of potash, sulphate of potash containing 48 per cent water-soluble potassium oxide (K_2O).

Apply the same process outlined in (2), whereby it is found that 1000 pounds of dried ground fish, 714 pounds of 14 per cent acid, and 333 pounds of sulphate of potash contain the plant food desired for compounding 1 ton of fertilizer analyzing nitrogen equivalent to 5 per cent of ammonia, 8 per cent phosphoric anhydride, and 8 per cent water-soluble potash; but that the mixture weighs 2047 pounds instead of 2000 pounds. Therefore the plant food is mixed in the same proportions as a " 5-8-8 " fertilizer (fertilizer containing 5 per cent ammonia, 8 per cent phosphoric anhydride and 8 per cent water-soluble potash); but due to the increased weight, the per cent is correspondingly diminished.

The results are tabulated as follows:

Lbs. of Material.	Percentage, Composition and Source of Material	Lbs. of Nitrogen (N) equivalent to Ammonia (NH_3).	Lbs. of Phosphoric Acid (P_2O_5).	Lbs. of Water-Soluble Potash (K_2O).
714	14% (P_2O_5) acid phosphate........		100.0	
1000	10% (NH_3) ammonia and 6% phosphoric anhydride dried ground fish	100.0	60.0	
333	48% (K_2O) sulphate of potash.....	......	......	160.0
2047	20.47	100.0	160.0	160.0
	Formula..................	4.89	7.82	7.82

Therefore the number of pounds to be applied that will contain the same amount of plant food as 1000 pounds of a 5-8-8 fertilizer can be calculated by making use of the following proportion:

$$2000 : 2047 = 1000 : x = 1024 \text{ pounds.}$$

(4) *Given, high-grade materials; make to the proportion of a low-grade formula, and avoid the use of a filler.*

Problem: Calculate a formula analyzing nitrogen equivalent to 3 per cent of ammonia, 8 per cent of available phosphoric acid, and 3 per cent of water-soluble potash, one-third of the nitrogen to be derived from sulphate of ammonia, which contains 24 per cent of ammonia, and two-thirds from cottonseed meal; the phosphoric anhydride, from 16 per cent acid phosphate; and the potash, from 48 per cent muriate of potash. Calculate the analysis of the formula if no filler is added, and the number of pounds of this mixture equivalent to 500 pounds of a "3-8-3" fertilizer.

(*a*) Proceed as in (3). In this case there is a difference from the type given under (3) in that there are two sources of nitrogen given, but the amount to calculate to each source is also fixed, hence we find 571 pounds cottonseed meal, 7–2–1.5, will carry nitrogen equivalent to 7 per cent of ammonia and that 83 pounds of sulphate of ammonia will carry one unit of ammonia. The available phosphoric anhydride not furnished by the content of the 571 pounds of cottonseed meal will be furnished by 932 pounds of 16 per cent acid phosphate; and the water-soluble potash not furnished by the water-soluble potash content of 1.5 per cent contained in the cottonseed meal will be furnished by 107 pounds of 48 per cent muriate of potash.

(*b*) Proceed as in (1). Adding we find that 1693 pounds of a mixture of cottonseed meal, sulphate of ammonia, acid phosphate, and muriate of potash in the proportions shown under (*a*) contains nitrogen equivalent to 60 pounds of ammonia, 160 pounds of phosphoric anhydride, and 60 pounds of water-soluble potash; hence, if we divide these figures by 16.93, we will obtain the number of pounds of actual plant food in each hundred pounds of the mixture or the per cent., 9.6 per cent available phosphoric acid, nitrogen equivalent to 3.6 per cent ammonia, and 3.6 per cent of water-soluble potash.

(*c*) The number of pounds of this mixture equivalent to 500 pounds of a 3–8–3 fertilizer is solved as under (3):

$$2000 : 1693 = 500 : x = 423 \text{ pounds.}$$

This proportion is based on the fact that 2000 pounds, the weight of a ton, is to 1693 pounds, the weight of the mixture containing the amount of plant food in the ton, as 500 pounds, the portion of the ton used, is to x, x representing the proportion of the mixture equivalent to 500 pounds of 3–8–3 fertilizer. To use this mixture on the 3-8-3 basis 423 pounds should be applied where 500 is called for.

(5) *To determine the amount and composition of a fer-*

tilizer when a portion is used under the crop and the remainder as a side application or topdressing.

Problem: Suppose that 500 pounds of a 3–8–3 mixture is applied to corn land before the crop is planted, 200 pounds of 7–5–5 mixture is applied at the time of the second cultivation of the crop, and that 100 pounds of nitrate of soda is applied when the plants are about 4 feet tall, what percentages and what composition will the entire fertilization give?

This is a different application of the principles given under (1); however, the same type will serve as an illustration. The calculation shows that the entire application is 800 pounds of fertilizer analyzing nitrogen equivalent to 5.88 per cent of ammonia, 6.25 per cent phosphoric acid, and 3.13 per cent of water-soluble potash.

(6) *To convert fertilizers from one formula to another.*

Problem: Convert a 4–8–4 fertilizer to a 3–9–2 formula, using dried ground fish, 10 per cent ammonia and 6 per cent available phosphoric acid, and 16 per cent acid phosphate. Calculate the number of pounds of each of these materials and of filler. An inspection of the two formulas shows that the greatest difference is in the potash content of the two formulas, hence the potash content of the 4–8–4 fertilizer will limit the number of pounds that can be used. A ton of 4–8–4 fertilizer contains 80 pounds of potash, while a ton of 3–9–2 fertilizer contains only 40 pounds of potash, therefore 1000 pounds of the 4–8–4 fertilizer can be used. This leaves 20 pounds of nitrogen and 100 pounds of phosphoric acid to be furnished by dried ground fish and acid phosphate. The nitrogen is the smallest amount and should be supplied first because the dried ground fish also furnishes some phosphorus, which must be deducted from the balance to be furnished before the amount of acid phosphate is calculated. Twenty pounds of nitrogen is furnished by 200 pounds of dried ground fish analyzing nitrogen equivalent to 10 per cent of ammonia, 6 per cent or 12 pounds of phosphoric acid is also furnished, and this amount, deducted from 100 pounds, leaves 88 pounds to be furnished by 16 per cent acid phosphate. Sixteen will go into 88 five and one-half times, hence 550 pounds of acid phosphate will be required. Adding, we have 1750 pounds of material to which must be added 250 pounds of make-weight or filler.

Type of conversion of fertilizer from one formula to another:

Lbs. of Material.	Source and Composition of Material.	Nitrogen equivalent to Lbs. of Ammonia	Lbs. of Phosphoric Anhydride.	Lbs. of Water-soluble Potash (K_2O).
1000	4-8-4 fertilizer	40.0	80.0	40.0
200	Dried ground fish 10% NH_3—6% P_2O_5	20.0	12.0	
550	16% acid phosphate	......	88.0	
250	Filler			
2000		60.0	180.00	40.0
		3.0%	9.0%	2.0%

In the above calculations the plant food elements have been computed on the basis of the phosphorus combined as phosphoric anhydride (P_2O_5), the nitrogen as ammonia (NH_3), and the potassium as potassium oxide (K_2O). The reason for this is that it is on this basis that it has become customary to buy and sell the elements.

The above types will cover all of the contingencies likely to arise in the home-mixing of fertilizers.

CHAPTER XVII

ANIMAL NUTRITION

116. Purposes of Animal Food. Food serves the animal in three ways.

1. To act as a fuel to keep up the temperature above that of the surrounding air. This is accomplished by the oxidation of the combustible portion of the food throughout the body in the capillaries wherein the oxygen in the blood corpuscles comes in contact with combustible matter in the blood serum.

2. To furnish energy by which the mechanical or mental work of the body may be produced.

3. To build up or keep in repair the bodily structures.

117. Classes of Foods. Plants can sustain themselves upon very simple foods such as water, carbon dioxide and mineral salts, while animals are so constructed that they demand more highly organized foods and are therefore dependent upon plant structures or upon animals that subsist upon vegetable food.

Foods of animals fall into one of four classes:

1. *Proteins.* These are composed of carbon, hydrogen and oxygen with a rather large amount of nitrogen (16 per cent) and generally small portions of sulphur and iron. The amount of protein is calculated by multiplying the nitrogen content of the material by the factor 6.25. Proteins are utilized by animals to build up worn-out muscular tissue. They are found in the gluten of flour, beans, nuts and generally in the seeds of plants, in lean meat, milk, cheese and whites of eggs, as well as in various feeds.

2. *Carbohydrates.* These are made up of carbon, hydrogen and oxygen, the two latter in the same proportion as

they are found in water. They supply the animal with heat and energy. Starches and sugars are carbohydrates. Carbohydrates are also contained in potatoes, in wheat flour, oatmeal and other cereals.

3. *Fats.* These are composed almost entirely of carbon, hydrogen and oxygen with a high percentage of carbon. Like the carbohydrates they supply heat and bodily energy, having per pound more than twice the value of the carbohydrates. Fats are found in butter, meat fats and the oils of various nuts. The fats stored up in the body are mainly derived from the carbohydrate food.

4. *Mineral Compounds.* These have varied composition, but very few contain carbon. They serve a variety of purposes in the body. Water and the salts of sodium and calcium are the most important articles of this class of foods.

118. Development of a Science of Animal Nutrition. The science of animal nutrition had its beginning in 1859, when Grouven suggested the first feeding standard for farm animals. Grouven's standard was based upon the *total amount* of crude protein, carbohydrates, and fat contained in the material fed. Later work has shown that this was an irrational basis, because of the variation in the digestibility of these proximate constituents in different animal feeds. It is even more necessary to consider the digestibility of the feed for animals than it is to consider the availability of a fertilizing material for plants, because, after a certain length of time, the feed undigested is voided by the animal, while the unavailable plant food remains in the soil and may later be made available by natural agencies.

In 1864, Dr. Emil von Wolff presented a table of feeding standards based on the amount of *digestible nutrients* contained in each particular feeding stuff. Wolff's standard has since furnished the basis for rational feeding methods. In 1874, ten years after Wolff published his standard, Dr. Atwater brought it to the attention of the American people, and in 1880 Armsby published his "Manual of

Cattle Feeding." The Wolff standard was used unaltered until 1896, when as a result of further experiments, some alterations were made. It was presented annually from 1896 to 1906 by Dr. C. Lehman, under the name of the *Wolff-Lehmann Standards.* Table XVI gives the last of these standards.

119. Digestible Nutrients. The term digestible nutrient is applied to the digestible portion of feeds. The digestible nutrients are the carbohydrates, the fats and protein.

The percentage of each feed that is digestible is determined by feeding experiments with various classes of mature animals. Experiments show that ruminants digest the same kind of food about equally well, while horses and swine digest less fiber than do the ruminants; however, they seem to digest the concentrates about as well as the ruminants. Age and breed seem to have no definite influence on digestion.

120. Metabolism. Metabolism is the process by which digested nutrients are used for the building of tissue and by which these tissues are broken down with the production of heat. The building-up processes are called *anabolism,* while the breaking-down processes are called *catabolism.*

The digested sugars are taken up by the capillaries and carried into the veins, by which they are transferred to the liver, where they are made into *glycogen* or animal starch and stored temporarily as such. This constitutes the animal's reserve supply of sugar, for it is reconverted into sugars and made use of by the animal as required, especially when work is being done. The fats seem to be absorbed as soaps and glycerin into the intestinal walls, where they are converted into neutral fats and find their way into the circulatory system. The products of the protein digestion are absorbed from the small intestines and converted into *serum albumin* and *serum globulin,* which are the nitrogenous materials used in the building of body tissues. All of these materials are transported by the blood to the various

TABLE XVI.—THE WOLFF-LEHMAN FEEDING STANDARD

	Per Day per 1000 lbs. Live Weight.					
		Digestible Nutrients.				
	Dry Matter.	Crude Protein.	Carbohydrates.	Fat.	Sum of Nutrients.	Nutritive Ratio, 1.
1. *Oxen:*	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	
At rest in stall.....	18	0.7	8.0	0.1	7.5	11.8
At light work......	22	1.4	10.0	0.3	9.7	7.7
At medium work...	25	2.0	11.5	0.5	12.0	6.5
At heavy work....	28	2.8	13.0	0.8	15.0	5.3
2. *Fattening cattle:*						
First period.......	30	2.5	15.0	0.5	15.6	6.5
Second period.....	30	3.0	14.5	0.7	17.0	5.4
Third period......	26	2.7	15.0	0.7	17.2	6.2
3. *Milch cows:*						
When yielding daily						
11.0 lbs. of milk ...	25	1.6	10.0	0.3	10.2	6.7
16.6 lbs. of milk....	27	2.0	11.0	0.4	12.2	6.0
22.0 lbs. of milk....	29	2.5	13.0	0.5	14.4	5.7
27.5 lbs. of milk....	32	3.3	13.0	0.8	16.0	4.5
4. *Sheep:*						
Coarse wool.......	20	1.2	10.5	0.2	9.1	9.1
Fine wool.........	23	1.5	12.0	0.3	10.5	8.5
5. *Breeding ewes*						
With lambs.......	25	2.9	15.0	0.5	16.3	5.6
6. *Fattening sheep:*						
First period.......	30	3.0	15.0	0.5	16.5	5.4
Second period.....	28	3.5	14.5	0.6	16.9	4.5
7. *Horses:*						
Light work........	20	1.5	9.5	0.4	10.0	7.0
Medium work.....	24	2.0	11.0	0.6	12.8	6.2
Heavy work.......	26	2.5	13.3	0.8	15.5	6.0
8. *Brood sows*..........	22	2.5	15.5	0.4	19.0	6.6
9. *Fattening swine:*						
First period.......	36	4.5	25.0	0.7	31.2	5.9
Second period.....	32	4.0	24.0	0.5	29.2	6.3
Third period......	25	2.7	18.0	0.4	22.0	7.0

TABLE XVI.—*Continued*

		Per Day per 1000 Lbs. Live Weight.					
			Digestible Nutrients.				
		Dry Matter.	Crude Protein.	Carbohydrates.	Fat.	Sum of Nutrients.	Nutritive Ratio, 1.
10. *Growing cattle:* Dairy breeds.							
Age in Months	Av. Live Wt. per Head, Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	
2– 3	150.....	23	4.0	13.0	2.0	21.0	4.5
3– 6	300.....	24	3.0	12.8	1.0	17.0	5.1
6–12	500.....	27	2.0	12.5	0.5	13.7	6.8
12–18	700.....	26	1.8	12.5	0.4	12.8	7.5
18–24	900.....	26	1.5	12.0	0.3	11.8	8.5
11. *Growing cattle:* Beef breeds.							
2– 3	160.....	23	4.2	13.0	2.0	21.5	4.2
3– 6	330.....	24	3.5	12.8	1.5	19.0	4.7
6–12	550.....	25	2.5	13.2	0.7	15.8	6.0
12–18	750.....	24	2.0	12.5	0.5	13.9	6.8
18–24	950.....	24	1.8	12.0	0.4	13.2	7.2
12. *Growing Sheep:* Wool breeds.							
4– 6	60.....	25	3.4	15.4	0.7	18.4	5.0
6– 8	75.....	25	2.8	13.8	0.6	15.8	5.4
8–11	80.....	23	2.1	11.5	0.5	12.8	6.0
11–15	90.....	22	1.8	11.2	0.4	12.0	7.0
15–20	100.....	22	1.5	10.8	0.3	11.0	7.7
13. *Growing sheep:* Mutton breeds.							
4– 6	60.....	26	4.4	15.5	0.9	20.9	4.0
6– 8	80.....	26	3.5	15.0	0.7	17.8	4.8
8–11	100.....	24	3.0	14.3	0.5	16.3	5.2
11–15	120.....	23	2.2	12.6	0.5	13.8	6.3
15–20	150.....	22	2.0	12.0	0.4	12.8	6.5

TABLE XVI.—*Continued*

		Per Day per 1000 Lbs. Live Weight.					
			Digestible Nutrients.				
		Dry Matter.	Crude Protein.	Carbohydrates.	Fat.	Sum of Nutrients.	Nutritive Ratio, 1.
14. *Growing swine:* Breeding stock.							
Age in Months	Av. Live Wt. per Head, Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	
2– 3	50.....	44	7.6	28.0	1.0	38.0	4.0
3– 5	100.....	35	4.8	22.5	0.7	29.0	5.0
5– 6	120.....	32	3.7	21.3	0.4	26.0	6.0
6– 8	200.....	28	2.8	18.7	0.3	22.2	7.0
8–12	250.....	25	2.1	15.3	0.2	17.9	7.5
15. *Growing, fattening swine:*							
2– 3	50.....	44	7.6	28.0	1.0	38.0	4.0
3– 5	100.....	35	5.0	23.1	0.8	30.0	5.0
5– 6	150.....	33	4.3	22.3	0.6	28.0	5.5
6– 8	200.....	30	3.6	20.5	0.4	25.1	6.0
9–12	300.....	26	3.0	18.3	0.3	22.0	6.4

tissues nourishing the body and serve as a source of heat and energy.

121. Rations for Various Purposes. A ration is the quantity of food consumed by animals per 1000 pounds of live weight during twenty-four hours. The age of the animal and the purpose for which it is kept exert important influences on the kind and amount of food that is desirable.

122. Growth Rations. Young and growing animals need a ration that will produce bone and muscle. When maturity is reached, there is little subsequent increase in either the bones or the muscles. The bones, in part, and the ligaments, muscles, nervous system, and tendons consist almost entirely of protein, therefore the young and growing animals make economical use of large amounts of protein. It is not desirable to feed large amounts of protein to mature animals unless they are either pregnant, or giving milk, or producing wool, because the protein eaten above the amount needed for maintaining the body tissues is uneconomically used.

The protein of the milk which the young animal takes is very largely stored in the body. Soxhlet found that 72.6 per cent of the protein, 96.6 per cent of the lime, and 72.6 per cent of the phosphorus fed in the milk was stored in the body of a calf between two and three weeks old. The proportion stored diminishes as the animal approaches maturity.

Growing animals should get an abundance of succulent, highly nitrogenous forage plants. These plants usually contain a liberal amount of mineral elements. Some concentrate (such as bran, meal, oats) is usually desirable and an abundant supply of common salt.

123. Maintenance Rations. A certain amount of food is required by mature animals to perform the body functions, such as furnishing heat to maintain the body temperature, energy to perform the vital functions, and various materials to replace the waste tissue that is constantly being broken down. This is known as the *maintenance ration.* If it is too much reduced, starvation will result.

These rations may consist largely of coarse hay and straw or " roughages," as they are called. The main requirement is the production of heat, and roughages contain a large amount of carbonaceous material, which produces heat economically. Very little protein is required in the maintenance ration, because protein is only needed for the replacement of waste tissue, a requirement which is low in mature animals.

Experiments have shown that the temperament of the animal, the condition with respect to flesh, the conditions under which the animal is kept, the body covering and the bodily surface exposed, and the severity of the weather all exert influence on the maintenance ration required. As wide a nutritive ratio as 11.8 parts of digestive carbohydrates to one part of digestive protein may be used successfully for a maintenance ration. The nutritive ratio is determined by adding 2.25 times the digestible fat to the digestible carbohydrates, and dividing by the digestible protein.

124. Fattening Rations. The main object of fattening is to improve the quality of the meat; the accumulation of fatty tissue is a secondary object. The formation of fat and its accumulation in the animal is governed by the quantity and quality of the food consumed above the amount required for growth and maintenance. It is difficult to fatten young animals on account of their tendency to make use of a large part of the food eaten for growth. Exertion or excitement of any kind lessens the amount of fat formed from a given quantity of feed. The fattening ration for beef animals depends upon their condition when feeding is begun. If the animals are thin, a ratio of one part of protein to six parts of carbohydrate is recommended, allowing a liberal amount of protein during the first period of fattening, in order that the muscular tissues may be built up. From 12 to 15 pounds of digestible nutrients in the proportion already mentioned should be given per 1000 pounds of live-weight. For mature animals in good condition, a nutritive ratio as wide as 1 to 10 or 12 is suggested. The nutritive ratio will depend to some extent on the relative cost of feeds containing protein to the cost of carbohydrate feeds. In the Southern States, the cheap cottonseed meal will warrant a narrower ration, i.e., one having less carbohydrate in proportion to the protein than is usually recommended elsewhere.

Hogs make good gains on a narrower nutritive ratio than is needed for steers. The ratios showing best results range from 1 to 6 in the beginning to 1 to 7 toward the end of the fattening period. It has been shown that 100 pounds of dry feed consumed will form 6.2 pounds of increased weight in cattle, 8 pounds in sheep, and 17.6 pounds in hogs. An inspection of the quotations from the various stock markets will show that on this basis pork is the most profitable meat to produce.

125. Milk-Cows' Ration. The Wolff-Lehmann standards advise for milk-cows a nutritive ratio of 1 to 5.7 (i.e., digestible protein 1 part, digestible carbohydrates$+(2.25\times$fat$)=5.7$ parts). For a cow that is expected to give 22 quarts of milk, 29 pounds of dry matter is recommended per 1000 pounds of live-weight. The narrowest ration that is recommended in these standards is recommended for milk-cows. The feed of a dairy cow must of necessity contain a considerable amount of concentrates which are high in price compared with roughages; but the value of the product will warrant the increased expenditure. In calculating a ration, it is not always practicable to get the exact ratio within the prescribed number of pounds of dry matter. If possible, the number of pounds of dry matter should be under rather than over the standard, because the digestive organs of a highly specialized animal should not be overtaxed. The dairy cow is essentially a machine for the transformation of feed into milk; hence every effort should be directed to a large production per animal so as to reduce the cost of maintenance rations as low as possible by having fewer animals to maintain. With this end in view, the dairy cow, when in milk, should receive an abundant supply of concentrates even if she has a good pasture. While dry, she can be maintained like other animals, largely on roughage.

126. Ration for Work Animals. The activity of the muscles during the performance of work greatly increases the amount of food required above a maintenance ration. It has been shown by repeated experiments that energy is derived most cheaply through the oxidation of carbohydrates and fats in the body; that a sufficient supply of carbohydrates and fats is an adequate source for all the energy needed; and that, if these are insufficient, the protein compounds may be drawn upon as a source of energy. This latter source makes the cost of the energy greater, and it also imposes extra work on the urinary system, through which the nitrogenous products of the oxidation of protein are removed. During work, the quantity of carbon dioxide exhaled is much increased, due to the greater quantity of carbonaceous matter that is oxidized. The latest investigations show that no more nitrogenous tissue is broken down by animals while at work than at rest. Working animals thus require a more concentrated feed and less roughage.

The horse requires considerably less dry matter per 1000 pounds of live-weight than do the ruminants, and its food should be rich and easily digested. Horses must be fed in accordance with the work that they are doing, the ration being reduced when at rest or light work, to secure economical results. It is advisable to give most of the roughage at night. A moderate but not an excessive amount of hay is desirable. The Wolff-Lehmann standards recommend a nutritive ratio of 1 to 6.2 for a horse on medium work, and Henry states that " from 10 to 18 pounds of concentrates should be fed, according to the severity of the labor, the total grain and hay averaging not less than 2 pounds per hundred pounds weight of the animal."

CHAPTER XVIII

FEEDS—THE CALCULATION OF RATIONS

A BRIEF discussion of some of the more commonly used feeds is given in the following paragraphs:

1. THE CONCENTRATE FEEDS—CEREALS

127. Corn. Corn is essentially a carbonaceous feed, and is not as good for growing animals as is oats. Corn has very marked heat-giving and fattening properties and, for this reason, it is quite extensively used for fattening steers, sheep and hogs. It is highly prized as a feed for work horses and mules, giving most satisfactory results. It is quite useful for making up a part of the carbohydrates in a balanced ration.

128. Oats. Oats is an excellent feed for stock, because the nutrients are present in a good ratio for the work horse, the dairy cow, and for young and growing animals. Oats are used the world over as feed for horses, giving vigor and stamina. Ground oats have been found superior to wheat bran for producing both milk and butter-fat. The protein contained in oats shows a higher coefficient of digestibility than that of corn, while the carbohydrates of corn show a higher digestibility than those of oats.

129. Barley. Barley is used for a stock feed mainly on the Pacific slope, where it flourishes better than corn or oats. In some cases, barley is injured for brewing purposes by bad weather at harvest time, while its value for feeding purposes is unimpaired. It is extensively used in foreign countries for pork production and for the feeding of dairy cows. It produces pork of excellent quality and, along with oats, is regarded highly as a feed for producing milk and butter fat.

130. Dried Brewers' Grain. Dried brewers' grain is a by-product of barley, being the residue left from brewing. In brewing, the fermentable carbohydrates are converted into alcohol and the protein, fat, and crude fiber are largely left in the residue, hence dried brewers' grain is rich in these materials. The dry matter and carbohydrates of the dried brewers' grain are lower in digestibility than the same proximate constituents of barley, while, on the other hand, the protein and fat of the dried brewers' grain are more digestible than those of barley.

131. Rye. Rye is not keenly relished by stock. It is subject, also, to a fungus disease, *ergot*, that may be injurious.

132. Wheat. Wheat, on account of its cost of production and its value as a human food, cannot be used extensively for feeding stock. When fed to farm animals, it is best mixed with other grains, with the corn for work stock and with oats for growing stock.

The by-products of the manufacture of wheat into flour—*shorts*, *middlings* and *bran*—are very valuable stock feeds.

Wheat bran is the outer covering of the wheat kernel, and is that part which is first removed in the manufacture of flour. Its volume is large in proportion to its weight, therefore it is often used to give bulk to a feed ration. Bran contains a high percentage of crude protein and mineral matter. It is an excellent feed for breeding stock of all kinds, for horses, and for dairy cows. It serves to keep the animal's stomach in good order and to build up bone and muscles in young stock. It is also well suited for use in balancing the rations of dairy cows.

Wheat middlings are composed of the part of the kernel below the bran. It is even higher in protein content than bran and is an excellent material to form a part of the ration of hogs and dairy cows.

133. Rice. Rice is used as a human food over a large part of the world. In the process of milling, there are several by-products which are of value as stock feed. The rough rice is put through a machine which removes the hull and leaves the rice grain intact. The grains are then rubbed by mechanical means until the skin and the flour at the eye of grain are removed. Some grains which are inferior are so abraded that they grind up. The material is then sifted to remove the flour, and the fine chaff is removed by fanning. This chaff is then mixed with the flour, forming what is known as *rice flour* or *bran.*

Rice polish is obtained by the operation that rubs off the last covering layer and a good part of the starch. This is accomplished mechanically by rubbing the rice against pieces of moose hide or sheepskin. Rice polish contains a considerable amount of starch.

Rice meal may prove injurious to the intestines of hogs, on account of the irritation caused by fine splinters of silicious material that find their way from the hulls into the meal.

2. Highly Nitrogenous Concentrates

134. Cottonseed Meal. Cottonseed meal, a by-product of the cottonseed oil mills, is the cheapest source of digestible protein that can be bought in the form of a concentrate. On this account, there is grave danger of too liberal use of it, especially in the Southern States. Where used in limited quantities, it is a most excellent source of protein. Enough cottonseed hulls to reduce the nitrogen to about the equivalent of 7 per cent of ammonia is often added, the crushers claiming that this promotes a more complete removal of the oil. The cottonseed cake used for domestic purposes is usually ground and placed in 100-pound sacks, which is a convenient weight for handling. Cottonseed meal is high in protein and fat, but low in digestible carbohydrates.

In the South many steers are fattened on cottonseed meal as the sole concentrate. They are started on a comparatively small amount, about 3 or 4 pounds per day, which is increased to as much as 8 or 10 pounds before the end of the feeding period. Cottonseed meal could be used to better advantage as a part of the ration, some concentrate carrying a larger percentage of carbohydrates being substituted as the other part. The excessive feeding of cottonseed meal over a long period of time has led to harmful effects; in some cases blindness and partial paralysis are induced, but no such results are obtained where it is properly mixed with other feeds.

Cottonseed meal seems to vary in its poisonous qualities to hogs, some meals being quite toxic, while others have been fed in heavy amounts for a long period without producing death. Copperas has been used along with cottonseed meal, as an antidote, with good results. The feeder should realize that in feeding cottonseed meal he is using a cheap feed that may prove injurious, and the animals should be carefully watched.

Cottonseed meal may be fed to work horses, brood mares, and colts in limited quantities of from 1 to 2 pounds daily. It gives the animals a good coat, and is keenly relished after they learn to eat it. For dairy cows the use of cottonseed meal to an amount not exceeding 5 pounds per 1000 pounds of live weight per day is to be recommended. Its excessive use has a tendency to raise the melting point of the butter. Cottonseed meal is giving good results as a poultry feed.

135. Linseed Meal. Linseed meal is made by two processes. The *old-process meal* is the residue obtained by expressing the oil while cold, by means of pressure. *New-process meal* is the residue of the extraction of the oil by means of naphtha, which is later driven off by steam. This cooking makes the crude protein slightly less digestible. The new process meal contains more crude protein, but only about one-fourth as much crude fat, the new process being a much more effective means of removing the oil.

Linseed meal may be fed in small quantities to all classes of live stock with excellent results. It is considerably higher in price than cottonseed meal, and, consequently, there is not the same tendency to over-feed it.

136. Meat Scraps. Meat scraps, or tankage, is very high in protein. In buying tankage for feeding, care should be exercised to avoid buying acidulated tankage. Tankage is rather a high-priced source of nitrogenous feed. It has been used for cattle, sheep, hogs, and horses with good results. Parts from diseased animals are often incorporated in tankage, and infection from this source is possible, though improbable; not a case of such infection has been reported by any Station experimenting with this feed. In preparation, the tankage is cooked by means of steam under pressure to facilitate the removal of the grease. This treatment should produce a sterile condition. This form of protein does not seem to have its digestibility harmfully influenced because of the cooking, for the protein is given as 93 per cent digestible. Tankage is highly prized as a poultry feed.

137. Dried Fish. Dried fish has been used to some extent as a feed for dairy cows without any harmful or objectionable influence on the quality of the milk. It is highly nitrogenous, containing as high as 48 per cent of protein as well as a high percentage of fat, both of which are highly digestible. In the table of digestibility the protein is given as 93 per cent digestible and the fat as 98 per cent.

138. Blood Meal. Blood meal is the richest available source of protein, and contains about 84 per cent, of which 84 per cent is digestible. It has given good results when fed to hardworked horses at the rate of about 1 pound per day, and when fed to sickly calves in their milk at the rate of from a teaspoonful to a tablespoonful. When fed to pigs, 1 pound of blood meal may replace 12 pounds of skim milk if mixed with some material that the pigs will eat, and, for lambs ½ pound of blood meal may be fed per 100 pounds of live weight with good results.

139. Soybean Meal. Soybean meal is highly nitrogenous, containing about 33.5 per cent of protein which shows a digestibility of 87 per cent. It forms a better feed after the oil is expressed than when the whole bean is ground and fed.

140. Peanuts. Peanuts run high in both protein and fat, and form an excellent source of feed for hogs. Peanuts yield about 40 bushels per acre, and are best harvested by the hogs. Unless the fattening is completed by feeding corn, the lard will not solidify at ordinary temperatures. When the oil is extracted, the peanut meal may be used to some extent as a feed for stock. This meal contains the highest protein content of any vegetable material—about 47 per cent.

3. The Roughages

141. Timothy. Timothy is the most popular hay for city markets, and serves well as a roughage along with such a concentrate as oats; but under farm conditions other hays are more cheaply grown, because they yield more heavily. The early cut timothy hay contains more protein in proportion to the carbohydrates present, and therefore is well suited to the requirements of dairy cows and young and growing stock. The late cut hay is better for horses and for fattening cattle. Late cutting also gives a better yield. On account of its quality, timothy is highly valued for horses, but it does not contain a large amount of digestible nutrients. Timothy is not an economical feed for fattening cattle nor for dairy cows; in fact, it is most valuable as a roughage for driving, saddle, and race horses. From the farmer's viewpoint, the chief value of timothy lies in the fact that it is an easily marketed hay.

142. Cereals. The cereals are used to some extent as roughages, and even where they are harvested and threshed, the straw has some value as roughage.

Oat straw is the most nutritious of the straws, and may be used to advantage as a part of a maintenance ration.

Oat hay is easily grown, and is much relished by stock. The time of cutting should be decided to some extent by the stock for which it is to be used. The protein content increases until early in the milk stage of growth, when the hay should be cut, if a maximum protein content is desired. Most of the starch in oats is formed after the beginning of the milk stage; hence, if a feed high in nitrogen-free extract is desired, the cutting should be delayed as long as possible, for there is a rapid increase in the total dry matter of about 40 per cent from the early milk stage to maturity, the combined starch and sugars increasing at this time from about 13 to 30 per cent. For dairy cows and young and growing stock, the early cutting would be advisable. For feeding along with highly nitrogenous feeds, the later cutting will be best.

143. Legumes. The legumes should be grown and used for roughage as much as possible on account of their beneficial influence on the soil, in addition to their high content of digestible nutrients.

Alfalfa hay is especially valuable for practically all classes of stock. It is excellent for dairy cows and fattening steers. For dairy cows it may be used as a substitute for a small part of the concentrate, yielding cheaper milk; while in fattening beef cattle it may be used to a larger extent in replacing the concentrates. It has an especial value as a maintenance ration for young hogs, and can be used to some extent for fattening hogs. Sheep thrive on alfalfa hay. Work horses can use it to good advantage, but it is not advisable to feed it to driving horses.

Red clover is much used in rotations in the Northern part of the United States. When well cured red clover hay is a desirable feed for horses. Experiments show that it gives splendid results for fattening beef cattle, both by reducing the amount of concentrates necessary and by shortening the feeding period. For dairy cows, clover hay is a splendid roughage, being rich in protein and in mineral elements. It is excellent for young stock on account of its high content of bone- and muscle-producing materials. Clover is especially valuable as a feed for hogs.

Crimson clover makes a hay of fair quality when cut early; if cut late, the blossoms are covered with very small barbed heads which may accumulate in spherical balls in the stomachs of horses, and in some cases may stop up the intestines so that death may ensue.

Japanese clover on rich land yields a hay of good quality.

Canadian field peas or common field peas are grown in the Northern States along with oats for hay. This hay is both nutritious and keenly relished and fills very much the same place in the North as oats and vetch do in the South.

Cowpea vines are harvested for hay in the Southern States. The vines should be cut about the time that the first pods begin to ripen, in order that a large yield may be secured and that the leaves may be cured along with the vines. It has been found that the leaves make up about 30 per cent of the weight of the hay and that they are much richer in protein than are the stems. Cowpea hay can be successfully substituted for a part of the concentrate for dairy cows and for fattening steers. It can be used for a maintenance ration for mules on Southern farms during the winter months when they are not at work.

Hairy vetch is adapted to a large part of the United States and makes a comparatively easily cured and nutritious hay. It should be sowed along with a cereal to support the vines. In the South these fields furnish good pasturage during the winter months when the land is dry enough for animals to walk on it.

Soybeans are planted for a hay crop to some extent, and the cured vines yield a nutritious hay, which can be produced at a low cost. Soybeans are more erect in their

TABLE XVII

Feeding Stuffs.	DRY MATTER.		CRUDE PROTEIN.		CARBOHYDRATES.				FAT.	
					Fiber.		Nitrogen-free Extract.			
	Per Cent of Total.	Per Cent Digestible	Per Cent of Total.	Per Cent Digestible.	Per Cent of Total.	Per Cent Digestible.	Per Cent of Total.	Per Cent Digestible.	Per Cent of Total.	Per Cent Digestible.
Green fodders and silage:										
Alfalfa	28.2	61	4.8	74	7.4	43	12.3	72	1.0	39
Red clover	29.2	66	4.4	66	8.1	49	13.5	71	1.1	61
Green dent, corn fodder	21.0	67	1.7	54	5.6	51	12.0	75	0.5	78
Corn silage	26.4	....	2.7	52	7.8	51	12.9	75	0.9	77
Corn silage, ears removed	26.3	....	2.2	50	6.5	....	15.1	....	0.9	77
Hays:										
Alfalfa hay	93.4	62	15.8	72	28.7	47	35.8	72	1.9	43
Red clover	84.7	57	12.3	58	24.8	54	38.1	64	3.3	55
Cowpea	89.5	59	18.9	65	21.2	43	42.6	71	2.6	50
Soybean	88.2	62	14.9	71	24.2	61	37.8	69	4.3	29
Timothy	84.7	55	5.9	48	29.0	50	45.0	62	2.5	50
Straws:										
Oat	90.8	48	4.0	33	37.0	54	42.4	46	2.3	36
Wheat	90.4	42	3.4	23	38.1	50	43.4	37	1.3	31
Root crops:										
Rutabagas	11.4	87	1.2	80	1.3	74	7.5	95	0.2	84
Mangels	9.1	87	1.4	70	0.9	37	5.5	95	0.2	
Turnips	9.9	87	1.3	73	1.2	51	6.3	92	0.2	

Oil seed:										
Cottonseed meal	93.0	77	38.6	83	6.3	35	24.6	78	10.2	94
Linseed meal, old process	91.2	79	33.9	89	7.3	57	35.7	78	7.8	89
Linseed meal, new process	91.0	82	37.5	84	8.9	74	36.4	80	2.0	89
Cereals:										
Corn meal	85.0	88	9.2	66	1.9	....	68.7	92	3.8	91
Corn-and-cob meal	84.9	79	8.5	52	6.6	45	64.8	88	3.5	84
Barley	89.2	86	12.0	70	4.2	50	68.7	92	1.8	89
Oats	89.6	70	11.4	77	10.8	31	59.4	77	4.8	89
Rye meal	91.3	87	11.3	84	1.5	....	74.5	92	1.9	64
Wheat	89.5	87	11.9	74	1.8	....	71.9	93	2.1	71
Wheat bran	88.1	66	15.4	77	9.0	41	53.9	71	4.0	63
Wheat middlings	90.0	82	19.2	88	3.2	36	59.6	88	4.8	86
Rice	87.6	98	7.4	86	0.2	....	79.2	100	0.4	90
Rice meal	89.8	74	12.0	62	5.4	....	51.2	92	13.1	91
Rice bran	90.3	62	11.9	64	12.0	21	46.6	78	10.1	72
Rice polish	89.2	83	11.9	66	3.3	22	62.3	93	7.2	74
Legumes:										
Cowpea meal	85.4	87	20.5	82	3.9	64	56.3	93	1.5	74
Soybean meal	88.3	79	33.5	87	4.5	....	28.3	73	17.2	85
Peanut kernels	92.5	83	27.9	90	7.0	9	15.6	84	39.6	90
Peanut cake	89.3	83	47.6	90	5.1	9	23.7	84	8.0	90
Dried brewers' grain	91.3	62	25.0	80	13.6	50	42.3	60	6.7	90
Malt sprouts	90.5	78	26.3	77	11.6	83	44.9	81	1.6	90
Dried beet pulp	91.6	77	8.1	51	17.5	72	60.8	86	0.7	
Meat scrap	89.3	93	71.2	93	.....	....	0.3	....	13.7	98
Dried fish	89.2	93	48.4	93	.....	....	.....	....	11.6	98
Blood meal	91.5	....	84.4	84	.....	....	.....	....	2.5	

habit of growth than the running varieties of cowpeas; consequently, they are more easily cut and harvested. The Tennessee Station has obtained good results from feeding soybean hay to dairy cows; in fact, it proved superior to alfalfa hay.

144. Composition and Digestibility of Feeds. Table XVII, which is compiled largely from Henry's " Feeds and Feeding," shows the composition and digestibility of a number of feeding stuffs.

145. The Calculation of Rations. The data of Table XVII and that given in the preceding chapter furnish all the information that is necessary for the calculation of *balanced rations.* Two concrete examples are here given to show the method and the operations involved in such calculations.

Example 1. The single feed, oats, is *nearly* a balanced ration for horses; its nutritive ratio is therefore calculated as the simplest illustration.

The Wolff-Lehmann standard shows that a ration for a horse consists of 24 pounds of dry matter. From Table XVII we find that 89.6 per cent of oats is dry matter. Hence, $24 \times 100 \div 89.6 = 26.8$ pounds, or 26.8 pounds of oats must be fed to furnish 24 pounds of dry matter. Therefore, calculating the nutritive ratio of 26.8 lbs. of oats, we have the values shown in Table XVIII.

In the calculation, the pounds of feed are multiplied by the percentage of each nutrient and the result is given in the third column of the table. This result is then multiplied by the *coefficient of digestibility,* or per cent of digestible material, and the amount of digestible nutrients are placed in each case under the proper head in the table. The digestible carbohydrates are added to 2.25 times the digestible fat (because fat is estimated to have 2.25 times the heat-giving power of carbohydrates) and the sum is divided by the digestible protein. The quotient gives the nutritive ratio compared with the digestible protein as the unit.

TABLE XVIII.—THE NUTRITIVE RATIO OF 26.8 POUNDS OF OATS

Nutrient.	Per Cent of Total.	No. Lbs. in Ration.	Per Cent Digestible.	Digestible Nutrients.				Nutritive Ratio. Protein (Carbohyrates—2.25 fat)
				Dry Matter.	Crude Protein.	Carbohydrates.	Fat.	
Dry matter	89.6	24.0	..	24.0				
Crude protein	11.4	3.05	77	..	2.35			
Crude fiber	10.8	2.89	31	..	..	0.90		
Nitrogen-free extract	59.4	15.92	77	..	..	12.26		
Fat	4.8	1.29	89	..	..	...	1.15	
Ration	..	...	..	24.0	2.35	13.16	1.15	1:6.7
Wolff-Lehmann	..	...	..	24.0	2.0	11.0	0.6	1:6.2

Thus in this case, $\frac{89.6}{100}\times 26.8$ pounds$=24$ pounds, the amount of dry matter; $\frac{11.4}{100}\times 26.8=3.05$ pounds protein, etc. Of this protein, 77 per cent or $\frac{77}{100}$ is digestible; hence $\frac{77}{100}\times 3.05$ pounds$=2.35$ pounds digestible protein, similarly, $\frac{31}{100}\times 2.89$ pounds$=0.90$ pound digestible crude fiber, etc., etc. The *nutritive ratio*=digestible protein: (digestible carbohydrates + 2.25 × fat) = 2.35 : (0.90 +12.26+2.25×1.15)=1 : 6.7.

The foregoing calculation shows that oats contain a nutritive ratio well suited to the needs of the horse, but that the proper amount of digestible dry matter contains too large an amount of nutrients; therefore, even with oats, some hay should be fed to give bulk. When this is done, the amount of oats fed will be reduced.

Example 2. The calculation of a ration for a dairy cow giving 27.5 pounds of milk will serve as an example of a more complicated problem. Suppose that it is proposed to feed 4 pounds of cottonseed meal, 6 pounds of wheat bran, 10 pounds of alfalfa hay, and 40 pounds of silage; the results based on the percentages given in table XVII and calculated as in Example 1, are tabulated in table XIX.

TABLE XIX.—AN UNCORRECTED RATION

	Lbs. as Fed.	Dry Matter.	Digestible Nutrients.			Nutritive Ratio.
			Protein.	Fiber and N-Free Ext.	Fat.	
Cottonseed meal...	4.0	3.72	1.28	0.15 0.76	0.39	
Wheat bran.......	6.0	5.29	0.71	0.22 2.29	0.15	
Alfalfa hay.......	10.0	9.34	1.14	1.35 2.58	0.08	
Corn silage.......	40.	10.56	0.56	1.59 3.87	0.28	
Total..........	60.0	28.91	3.69	12.81	0.90	1:4
Wolff-Lehmann...	....	32.00	3.30	13.00	0.80	1:4.5
(From Table XVI.)						
		− 3.09	+0.39	− 0.19	+0.10	

An inspection of the results in Table XIX shows that the protein content is more than is required, while the fat and carbohydrates are about right in amount. It is desirable to keep the total dry matter lower, if possible, than the Wolff-Lehmann figure. The correction of this ration can be accomplished by reducing the cottonseed meal and increasing the bran or by reducing the alfalfa hay and substituting a hay cheaper and less nutritious. In sections where cottonseed meal is cheap, its reduction will not be desirable; but, in sections where it is expensive, 1½ pounds of it may be replaced with an equal weight of corn meal. Table XX shows such a correction.

TABLE XX.—A CORRECTED RATION FOR A DAIRY COW PRODUCING 27.5 LBS. OF MILK

	POUNDS.		DIGESTIBLE NUTRIENTS.			Nutritive Ratio.
	Feed.	Dry Matter.	Protein.	Fiber and N-Free Ext.	Fat.	
Cottonseed meal...	2.5	2.33	0.80	0.06 0.48	0.24	
Corn meal........	1.5	1.28	0.09	0.95	0.05	
Wheat bran.......	6.0	5.29	0.71	0.22 2.29	0.15	
Alfalfa hay.......	10.0	9.34	1.14	1.35 2.58	0.08	
Corn silage.......	40.0	10.56	0.56	1.59 3.87	0.28	
Totals.........	60.0	28.80	3.30	13.39	0.80	1:4.6
Wolff-Lehmann... (From Table XVI.)	....	32.00	3.30	13.00	0.80	1:4.5
		− 3.20	+ .00	+ 0.39	+ .00	

The substitution of corn meal in place of 1½ pounds of the cottonseed meal served to balance the ration very satisfactorily.

These type calculations, problems 1 and 2, show the steps involved in calculating rations. Considerable liberty may be taken with the nutritive ratios in order to use cheap feeds, but they serve as a guide and should be followed as closely as possible for best results.

CHAPTER XIX

MILK AND ITS PRODUCTS

146. Milk. Milk contains water, fat, casein, albumin, milk-sugar, and mineral salts in proportions especially suited to the young of the mammal producing it. Table XXI shows the average composition of the milk of a number of mammals:

TABLE XXI.—THE COMPOSITION OF VARIOUS MILKS

Mammal.	Per Cent of Water.	Per Cent of Total Solids.	Per Cent of Proteids.	Per Cent of Fat.	Per Cent of Sugar.	Per Cent of Ash.
Human..........	88.00	12.00	1.50	3.50	6.80	0.20
Cow.............	87.25	12.75	3.50	4.00	4.50	0.75
Goat.............	86.60	13.40	4.60	4.30	4.00	0.60
Ewe.............	81.30	18.70	6.30	6.80	4.80	0.80
Mare............	90.00	10.00	1.90	1.10	6.70	0.30
Ass..............	89.60	10.40	2.20	1.60	6.10	0.50
Elephant.........	67.80	32.20	3.10	19.60	8.80	0.70
Porpoise..........	41.10	58.90	11.20	45.80	1.30	0.60

147. Milk from Different Breeds of Cattle. The nutritive ingredients of milk are combined in such proportions that it serves excellently as a part of the diet of adults, and its products, butter and cheese, are widely used and highly nutritious foods. For the production of butter, the content of fat in the milk is of prime importance, provided that the yield of milk is not sacrificed to this end. In table XXII are shown the differences in composition of milk of different breeds of cattle.

TABLE XXII.—A COMPARISON OF THE COMPOSITION OF MILK FROM DIFFERENT BREEDS

Breed.	Per Cent of Water.	Per Cent of Total Solids.	Per Cent of Proteins.	Per Cent of Fat.	Per Cent of Sugar.	Per Cent of Ash.
Jerseys	85.66	14.34	3.96	4.78	4.85	0.75
Shorthorns	87.55	12.45	3.27	3.65	4.80	0.73
Holstein-Friesians	87.88	12.12	3.28	3.51	4.69	0.64

The Jersey breed is noted for the production of rich milk, cream, and butter. The Holstein-Friesian breed is highly specialized for the production of a large quantity of milk. This milk serves well for the manufacture of cheese, and where the per cent of fat meets city inspection requirements, a dairy of this breed will prove especially profitable on account of the large yield of milk. The milking strains of the Shorthorn breed are desirable both for the production of the home milk supply in rural districts and as beef animals.

148. Danger from Infected Milk. Before being used for feeding infants, cows' milk must be changed in composition to make it more nearly conform to the composition of human milk. This is accomplished by diluting it with water to reduce the protein and fat and by adding sugar.

Great care should be taken with the milk used for children. It is estimated that 500,000 deaths occur annually in the United States from diseases and derangements due to infected or bad milk. Milk is an excellent medium for the growth of harmful bacteria, and every precaution should be taken to assure its purity. Where milk is purchased, there is danger from watering, leading to a lowering of its nutritive value, and from preservatives. Even when produced at home, every care should be exercised to see that the cows are healthy and that no poisonous weeds are fed. Any unusual appearance or odor of milk should be regarded with suspicion.

An abnormal color in milk is easily noticeable. Blue color may be due to microorganisms; yellow color to chromogenic organisms or to the fact that rhubarb has been eaten; red color to the eating of rhubarb, madder, and also to several

Fig. 65.—A clean dairy.

groups of bacteria, and green color is caused by pus-forming bacteria. Any unusual color is to be regarded with instant suspicion, and such milk should not be used until the source and harmless character of the color is established.

Typhoid fever, scarlet fever, diphtheria, foot and mouth disease, cowpox, anthrax, and glandular tuberculosis are some of the forms of diseases that are known to be occasioned by the use of infected milk.

Milk is so liable to become a source of danger as a food that all well-governed cities have placed the milk supply under government inspection. In many cases this control is so efficient that milk obtained in the city is safer and better than that obtained in the country. To pass the inspection the farmer is compelled to deliver a purer and higher grade of milk for city markets. The New York Board of Health have ruled that milk containing more than 88.5 per cent of water or less than 3 per cent of fat or less than 11.5 per cent of solids cannot be offered for sale legally in that city. The Boston Board of Health prohibits the sale of milk containing more than 500,000 bacteria per cubic centimeter or which is delivered at a temperature higher than 50° F.

149. Preservatives. Milk becomes infected a short time after production. If the use of the milk as a food is delayed, bacteria increase to inconceivable numbers. At the temperature of the human body (98.6° F. or 36° C.) one bacterium in milk will multiply to 75,000 in twenty-four hours. If the temperature is reduced to 50° F. bacteria will increase very slowly, if at all. All bacteria are not dangerous; some species are friendly, aiding in the processes of digestion and assimilation. There are three ways of controlling the number of bacteria: First, by preventing as far as possible infection, by healthy cows, cleanly methods of production and handling and control of temperature; second, by treating the milk by sterilization or pasteurization and then guarding against further infection; third, by adding to the milk some preservative which is germicidal. The last of these methods is to be condemned. Some preservatives are harmful, and all serve to preserve the milk by producing conditions that are not conducive to easy digestion. *Formalin,* which is a 40 per cent solution of formaldehyde (HCHO), is used in proportions of from 1 part formalin, 20,000 parts milk or to 50,000 parts milk, the smaller quantity will preserve milk for two days. *Sodium carbonate* (Na_2CO_3) and *magnesium carbonate* ($MgCO_3$) serve to neutralize acidity and to improve the appearance of the milk. *Potassium carbonate* (K_2CO_3), *borax* ($Na_2B_4O_7$) and *boracic acid* (H_3BO_3) are used as preservatives. They tend, however,

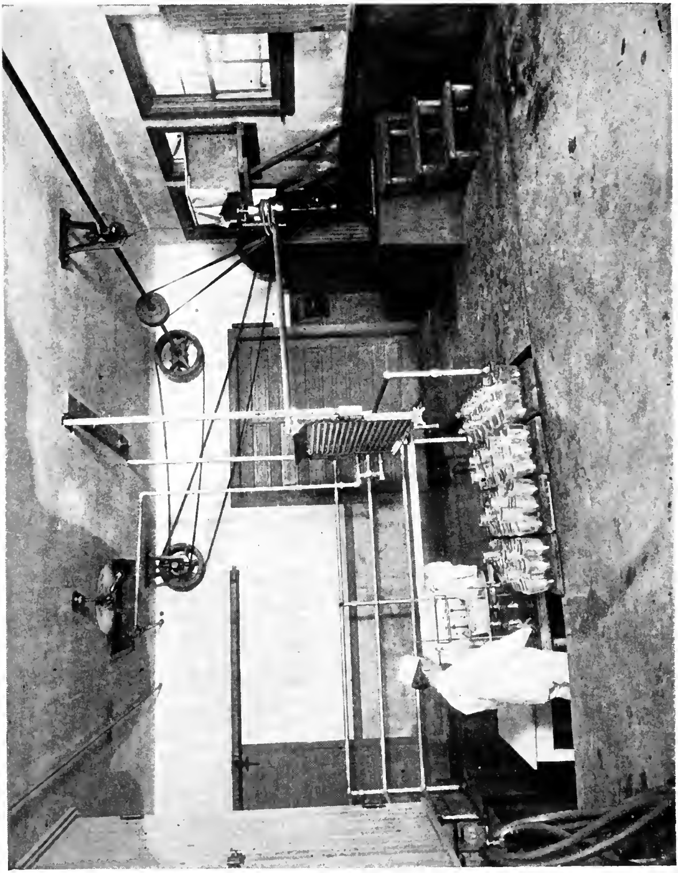

FIG. 66.—Sterilizing milk bottles.

to retard the separation of the cream. *Sodium benzoate* (C_6H_5COONa), *salicylic acid* ($C_6H_4OHCOOH$), *potassium nitrate* (KNO_3), *calcium peroxide* (CaO_2) and *hydrogen peroxide* (H_2O_2) in milk are all harmful. The *fluorides, fluosilicates* and *fluoborates* are dangerous poisons. Milk that is properly produced will keep as long as is necessary without preservatives, and the use of preservatives but serves to hide filthy handling and bad management.

The pasteurization of milk consists in keeping it at a temperature between 63° C. and 75° for at least twenty minutes, then rapidly chilling the milk. The necessity for pasteurizing milk should be avoided, because lecithin, which is beneficial to growing children, is destroyed, and also because enzymes which are helpful to digestion are killed. Pasteurization serves to kill disease-producing bacteria when present. Imperfect pasteurization of milk is, however, a source of danger, because incomplete heating kills the harmless lactic acid bacteria, while the dangerous putrefactive bacteria may not be affected. Such milk will keep from souring for a long time, and so the buyer, deceived by the absence of souring, may use milk impregnated with disease-producing germs.

150. The Detection of Formaldehyde in Milk. The presence of formaldehyde in milk may be detected as follows:

Method 1: *Sulphuric Acid Test:* Place 5 to 10 cubic centimeters of the milk in a large test-tube, or clean bottle, and add one-half the amount of commercial sulphuric acid, carefully pouring the acid down the side of the tube or bottle so that the milk and acid are not mixed. As the acid is heavier than the milk, it will sink to the bottom of the vessel. If a violet zone is formed at the junction of the two liquids, formaldehyde is present. The sulphuric acid should contain some iron; if chemically pure acid is used, a little ferric chloride must be added.

Method 2: *Hydrochloric Acid Test.* First prepare the acid for the test by adding two drops of ferric chloride solution to 50 cubic centimeters of the concentrated acid (sp. gr. 1.20). Place 10 cubic centimeters of the milk in a casserole or a porcelain evaporating dish, add an equal volume of the prepared acid and heat the mixture nearly to boiling. While heating, swirl the contents of the dish gently so as to break up the curd.

The presence of formaldehyde is indicated by a violet color varying in intensity with the amount of formaldehyde present. If no formaldehyde is present, the mixture turns brown.

151. Detection of Boracic Acid. To 10 cubic centimeters of the milk add 6 drops of concentrated hydrochloric acid and mix thoroughly. Dip a strip of turmeric paper in the mixture and dry the paper by wrapping it about a test-tube which contains boiling water. In the presence of boracic acid or a borate the turmeric paper, which is a reddish-brown color, will turn to a greenish-black color upon treatment with a drop of sodium hydroxide.

152. Testing Milk for Per Cent of Fat. The Babcock test is a rapid, accurate, and inexpensive method for determining the amount of fat in milk and other dairy products.

For making the test, a centrifuge, two forms of which are shown in Fig. 67 and the test bottles, pipette for measuring the milk, acid measure, brush for cleaning the bottles, and sulphuric acid, shown in Fig. 68, are required.

The neck of the test bottles are marked with a graduated scale, each small division representing two-tenths of 1 per cent of fat. Every fifth division is a long one and represents 1 per cent. In making the test 17.5 cubic centimeters of milk, which weigh 18 grams, are first slowly run into the bottle by means of the pipette, holding the pipette at an angle as is shown in Fig. 69. This method of running in the milk prevents overflowing due to the stopping of the outlet for air.

The reason for the use of 18 grams of milk is that the neck of the test bottle is graduated to hold just 2 cubic centi-

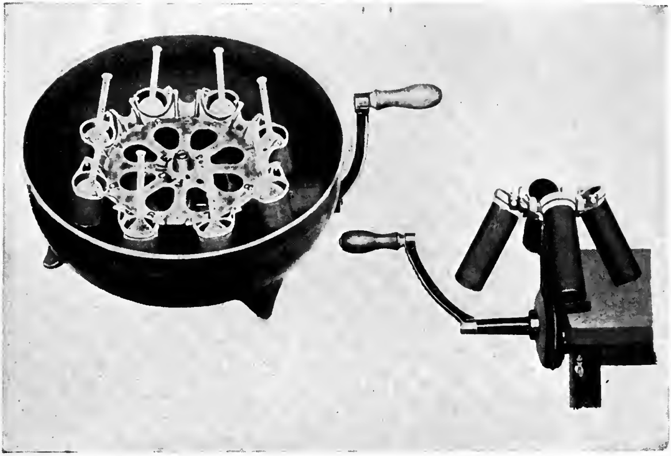

FIG. 67.—Centrifuge for the Babcock test.

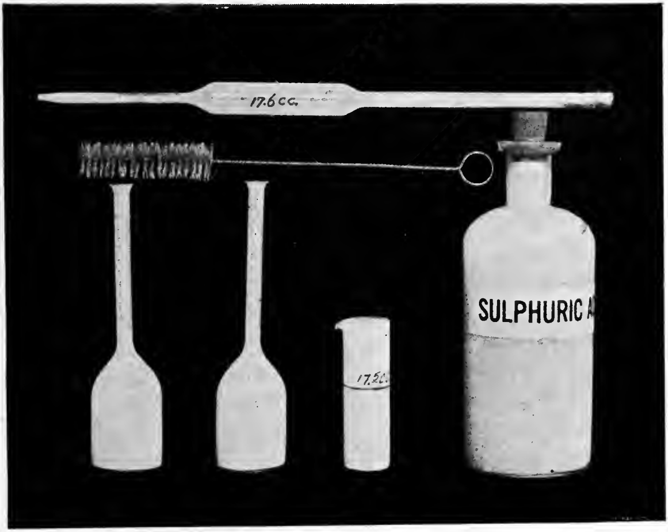

FIG. 68.—Additional apparatus for the Babcock test.

meters in the graduated portion. The specific gravity of milk fat is 0.90, therefore the amount required to fill the graduated portion is 0.90×2=1.8 grams, which is 10 per cent of 18 grams of milk. The milk pipette holds 17.6 cubic centimeters, but will deliver 17.5 cubic centimeters of milk because .1 cubic centimeter will adhere to the sides of the pipette. The acid cylinder is graduated to deliver 17.5 cubic centimeters.

The sulphuric acid used for the Babcock test should be of a specific gravity of between 1.82 and 1.83 at 60° Fahrenheit. Commercial acid, which is good enough for this test, is bought at a density of 1.84. To dilute this for use in the dairy, 1000 cubic centimeters of the acid should be poured into 45 cubic centimeters of water, or 100 cubic centimeters of water for every ordinary 5-pint bottle of acid. In reducing the specific gravity of sulphuric acid, *always pour the acid into water, and never pour water into the acid.*

Fig. 69.—Placing the milk in a test bottle.

After dilution, the acid must be cooled to 60° F. before being used in the test.

The details of the test are as follows: Mix thoroughly the sample of milk, which should be at a temperature of about 60° F. Quickly fill the pipette to the mark with milk, and run the milk into the test bottle. Fill the acid measure to the mark with the sulphuric acid and pour the acid cautiously into the test bottle. Mix the milk and acid thoroughly by giving the test bottle a rotary motion. Let the bottle and contents stand from two to five minutes and then mix again.

Fig. 70.—Appearance of completed test.

Put the test bottles in the centrifuge and whirl for four or five minutes at a speed of 600–1200 revolutions per minute. Then add hot water to fill the test bottle to the neck and whirl again for one minute; next add hot water to near the top of the graduated portion and whirl one minute more.

The reading of the per cent of fat should be taken at about 130° F. This is best accomplished by means of a pair of dividers. The appearance of the test bottle after completed test is shown in Fig. 70.

The results obtained in this determination are due to the actions of strong sulphuric acid and the use of centrifugal force. The action of the acid is threefold: It destroys the adhesive force exercised by the casein, albumin, sugar, and salts present in the milk; the mixture of sulphuric acid and milk generates heat, which causes the fat globules to run together and makes their separation from the mass comparatively easy; third, the weight of the sulphuric acid increases the specific gravity of the non-fatty materials, causing the lighter fat the more readily to rise to the surface. The completion of the separation of the fat is accomplished by the use of centrifugal force when the bottle containing the mixture is whirled in a suitable apparatus, which may be run either by hand or by power.

153. Determination of Specific Gravity. The normal specific gravity of milk from a herd usually falls between 1.030 and 1.034. The specific gravity of milk is quickly determined by taking the reading of a lactometer floating in the milk. The lactometer is a specialized form of a hydrometer. The Quevenne lactometer has a scale graduated from to 15 to 40°, corresponding to specific gravities from 1.015 to 1.040. The milk should be tested at a temperature ranging from 55° F. to 60° F., adding a correction of 1° (equivalent to 00.001 specific gravity) to the reading for each degree F. above 60° F. and subtracting 1° for each degree F. below 60° F.

The addition of water to milk lowers the specific gravity, while the skimming of cream from the milk raises the specific gravity. It is therefore possible, by skillful manipulation, for dishonest handlers both to water and to skim the milk so as to leave it with a specific gravity corresponding to normal milk. Such tampering, however, will give the milk a suspicious appearance, and if the percentage of solids, not fat, falls below 7.7, such milk may be considered adulterated.

154. Determination of Water and Total Solids. To determine the water and total solids in milk the procedure is as follows: Clean and weigh crystallizing dishes with a capacity of about 100 cubic centimeters or, if available, a platinum dish 3 inches in diameter. Weigh these with small glass rods in each for use in breaking the surface film so as to increase the rate of drying. With the pipette run 5 cubic centimeters of the well-mixed milk sample into the dish and obtain the exact weight of the milk. Dry it in an oven at 100° C. or on the surface of a steam bath to constant weight. Two or three hours ought to be sufficient for complete drying. Weigh and compute the dried residue as total solid and the loss by evaporation as water. If the ash is not to be determined, an excellent dish for the determination of water and total solids is the shallow cover of a tin baking-powder box.

155. Determination of Ash. If a platinum or a porcelain dish was used for the determination of water and total solids, the dried residue from that process may be ashed by heating cautiously to a temperature just below red heat till the ash is white or of uniform light gray color. When the weight is constant, compute the residue as ash.

156. Butter. Butter, in addition to butter fat, contains water, curd and salt. In making butter, where the work is carefully conducted, the butter procured is usually one-sixth more than the butter fat contained in the cream.

TABLE XXIII.—COMPOSITION OF CREAMERY BUTTERS.
(Wisconsin Experiment Station)

	Per Cent of Water.	Per Cent of Fat.	Per Cent of Curd.	Per Cent of Salt and Ash.	Sum of Water, Curd, Salt, and Ash.
Highest......	17.03	87.50	2.45	4.73	22.95
Lowest.......	9.18	77.07	0.36	1.30	12.50
Average......	12.77	83.08	1.28	2.87	16.92

Good butter should contain at least 80 per cent fat and, preferably, it should run 83 per cent fat. Genuine butter may usually be distinguished from *oleomargarine* without any special test. Most oleomargarine is more solid than butter and is brittle and hard when cold. When soft, it is smeary and shows no grain.

Process butter is manufactured from old or poor butter. It is first melted and treated with steam to carry off any of the disagreeable acids which have resulted from the decomposition of the fat. It is then mixed with milk, solidified, salted and worked. Process butter has properties similar to those of oleomargarine.

A simple test for butter is to heat it to boiling, carefully, in a tablespoon. Good butter boils with little noise and spatter and produces an abundance of foam. Oleomargarine and process butter boil with considerable spattering and produce little foam. The "meaty" odor when hot is characteristic of the animal fats used in oleomargarine.

157. Cheese. Cheese is made by coagulating milk when heated. American cheddar cheese is made by heating the milk to 80° Fahrenheit and adding a small amouut of rennet extract. The casein in the milk is coagulated by the rennet and holds the fat. The green cheese analyzes about 37 per cent water, 34 per cent fat, 24 per cent proteids, the other 5 per cent consisting of mineral salts, lactic acid, and milk sugar. Most of the milk sugar and albumin is drawn off in the whey.

158. Condensed Milk. Condensed milk is manufactured either from whole or partly skimmed milk. In some cases, sugar is added to improve its keeping qualities. Condensed milk should contain not less than 10 per cent fat, and must be free from preservatives.

CHAPTER XX

INSECTICIDES, FUNGICIDES AND DISINFECTANTS

159. Two Classes of Injurious Insects. The insects which are injurious to growing or stored crops may be separated into two main classes: insects that *bite,* and those that *suck.* Different remedies must be used in combating each class. Among the most common biting insects are the codling moth, potato bettle, the flea beetle, the grasshopper, the tussock, brown tail, and gypsy moths, the plum curculio, and the various caterpillars. The biting insects are destroyed by spraying the plants eaten with some poisonous material that will be taken by the insect with its food. The materials commonly used for this purpose are compounds of arsenic which has decided toxic effects. Some of these substances are arsenate of lead, Paris green, green arsenoid, London purple, and arsenate of lime. The last named is a product recently put on the market.

Sucking insects draw the plant juices from the leaves and the bark; the most common are plant lice, the Chinch bug, San José scale, scurfy scales, etc. They are killed by materials that close their breathing pores, fill the surrounding atmosphere with poisonous fumes, or kill by reason of their caustic properties. The following materials are used for this purpose: kerosene emulsion, soaps, lime-sulphur mixtures, nicotine sulphate solutions, carbon bisulphide, and hydrocyanic acid gas.

160. Injurious Fungi. Injurious fungi are minute vegetable organisms that attack living tissue. The fungicides include Bordeaux mixture (made from milk of lime and copper sulphate), lime-sulphur, sulphur, copper sulphate, ammoniacal copper carbonate, and formaldehyde solutions.

The compounds of copper have decided poisonous effects upon the lower organisms.

161. Insecticides for Biting Insects. *Lead arsenate* may be purchased in the form of a thick paste or dry powder.

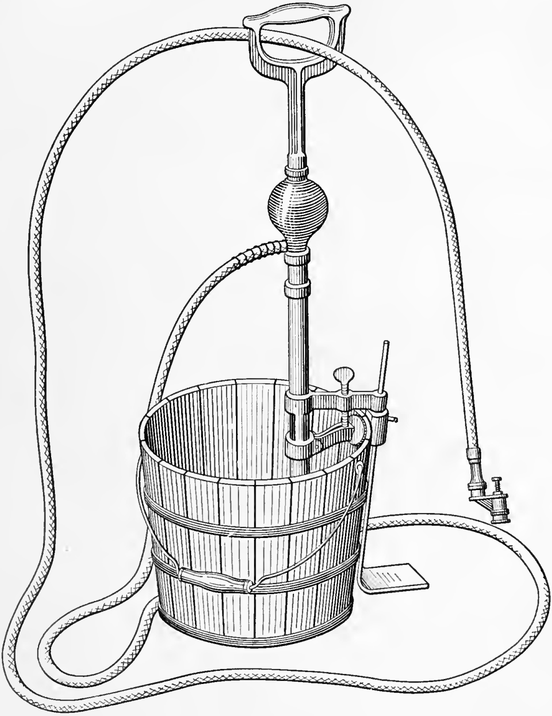

Fig. 71.—Pail spray for small herds. (Farmers' Bulletin, U. S. Dept. Agr.)

It is prepared by the action of lead nitrate or lead acetate on crystallized disodium hydrogen arsenate. It contains little or no soluble arsenic and, for this reason, is especially applicable to plants with tender foliage. Lead arsenate is applied in suspension in water or in combination with fungicides by means of a spray, usually at the rate 2 to 7 pounds of the paste or half of that quantity of the powder, to 50 gallons of the spray solution. Whether used as paste or powder, the lead arsenate should first be stirred or ground very thoroughly in a small amount of the spray solution, and gradually diluted until a very smooth paste is formed.

Paris green is a mixture of copper acetate and copper arsenite. It is somewhat more soluble than is lead arsenate and, for this reason, it may injure tender foliaged plants. Paris green has been largely superseded as an insecticide by lead arsenate. It may be applied dry by diluting with from 10 to 50 parts of land plaster, flour or road dust. When used in this way, there is danger of burning tender foliage. A solution of 1 pound of Paris green and 3 pounds of stone lime in 100 to 250 gallons of water, depending on the foliage, is advised.

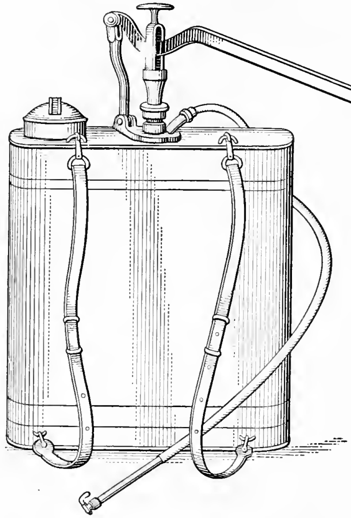

Fig. 72.—Knapsack sprayer. The handle can be removed and the tank carried in the hand instead of on the back, if desired. (Farmers' Bulletin 243, U. S. Dept. Agr.)

Green arsenoid is an insecticide similar to Paris green, and applied in the same manner, but is less used.

London purple is a by-product of the manufacture of anilin dyes. It is composed of calcium arsenate and calcium arsenite together with an organic dye residue. London purple is quite variable in composition, and is very little used.

162. Insecticides for Sucking Insects. *Kerosene emulsion* is prepared by emulsifying soap. A good quality of laundry soap is satisfactory. Two to four pounds of soap and 5 to 10 gallons of kerosene to 50 to 100 gallons of spray solution are the usual proportions. The soap should be dissolved in from 5 to 10 gallons of hot water, placed, together with the kerosene, in the spray barrel, then emulsified by pumping air through the spray rod into the spray solution. Kerosene-emulsion should be used promptly after preparation.

Soaps are sometimes used to destroy soft-bodied insects. Fish-oil soap is one of the best and most commonly used soaps for this purpose. Potash soap is better than soda, soap. The soap is more easily dissolved in hot water, and the solution applied by means of the spray pump. A solution of 2 pounds of rosin fish-oil soap in 50 gallons of water is often used as a " sticker " for fungicides with poor adhesive qualities.

Lime-sulphur mixtures are prepared by boiling sulphur with milk of lime. The chief constituents of these mixtures are polysulphides of calcium, the tetra- and the pentasulphide being most desired, and calcium thiosulphate.

Nicotine solutions are obtained from decoctions of tobacco, the nicotine being the active agent. One-half pound of tobacco is steeped in boiling water and then diluted to 5 or 10 gallons. These solutions are used chiefly for the control of plant lice.

Nicotine sulphate solutions, such as Black Leaf—40 are used extensively and have replaced kerosene emulsion for *aphis.*

Carbon bisulphide (CS_2) when partially decomposed by standing is a vile-smelling liquid which vaporizes at ordinary temperatures. Its use in the field is limited, being mainly confined to the control of certain root-infesting plant lice. It is extensively used for the control of insects in granaries. In tight cribs it is best applied on top of grain or corn at the rate of 6 pounds to 100 bushels applied when the temperature is above 65° F.

Hydrocyanic acid gas (HCN) is prepared by treating potassium cyanide with excess of sulphuric acid; $2KCN + H_2SO_4 = 2HCN + K_2SO_4$. *This gas is very poisonous and its use is not advised.* When used, the proportion of 1 pound of the potassium cyanide, 2 pounds of sulphuric acid and 4 pounds of water gives a rapid evolution of the gas. *Care must be exercised not to inhale the extremely poisonous fumes.*

163. Fungicides. *Bordeaux mixture* is prepared from copper sulphate ($CuSO_4$) and calcium hydrate ($Ca(OH)_2$). The most common proportions are 4 pounds of copper sulphate and 4 pounds of quicklime to 50 gallons of water. The copper sulphate should be dissolved and made up to 25 gallons of water. The lime should be carefully slaked with water and made to twenty-five gallons. Pour the dilute solutions into the spray barrel, stirring vigorously and use while fresh. The above proportions may be widely varied to meet special needs.

Copper sulphate is difficult to dissolve. The solution may best be accomplished by putting the powdered crystals in a small bag which is suspended over night in the water, near the surface. The copper sulphate solution, being more dense than water, sinks, leaving the copper sulphate crystals in constant contact with an unsaturated solution. Powdered portions of the crystals will dissolve rapidly in hot water.

Lime-sulphur has already been discussed. As a fungicide for plants in foliage, the commercial product, 32° Baumé, is applied at the rate of 1 to 2 gallons in 50 gallons of water, depending upon the liability of the plant to lime-sulphur injury.

Self-boiled lime-sulphur is prepared from quick-lime (CaO) and sulphur flour. The sulphur is put in suspension through the agency of the slaking lime, very little chemical union of lime and sulphur probably occurring. The usual proportions are 8 pounds of lime and 8 pounds of sulphur in 50 gallons of water. The process is carried out to best advantage when four times the above quantities are used. This spray is especially adapted to use on tender-foliaged plants.

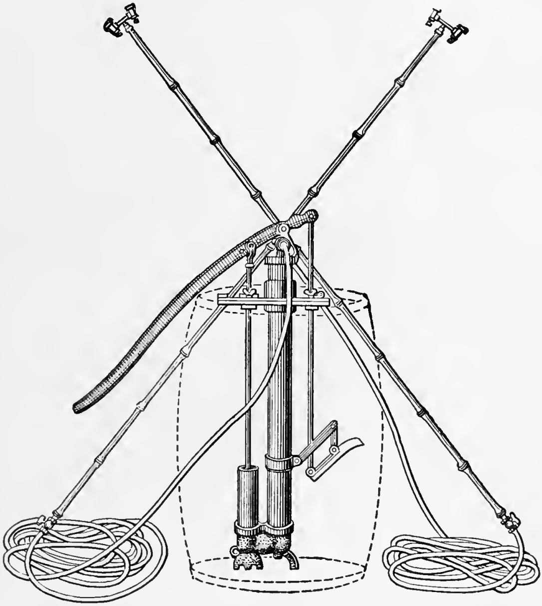

Fig. 73.—Barrel spray pump with hose and bamboo extension rods for orchard spraying. (Farmers' Bulletin 243, U. S. Dept. Agr.)

Finely divided sulphur in suspension is largely replacing self-boiled lime-sulphur and ordinary lime-sulphur. Several proprietary preparations of this nature are on the market.

They are more expensive than self-boiled lime-sulphur, and about equally effective. Their advantages are that they are more easily prepared and that they leave less residue upon both fruit and foliage.

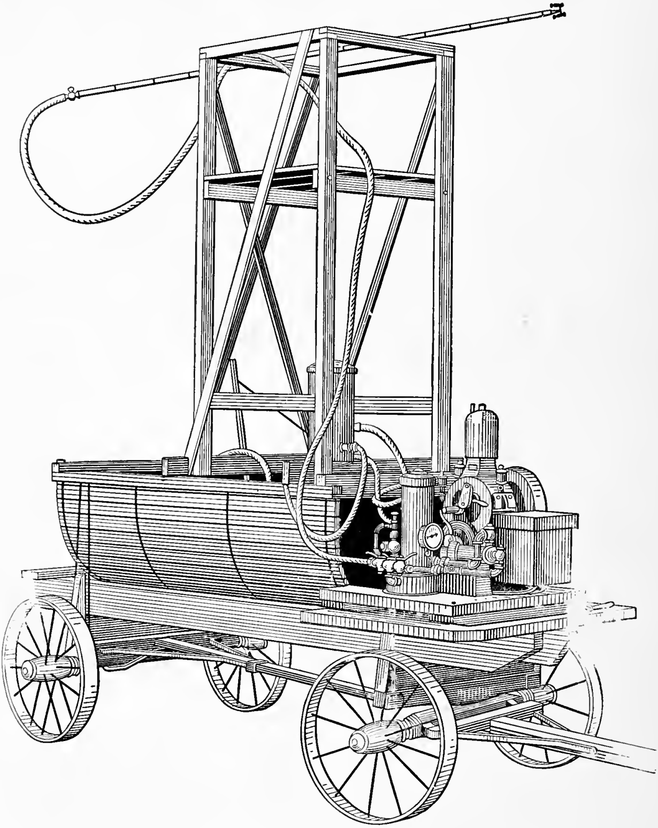

Fig. 74.—Gasoline power spray. (Bulletin 243, U. S. Dept. Agr.)

Copper sulphate ($CuSO_4$) is used as a dormant spray for certain types of fungus diseases of plants. A notable example of this is its use in connection with the control of peach leaf curl. It is one of the most toxic of fungicides, but its period of activity is of short duration, due to the fact that it is quickly washed off the plant. Copper sulphate is very successfully used for the destruction of algæ in water.

Ammoniacal copper carbonate ($Cu(NH_3)4CO_3$) is used in special cases on ornamental plants and on certain fruits just before ripening, where residues from other sprays would be objectionable. The chief objections to this preparation are its relatively high toxicity to the host plant, its cost, and the difficulty of its preparation.

Formaldehyde solutions (CH_2O) are chiefly used for the treatment of seeds and vegetable reproductive materials, as tubers, to rid them of disease before planting. The solution is prepared by adding 1 pint of formalin to 30 gallons of water.

164. Common Disinfectants. Disinfectants are used to destroy organisms that bring on disease, decay, and disagreeable odors. There are several common and effective kinds. In handling disinfectants great care should be exercised, as many are very poisonous.

Lime. Unslaked lime (CaO) and water-slaked lime ($Ca(OH)_2$) are the cheapest and most easily obtained disinfectants. Air-slaked lime ($CaCO_3$) has no disinfecting properties except that due to absorption. Lime that is to be used for disinfecting purposes should be kept in receptacles that are tight enough to exclude air. It is best applied in the form of milk of lime, prepared as follows: Treat a lump of quick-lime in a covered vessel with water until a creamy liquid is formed. This should be kept in an air-tight receptacle when not in use. Quicklime may be pulverized and sprinkled on dry; this form is especially useful in closets, replacing earth.

Chlorinated Lime (Bleaching powder, $CaCl_2O$). This material is prepared by showering slaked lime powder through chlorine gas. It is a white powder, which decomposes slowly on exposure to moisture, giving off hypochlorous acid, which is the substance that gives the characteristic odor to bleaching powder. It should be kept in sealed containers. Chlorinated lime is prepared for use by mixing in the proportion of 6 ounces of the powder to each gallon of water. It is largely used for the disinfection of refuse, stock-pens, or cars, and is the most efficient disinfectant. It has a bleaching effect on fabrics when there is need of concentrated effect; the chlorinated lime may be treated with dilute acid.

Formaldehyde. Formaldehyde (HCHO) is commonly purchased under the name *formalin,* which is a solution containing about 40 per cent formaldehyde. It may be used for disinfecting purposes either as a liquid or as a gas. A 5 per cent solution of formalin is considered to be superior to carbolic acid of the same strength, as a disinfectant. Formaldehyde is peculiarly effective as a disinfectant, as it is an unstable compound which on the one hand is easily reduced to methyl alcohol by the addition of hydrogen or of reducing agents, which it abstracts from the organism which needs disinfection, and on the other hand, it is easily oxidized into formic acid by the addition of oxygen, which it takes from the substance to be disinfected—in either case sterilizing the infecting material.

These opposing actions are represented by the following equations:

$$\underset{\text{Formaldehyde}}{HCHO+H_2} = \underset{\text{Methyl alcohol}}{CH_3OH}$$

$$\underset{\text{Formaldehyde}}{HCHO+O} = \underset{\text{Formic acid}}{HCOOH}$$

When disinfecting with gaseous formaldehyde, it is necessary to close tightly the place to be disinfected in order that the concentrated gas may be in contact with the infected material for some time and the temperature should be warm. The gas may be produced from formalin in several ways, but the chemical means are usually most convenient. The various methods are: heating under pressure, heating without pressure, spraying and by an oxidizing agent. The last two are ordinarily used. When spraying is resorted to, the compartment should be kept closed for at least twenty-four hours. An ounce of formalin is required to each 100 cubic feet, therefore a room 10 feet square and 10 feet high would require ten ounces. The formalin is sprayed on sheets hung in the room.

The gas is readily liberated by several chemicals, but the use of potassium permanganate has found most favor. The proportion which is most effective seems to be 6 parts of formalin to 5 parts of potassium permanganate. For disinfecting 1000 feet of space, 20 ounces of formalin and $16\frac{2}{3}$ ounces of potassium permanganate are required. The crystals of potassium permanganate may be placed on the bottom of an ordinary dishpan and the formalin poured on quickly in order that the person so engaged may make a rapid exit. Some of the formaldehyde is oxidized to formic acid by the permanganate and this generates heat enough to drive the remainder out as a gas. The compartment should be kept

Fig. 75.—Making Bordeaux mixture. The two men pour together the diluted lime milk and the bluestone solution into a barrel or spray tank and stir well. (Bulletin 243, U. S. Dept. Agr.)

closed for not less than twelve hours. The temperature of the room should not be less than 65° F. for the treatment to be effective. It is well to sprinkle the floor and other objects not harmfully affected by water, before the treatment, as it is more effective in a damp atmosphere.

Sulphur. Barns and other outbuildings may be more cheaply but not as thoroughly disinfected with sulphur fumes. These fumes bleach fabrics and discolor some paints, for which reason their use is not always to be recommended. Use not less than 4 pounds of sulphur to each 1000 cubic feet. Break the roll sulphur into small pieces and put them into an iron pot which should be set in a tub containing a few inches of water as a preventive of fire. Pour alcohol on the sulphur and ignite. If possible, keep the compartment closed for twelve hours.

Carbolic Acid. Carbolic acid or phenol (C_6H_5OH) has been extensively used as a disinfectant for years. It is poisonous and should be carefully handled. Pure carbolic acid is a solid at ordinary temperatures and crystallizes into long pink or white needles. It is often sold in the liquid form, which is prepared by adding 1 part of water to 9 parts of the crystals. Carbolic acid used in the proportion of 1 part of acid to 20 parts of water is a very effective disinfectant. The carbolic acid is not readily soluble: for this reason it should be carefully dissolved in warm water. When garments are to be disinfected they should remain in the solution prepared as directed above for not less than one hour.

Carbolic acid is poisonous, expensive and will destroy the spores of anthrax and other spore-forming bacteria. It has several advantages in that it destroys non-spore-bearing bacteria, is little interfered with by albuminous matter, when diluted does not destroy fabrics nor corrode metals, and that it is easily obtained at any drug store.

Crude Carbolic Acid. Crude carbolic acid is very extensively used as a disinfectant. It is variable in its composition and uncertain in its effects. It consists of a mixture of coal tar oils, cresol and a very little phenol. The oil has practically no disinfectant properties, although the odor is popularly considered an indication that disinfection is being accomplished. Its value as a disinfectant depends on the content of cresol. When the cresol content is known, the material should be diluted until it contains 2 per cent of that acid.

Cresol ($CH_3C_6H_4OH$), tricresol, straw-colored carbolic acid, or liquid carbolic acid as it is variously termed, is found on the market in various degrees of purity. Cresol as described by the United States Pharmacopœia is a colorless liquid having an odor similar to carbolic acid. On account of a small amount of impurities it is usually sold of a 90 to 98 per cent purity. It should not contain less than 90 per cent cresylic acid, as the cresol containing less amounts usually carries enough coal tar oil to interfere with the solution of the cresol in water. This material is relatively cheap and well suited to disinfect yards, barns, and cars. The solution used for disinfecting should contain about 2 per cent of cresol, which is said to be more effective than 5 per cent carbolic acid. It is applied the same as the carbolic acid solution. This material is not readily soluble in water, hence care must be exercised to get a strong enough solution. Its advantages are that it is cheap, does not destroy fabrics or metals, is more effective than carbolic acid for destroying spore-forming bacteria, and its action is not hindered by albuminous substances.

Cresol is made more soluble by mixing with an equal part of linseed-oil-potash soap. Care must be taken to assure the presence of 50 per cent of actual cresol in the mixture. There should be 3 or 4 per cent of cresol in this sort of a mixture when used for disinfecting, hence an increase in cost over the straight cresol solution.

Bichloride of Mercury. Bichloride of mercury ($HgCl_2$) is a white crystalline, *poisonous* substance. It is prepared in tablet form mixed with ammonium chloride (NH_4Cl), which facilitates its solubility. It is used in the proportions of 1 to 500 or 1 to 1000. It combines with albuminous substances and is rendered inert. This material is a powerful germicide, but *it is a deadly poison.*

All disinfectants are selected because of their chemical activity, and care should be exercised in handling them because of their poisonous nature. The remnants after use should be destroyed rather than stored.

CHAPTER XXI

PAINTS AND WHITEWASHES

165. Paints. Few farmers realize fully the economic value of paint on farm buildings and farm machines; its use is sometimes regarded as a luxury that may readily be dispensed with. Paint not only improves the appearance of the various objects to which it is applied, but it has a greater value in preventing or delaying the rusting or decaying of both machinery and buildings, thereby increasing their length of service. One does not have to be a skilled painter to do the ordinary painting on the farm. With the aid of a few inexpensive utensils, paint may readily be applied.

Paint consists of a pigment or of several pigments held in suspension by a liquid, or vehicle, as it is called. If the paint is to be used for outside work it must be insoluble in water and possess a high resistance to the chemical action of atmospheric elements. Pigments are stable organic bodies or mineral compounds which are used to impart either a protective covering or a color or both, by mechanical adhesion or by admixture with the substance to be painted. The color of a pigment is dependent upon the amount and kind of light that it reflects. It should be opaque if it is desired to conceal the surface to which it is applied. The vehicle is the liquid portion of the paint and is usually a drying oil; sometimes water with gum or size is used for inside work. Linseed oil seems to be the best paint vehicle.

166. Drying Oils. The so-called drying oils are named for their peculiar property of hardening. When linseed oil, and any one of a number of other oils having somewhat similar properties, is spread in a thin layer over a surface, it will dry and set in a hard film, due to the absorption of oxygen from the atmosphere. Corn oil and soybean oil, to a limited extent, behave in a similar manner. The drying of these oils is aided by sunlight and hindered by moisture; it does not occur in the absence of oxygen. Boiled oil dries more quickly than raw oil.

167. Driers. The drying of paints may be hastened by certain compounds of lead and manganese which are known as driers. When the drier is applied in the form of a liquid it is known as a *Japan drier.* The use of a small amount of a drier seems more effective than when a large amount is applied. With an excessive amount of drier the film produced is not so durable. Some pigments, red lead for example, act as driers as well as pigments. It is generally believed that the greater the proportion of the pigment the more resistance the film will show, provided that all of the particles of the pigment are covered with oil.

For thinning paint to make it work easier, certain volatile materials are used, such as turpentine or benzine.

168. White Pigments. *White lead* is the most important of all pigments. This material is a basic lead carbonate in which there are two molecules of lead carbonate to one molecule of lead hydroxide ($2PbCO3 \cdot Pb(OH)2$). White lead is very heavy, being 6.47 times heavier than the same volume of water. Its great value as a pigment is due to its covering power, its permanency, and to the readiness with which it mixes with other pigments. Like all lead compounds it is poisonous.

Sublimed White Lead. This has recently come into extensive use. It has good covering power and color, mixes well with pigments containing sulphur, and is more durable in sea air than is white lead. With linseed oil it dries rapidly, forming a tough, impervious coating. Sulphur fumes will not affect it quickly. For these reasons it is frequently used as a substitute for white lead. It is composed of 75 per cent lead sulphate, 20 per cent lead oxide and 5 per cent zinc oxide. Whether it is a mixture or a compound is not determined.

Zinc Oxide or *Chinese White.* This material works well in oil, requiring a very large amount, approximately 20 per cent of its weight, and is used as a house paint and as an enamel for inside surfaces as bathtubs, plumbing, etc. It is the whitest of all the paint pigments. It will not collect dust as much as does white lead. When mixed with white lead it retards or entirely prevents the discoloration of the latter by hydrogen sulphide.

Lithopone. This is a mixture of zinc sulphide and barium sulphate, heated, suddenly chilled and then ground. This material has a brilliant color, and more body than has white zinc. It is permanent, is fine in texture and mixes well with oil and other pigments, except those containing lead or copper. It is used advantageously as a marine paint. It is largely used in the oilcloth industry.

Barytes. Barium sulphate is very heavy, and may be mixed with all pigments, but it has little body, dries slowly, and does not mix well with oil. When used as an adulterant of white lead its use is to be avoided. When applied in limited amount as an extender in mixed paint, it imparts desirable qualities. It is used by the United States Navy as a basis for battle-ship gray.

169. Green Pigments. Brunswick green is oxychloride of copper. This pigment works well with oil, has a fair covering power, but is rather pale in color. Other pigments sold under this name consist of a mixture of Prussian blue, chrome yellow, and barytes in varying proportions. They work well in oil, have good covering power, and last fairly well, but they cannot be used with alkaline substances, compounds of sulphur, or in the presence of hydrogen sulphide.

Chrome greens are mixtures of chrome yellow and Prussian blue. They are yellowish green in color, mix well with oil and with other colors, have good covering power, and are permanent.

170. Blue Pigments. *Ultramarine blue* is probably a double silicate of sodium and aluminum and sulphide of sodium. The composition is, however, somewhat variable. It is the most important blue pigment. Ultramarine is very sensitive to acids. In addition to its use as a pigment in paints it is used in coloring wall-paper, in calico printing and for neutralizing yellow-colored sugar, paper pulp, and cloth. It may also be made by grinding up the mineral lapis lazuli. This is not so easily affected by acids but has not so brilliant a color.

Prussian blue is ferrocyanide of iron. It is not affected by acids, mixes well with oil, but the color is destroyed by alkalies. It has good coloring powers, but is transparent and lacks body.

171. Red Pigments. *Red lead* is lead tetroxide (Pb_3O_4). It is a pigment of great brilliancy when a good compound is secured and it has remarkable covering power. It is made by heating litharge (PbO).

Iron reds are prepared in large quantities as by-products from other manufactures. They are valuable pigments, being very permanent. These pigments are not very bright, but they have several advantages; they work well in oil, mix with other pigments, have good body and are cheap. They are compounds of ferric oxide (Fe_2O_3).

Vermilion is mercuric sulphide (HgS). It is a heavy, opaque, brilliant pigment which does not work well with oil on account of its weight. It is quite permanent, and readily affected by either acids or alkalies, but it is very expensive.

172. Yellow Pigments. *Chrome yellows* are chromate of lead, zinc, or barium, each having a characteristic shade.

Lead chromate is a brilliant yellow which mixes well with oil and has great covering powers. If treated with a caustic alkali, its color changes to orange or red.

Yellow ochres are natural mineral products which vary in color, the color being due to hydrated oxide of iron.

173. Brown Pigments. *Umbers* are ochres containing a large amount of manganese. The best umber comes from Cyprus; it is very permanent, has good covering power, and mixes well with other pigments. It is neither affected by acids nor alkalies and it is very cheap.

Vandyke browns are mixtures of iron oxides and organic matter. They are permanent, mix well with other pigments, and have good body.

174. Black Pigments. *Lampblack,* as well as the other black pigments, has carbon for its basis. Lampblack is permanent, of good covering power, and fine grained. It is difficult to mix with water or oil and dries slowly.

175. Mixing Paints. The main object in mixing paint is to get every particle of the pigments in contact with the vehicle. The pigments are purchased dry or in the paste form mixed with a small amount of the vehicle. The latter form is usually preferable, because the pigment has been ground in a small amount of the vehicle in preparation and its dilution is easier than the suspension of the dry pigment.

A small hand mill can be purchased for about $10 that is satisfactory for mixing paints. For small jobs the ready mixed paints are more economical.

176. Whitewashes. *Government whitewash* is prepared by slaking one-half bushel of good quicklime in hot water, keeping it covered while slaking. Strain and add 4 quarts of salt, dissolved in warm water, 3 pounds of ground rice boiled to a thin paste, ½ pound Spanish whiting, and 1 pound of clear glue, dissolved in warm water. Mix and let stand for several days. Keep the wash thus prepared in a kettle or portable furnace, and when used put it on as hot as possible with a painter's brush or a whitewash brush. This wash may be made in quantities and heated as needed, but it should be put on hot.

Factory whitewash is used for interior work. Slake 1 bushel (62 pounds) of quicklime with 15 gallons of water;

keep the barrel covered and stir occasionally. Beat up separately 2½ pounds of rye flour in ½ gallon of cold water, then add 2 gallons of boiling water. Then dissolve 2½ pounds of rock salt in 2½ gallons of hot water. Pour the last two preparations into the first.

Waterproof Whitewash. Slake 1 bushel of quicklime with 12 gallons of hot water. Then dissolve separately 2 pounds of common table salt and 1 pound of zinc sulphate in 2 gallons of boiling water. Pour the last preparation into the first and add 2 gallons of skimmed milk.

177. Special Ingredients for Whitewash. An ounce of alum added to each gallon of lime whitewash increases its sticking properties. A pint of molasses to 5 gallons of whitewash renders the lime more soluble and increases its penetration. Silicate of soda solutions aid in fireproofing, while 1 pound of bar soap dissolved and added to 5 gallons of whitewash gives it a gloss.

178. Calcimine. The basis of calcimine is *whiting,* or carbonate of lime. This material is carried in water as a vehicle and is made to adhere by the use of glue. *Dampproof calcimine* is prepared by thoroughly mixing 16 pounds of Paris white or extra gilders' whiting with 1 gallon of boiling water. Soak separately ½ pound of white sizing glue for four hours in ½ gallon of cold water, then dissolve by heating on a water bath. Also, dissolve 4 ounces of sodium phosphate in 1 pint of boiling water. Mix the last with the first and add the second. For tinting use yellow ochres, sienna, umbers, Venetian red, para-red, maroon, oxid, ultramarine blue, ultramarine green, chromium oxide, or bone black, none of which is affected by lime.

If lampblack is used for tinting, it must be stirred in hot water containing a little soap or in cold water containing a little borax, the alkali serving to overcome the greasy nature of the lampblack.

179. Varnishes. A varnish is a dissolved resin, or a drying oil, which, when exposed to the air, becomes hard and impervious to air and water. After the varnish is applied, the solvent evaporates, leaving the resin, or the oil oxidizes and dries.

Spirit varnish consists of resin dissolved in alcohol, petroleum spirits or some other volatile solvent. Turpentine varnishes are those in which turpentine is the solvent used. Linseed oil varnishes may consist of linseed oil alone, or resin and turpentine may be added. The addition of turpentine tends to overcome the tendency to scale off. The most important varnishes are made with shellac, while mastic, sandarac, and dammar are sometimes used.

Oil Varnish. The greater part of the varnishes made are compounded of linseed oil, resin and turpentine. Turpentine varnishes dry slowly but they are tough and flexible. Linseed varnishes are the most important, but they do not show the surface brilliancy that some other varnishes show.

180. Shellac. Shellac is a form of the resin lac which is produced by the bite of certain insects on the small twigs of several species of trees which grow in the East Indies. The insects feed on the plant sap and exude the lac, which finally covers the insect and her eggs. The twigs bearing these exudations are collected and appear commercially as *stick lac.* The crude material is first treated by macerating in warm water to remove a red dye-stuff that it carries. This material is sold as *lac-dye,* and the residue from the maceration is known as *seed-lac.* This is refined by melting and straining through muslin bags. The melted lac is poured in thin films over cold surfaces, to which it will not adhere, and is allowed to cool. These flakes are sold as *shellac.* Shellac is completely soluble in caustic alkalies and in borax solutions. It is partly soluble in alcohol, turpentine, chloroform or ether.

181. Glue. Glue is a product of the decomposition of animal connective and elastic tissues. It contains two essential constituents, *gluten* and *chondrin.* The former has great adhesive properties and the latter is adhesive to a less extent. Glues are variously termed *hide glue, bone glue* and *fish glue,* due to the source from which they are derived. Bone glue and hide glue have essentially the same general characteristics, while fish glue has less jellying properties. *Liquid glue* is made by treating fish glue with acetic, hydrochloric, or nitric acid, any one of which will cause the loss of the property of gelatinizing when cold.

CHAPTER XXII

MATERIALS PRODUCING HEAT AND LIGHT—FIRE EXTINGUISHERS

182. Petroleum. Crude petroleum is found in enormous quantities in oil-bearing rock strata. The world's production of this most important material in the year 1912 was 350,000,000 barrels. California, Oklahoma, Illinois, West Virginia, Texas, Louisiana, Ohio and Pennsylvania are the principal sources of supply in this country, which furnishes 62 per cent of the world's production. In other countries Russia is the largest producer (19 per cent). Petroleum from the Appalachian fields is a thick greenish liquid. It is composed of a mixture of many hydrocarbons, some of which contain sulphur. Petroleum is economically conveyed through pipe lines, one of these extending from the Oklahoma field via Kansas City and Chicago to the seaboard, a distance of 1600 miles.

Petroleum is the source of very many substances of great value, as for the production of illumination, for fuel and for lubrication. By processes of distillation at different temperatures these products are separated from the petroleum and, passing off as vapors, are turned into liquids by condensation. In the distillation the products of low-boiling points coming off first are in succession petroleum-ether, gasoline, naphtha, benzine and kerosene. The remaining oil is then chilled and the solid waxes and paraffins are separated by filtering. The liquid remainder is then distilled fractionally into fuel oils and light and heavy lubricating oils. All these products from petroleum and many others not mentioned are composed of mixtures of hydrocarbon compounds having formulas varying from C_5H_{12} contained in petroleum-ether to $C_{28}H_{56}$ contained in paraffin. Within recent years, petroleum in its unrefined condition has come into use as a fuel for steamships and for manufacturing purposes, competing successfully with coal.

183. Kerosene. This is the most commonly used source of illumination in rural districts. Its use as a means of temporary or quick heating is both economical and convenient. Kerosene is a mixture of seven hydrocarbons ranging from $C_{10}H_{22}$ to $C_{16}H_{34}$ with specific gravity varying according to the grade of the oil, from 0.795 to 0.810. In the trade kerosene oil is classed according to color and to the temperature at which the oil gives off enough inflammable vapor to produce a momentary flash when a flame is applied. The grades of color are " Standard White " (pale yellow), " Prime White " (straws) and " Water White " (colorless). The flash tests required in different states of the United States vary from 100° F. to 120° F. Water White oil with flash-point of 150° F. is known as Head Light Oil. Low flash-points in kerosenes indicate the presence of benzines or naphthas whose inflammability makes the oil dangerous for use in lamps.

184. Gasoline. This is formed by the distillates of petroleum that pass off at lower temperatures than that required for kerosene. These are different grades of gasolines, but those most used in automobile engines have distilling temperatures varying between 70 and 90° C. corresponding to hydrocarbons with the formulas C_6H_{14} and C_7H_{16}. The volatility of gasoline enables it easily to be converted into vapor which when it is mixed with air becomes highly explosive and therefore suitable for the internal combustion demanded by engines of the automobile and steam-launch type.

185. Acetylene. When petroleum oil is " cracked " by dropping upon plates heated to a high temperature, among the decomposition products is Acetylene (C_2H_2).

It can be more easily produced by dropping water upon calcium carbide (CaC_2). The carbide may be produced by heating to a high temperature coke (C) and quicklime (CaO). This reaction is represented as follows:

$$\underset{\text{Carbon}}{3C} + \underset{\text{Quicklime}}{CaO} = \underset{\substack{\text{Calcium}\\\text{carbide}}}{CaC_2} + \underset{\substack{\text{Carbon}\\\text{monoxide}}}{CO}.$$

Water reacting with calcium carbide reacts as follows:

$$\underset{\substack{\text{Calcium}\\\text{carbide}}}{CaC_2} + \underset{\text{Water}}{2H_2O} = \underset{\substack{\text{Calcium}\\\text{hydroxide}}}{Ca(OH)_2} + \underset{\text{Acetylene}}{C_2H_2}.$$

Acetylene burns with an extremely hot flame which in an ordinary burner of a fish tail pattern is smoky. A special burner devised so that two fine streams of acetylene mixed with air impinge one on the other will produce a very small, brilliant flame which, when analyzed, is found to resemble in quality sunlight much more nearly than any other illuminant. The equation represented by the chemical action in the flame is,

$$\underset{\text{Acetylene}}{C_2H_2} + \underset{\text{Oxygen}}{5O} = \underset{\substack{\text{Carbon}\\\text{dioxide}}}{2CO_2} + \underset{\text{Steam}}{H_2O}.$$

The range of the mixture of acetylene and air which will explode is much greater than that of other illuminating gases and the violence of the explosion is far greater than in the case of other illuminants, therefore mixtures of acetylene and air are very dangerous. Nevertheless acetylene illumination is very efficient. *Prest-O-Lite*, generally used in automobile lights, is acetylene dissolved in acetone $(CH_3)_2CO$.

Acetylene decomposes, when heated, with the liberation of a large amount of heat. When this heat of decomposition is added to that produced when acetylene is burned in a

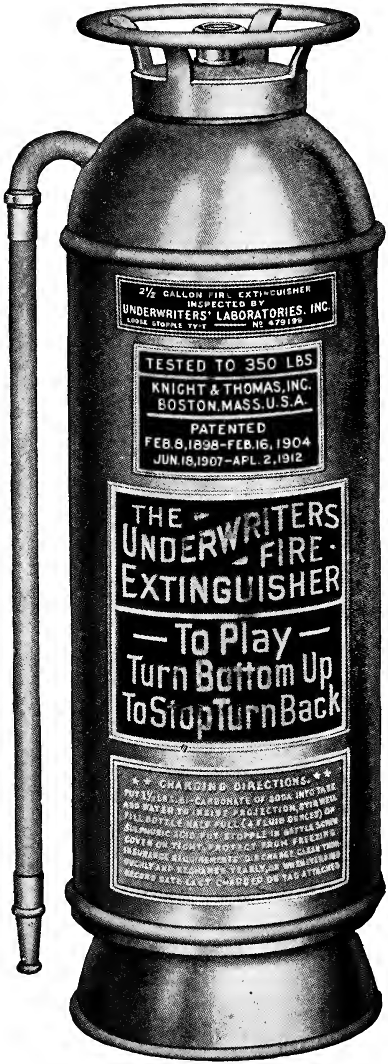

Fig. 76.—Fire Extinguisher. (Figs. 76 and 77, by permission of Mr. James C. Goddard, Philadelphia.)

stream of oxygen, the temperature obtained is remarkably high. Such a flame will eat its way through a six-inch steel shaft in less than one minute. The steel frames of modern buildings may be rapidly taken apart by this flame.

186. Fire Extinguishers. Fire extinguishers are effective means of extinguishing a fire before it gains headway. The presence of such a contrivance may prevent a disastrous conflagration and will surely pay for itself in the peace of mind of the farmer and his family. A convenient form shown in Fig. 76 consists of a heavy metal cylindrical container made to withstand a pressure of 350 pounds per square inch. The charge consists of a saturated water solution of $1\frac{1}{2}$ pounds of sodium bicarbonate (cooking soda, $NaCHO_3$), with which the cylinder is filled to the mark and 4 fluid ounces of sulphuric acid in a glass bottle which is held in place by a metallic device which permits the acid to flow out when the extinguisher is overturned. The arrangement of these

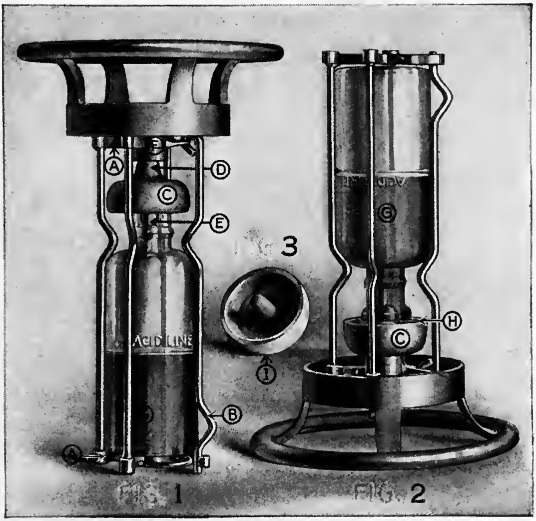

FIG. 77.—Working parts of Fire Extinguisher.

1. Position of acid bottle and decomposing cup *C* when the Underwriters Extinguisher is not in action. *A*, cage for acid bottle. *B*, movable support for opening cage. *C*, acid decomposing cup acting as bottle closure. *D*, upper projection or guide stem, operating in socket *F*. *E*, lower projection or guide stem, operating in the neck of the acid bottle. *F*, socket for upper guide stem *D*. *G*, sulphuric acid, correct charge bottle half-full. (The two guide stems *D* and *E* center and hold the decomposing cup *C* in its true position at the mouth of the acid bottle, either while the extinguisher is at rest or in action, or in starting and stopping it.)

2. Position of acid bottle and decomposing cup *C*, when the extinguisher is in action. *H*, decomposing cup *C* filled with acid, showing point where the chemicals come together, when the extinguisher is inverted. (It is at this point that the soda solution attacks and *eats* the acid out of the decomposing cup, and as decomposition takes place, a fresh supply of acid is fed from the bottle into the cup as fast as needed—but no faster—insuring uniform chemical action.)

3. Shows the depth and interior of the porcelain acid decomposing cup *C*.

materials inside the container is shown in Fig. 77. The reaction between the sulphuric acid and bicarbonate of soda rapidly generates carbon dioxide, which furnishes pressure, causing a mixture of the solution and gas to be thrown with great force on the fire. The chemical action of the bicarbonate and acid is as follows:

$$2NaHCO_3 + H_2SO_4 = 2CO_2 + 2H_2O + Na_2SO_4.$$

To operate the extinguisher it is turned upside down and the contents played on the fire by means of the hose attached at the top of the cylinder when in operation.

CHAPTER XXIII

CONCRETE

187. Use. Concrete is a mixture of cement, sand, crushed rock or gravel and water. It is a most excellent material for sidewalks, fence posts, foundations, floors and walls of buildings, beds or piers for machines and for structures under water. It is manufactured in enormous quantities and its use for these and many other purposes is rapidly increasing. A hundred millions of barrels are produced in the United States annually. The rapid decrease of timber supply has made an urgent demand for a new building material which is amply met by the use of concrete. On account of its economy, durability and safety from fire loss and ease of manipulation it is superior to lumber, brick or building stone for construction purposes. The farmer with little assistance and at convenient times can use successfully this most excellent material.

188. Cement Manufacture. Cement is a powdered, calcined intimate mixture which, before heating, contained in definite proportion limestone or marl or chalk ($CaCO_3$), clay ($HAlSiO_4$), and sand (SiO_2). In the manufacture of Portland cement these materials are mixed in the proper proportions as shown by chemical analysis, pulverized so that it will pass through a sieve with 100 meshes to the inch, burned in inclined rotary steel cylinders from 60 to 150 feet long lined with firebrick. In these furnaces the final temperature rises to 1400° C.–1600° C. To the resulting clinker is added a small amount of gypsum, which seems to affect the time required for the setting of the cement, and the material finally is ground to a very fine powder. Natural cement made from rock which has the correct proportions of lime, clay and sand and manufactured by heating moderately and grinding was formerly made in large quantities in this country. Owing to the cheapness with which Portland cement may be manufactured, with its properties governed by correct admixture, the natural cement is being replaced by the Portland cement. Portland cement when properly made is guaranteed to meet the standard fixed by the American Society for Testing Materials.

189. Setting of Cement. Cement after the sintering process of the furnace seems to be a mixture of calcium silicate ($CaSiO_3$) and calcium aluminate ($Ca_3(AlO_3)_2$). The latter seems to be the active agent causing the setting of the cement when it is mixed with water. This hydrolysis may be expressed as follows:

$$Ca_3(AlO_3)_2+6H_2O=2Al(OH)_3+3Ca(OH)_2.$$

The calcium hydroxide, crystallizing, binds the particles of calcium silicate together, while the aluminium hydroxide fills the interstices and makes the mass compact and impervious.

When water is added to cement, it becomes a soft, sticky paste and it will remain in this condition for about thirty minutes, when it begins to harden or set. To disturb the concrete after the setting is begun means a loss in the strength of the concrete. For this reason the concrete should be placed in position in less than thirty minutes after the cement is first wet. There are several precautions to be observed. A new cement should neither be exposed to the hot sun for any considerable length of time nor to freezing temperature. No material should be placed on the freshly made cement that will affect its color. The cement must be kept dry, before its use, because it readily absorbs moisture from the atmosphere when stored in damp places; this causes it to become lumpy and consequently worthless due to the setting of the cement. Lumps may sometimes be caused by pressure; these may often be broken up and the cement be as good as any, hence care should be taken to determine the cause of the lumping before discarding the cement.

190. Sand. Sand constitutes a large part of concrete. It is extremely important to secure the proper kind of sand, which should be coarse, clean, hard, and free from other materials. The screening of the sand should be done at the source of supply. This is accomplished by screening what passes a $\frac{1}{4}$-inch sieve against a sieve containing forty meshes to the linear inch and set at an angle of 45°, using the portion retained by the sieve.

The following test will show the proportions of sand, clay and loam in the source of supply of sand: Fill a pint preserving jar to the height of 4 inches with the sand and add water to within 1 inch of the top. The lid is then fastened and the jar is shaken for ten minutes, after which the contents of the jar are allowed to settle. The sand settles to the bottom and the clay and other material gather at the top. If more than one-half of clay and loam is present, the sand should be rejected. If other sand is not convenient, the sand in question may be washed. When washing is required, a simple way is to build a board platform 10 to 15 feet long with a 12-inch fall. On the sides and lower end, 2 by 8-inch pieces should be nailed to hold the sand. The sand is spread on this platform to a depth of 3 or 4 inches and is washed by means of a hose, the water being applied at the elevated end of the platform and run through the sand and over the lower end. The impurities in the sand should not amount to more than 10 per cent of the whole.

191. Gravel. The gravel or crushed stone which constitutes a large part of the concrete should vary from that retained on a $\frac{1}{4}$-inch screen to those that pass a $1\frac{1}{2}$-inch ring. This material should be as free as possible from dirt and, if necessary, may be washed in the way suggested for sand.

192. Quantity of Materials for a Given Mixture. Concrete is a manufactured stone and the object is to fill the interstices between the gravel with sand and those between the sand particles with cement, hence the volume of concrete is just about represented by the volume of crushed stone or gravel. A mixture consisting of one part by volume of cement, and two parts of sand and four parts of stone or gravel, is often used. Table XXIV gives the quantities of the various materials for cement or concrete mixtures; the relative values are shown in Fig. 78.

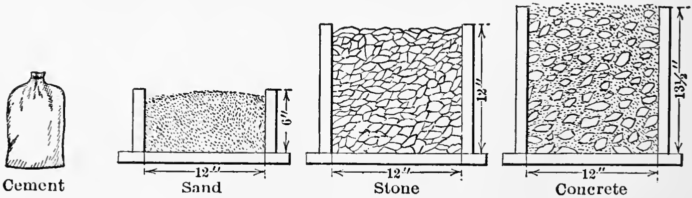

FIG. 78.—Required quantities of cement, sand, and stone or gravel for a 1 : 2 : 4 concrete mixture and the resulting quantity of concrete. (Bulletin 461, U. S. Dept. Agr.)

TABLE XXIV.—QUANTITIES OF MATERIALS AND THE RESULTING AMOUNT OF CONCRETE FOR A TWO-BAG BATCH.

(Farmer's Bulletin 461, U. S. Dept. Agr.)

Kinds of Concrete Mixture.	PROPORTIONS BY PARTS.			MATERIALS.			Concrete (cubic feet).	SIZES OF MEASURING BOXES (INSIDE MEASUREMENTS).		Water for medium wet mixture (gallons).
	Cement.	Sand.	Stone or Gravel.	Cement (bags).	Sand (cubic feet).	Stone or Gravel (cubic feet)		Sand.	Stone or Gravel.	
1 : 2 : 4..	1	2	4	2	3¾	7½	8½	2 feet by 2 feet by 11½ inches.	2 feet by 4 feet by 11½ inches.	10
1 : 2½ : 5.	1	2½	5	2	4¾	9½	10	2 feet by 2 feet 6 inches by 11½ inches.	2 feet 6 inches by 4 feet by 11½ inches.	12½

If the sand is very fine, the pore space will be increased, and therefore a little more cement will be required. The materials should be mixed until they assume a uniform color. If after thorough mixing the batch does not work well, the sand and cement does not fill the spaces between the stones, the proportion of stone should be reduced in succeeding batches.

Fig. 79.—Concrete board and tools for making concrete. (Farmers' Bulletin 461, U. S. Dept. Agr.)

TABLE XXV.—QUANTITIES OF MATERIALS IN 1 CUBIC FOOT OF CONCRETE

Mixture of Concrete.	Cement (by Barrels).	Sand (by Cubic Yards).	Stone or Gravel (by Cubic Yards).
1 : 2 : 4	0.058	0.0163	0.0326
1 : 2½ : 5	.048	.0176	.0352

Table XXV gives the quantities of each material required in 1 cubic foot of concrete. With this data it is easy to calculate the amount of material for any given structure. A sack of cement contains 1 cubic foot of cement and four sacks constitute a barrel.

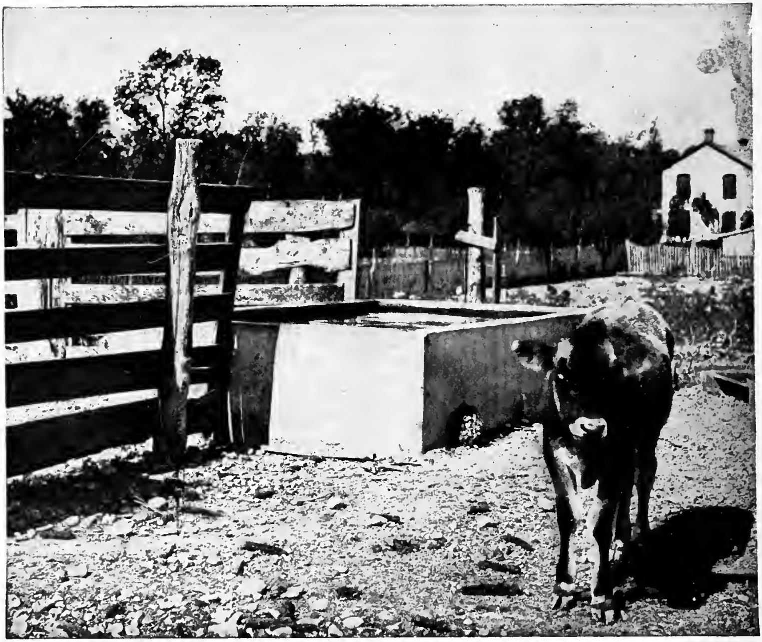

FIG. 80.—Concrete watering trough. (From Howe's "Agricultural Drafting.")

*Example.** Let us suppose that the work consists of a concrete silo requiring in all 935 cubic feet of concrete, of which 750 cubic feet are to be 1 : 2 : 4 concrete, and 185 cubic feet are to be 1 : 2½ : 5 concrete. Enough sand and cement are also needed to "paint" the silo inside

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* From U. S. Dept. of Agr. Bulletin, 461.

and outside, amounting in all to 400 square yards of surface, with a 1 : 1 mixture of sand and cement. One cubic foot of 1 : 1 mortar paints about 15 square yards of surface and requires 0.1856 barrel of cement and 0.0263 cubic yard of sand. The problem thus works out as follows:

Cement:	Barrels.
For the 750 cubic feet of 1 : 2 : 4 concrete (750×0.058)	43.5
For the 185 cubic feet of 1 : 2½ : 5 concrete (185×0.048)	8.9
For painting (400÷15×0.1856)	4.9
Total amount of cement	57.3

Sand:	Cubic Yds.
For 750 cubic feet of 1 : 2 : 4 concrete (750×0.0163)	12.23
For 185 cubic feet of 1 : 2½ : 5 concrete (185×0.0176)	3.26
For painting (400÷15×0.0263)	.70
Total amount of sand	16.19

Stone or gravel:	
For 750 cubic feet of 1 : 2 : 4 concrete (750×0.0326)	24.5
For 185 cubic feet of 1 : 2½ : 5 concrete (185×0.0352)	6.5
Total amount of stone or gravel	31.0

Thus the necessary quantities of materials are about 57½ barrels of Portland cement, about 16¼ cubic yards of sand, and 31 cubic yards of stone or gravel.

193. Mixing Concrete. In mixing concrete the sand is first spread over the mixing floor in a layer 3 or 4 inches in depth. The cement is then spread evenly over the sand. These materials are then mixed thoroughly with a shovel, the mixture is spread over the floor and the gravel is added. About three-fourths of the water to be used is then thrown as evenly as possible over the gravel layer and the materials are again thoroughly mixed with the shovel. Water should be added to the dry spots as the mixing proceeds, until the full amount has been used. After thoroughly mixing, the concrete is shoveled into a compact pile.

194. Placing the Concrete. Concrete should be placed immediately after mixing. Wooden *forms* to give the shape of the structure to be built, Fig. 81, are required and should be ready before the concrete is mixed. In placing the concrete, the shovel should be run down along the face of the form to press the gravel back and allow the cement to flow against the form, thus producing a smooth and finished surface when the form is removed.

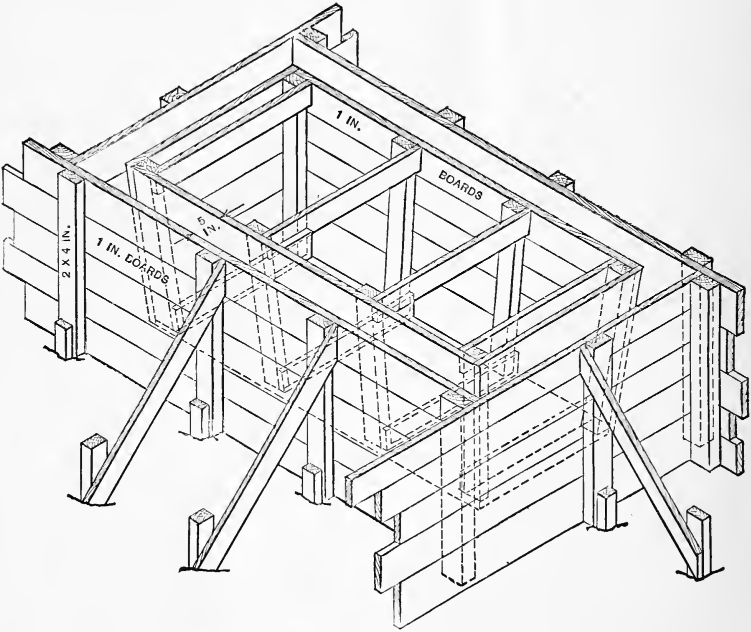

Fig. 81.—Forms for concrete watering trough. (From Howe's "Agricultural Drafting.")

New concrete should not be exposed to the sun until after it has hardened for five or six days. The forms should be left in place till the concrete has "set" thoroughly. To permit removal of the forms, the surface should be wet daily.

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