SCIENCE IN FARMING.

A TEXT BOOK

—ON THE—

Principles of Agriculture,

INCLUDING A TREATISE ON

AGRICULTURAL CHEMISTRY.

DESIGNED FOR USE IN

SCHOOLS, GRANGES, FARMERS' CLUBS, AND BY FARMERS AND THEIR FAMILIES.

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TO ALL WHO LABOR TO ADVANCE THE WELFARE, AND INCREASE

THE INTELLIGENCE AND HAPPINESS OF MANKIND,

THIS BOOK IS DEDICATED.

INTRODUCTION.

The preparation of this book was suggested by the number of inquiries I have received, both personally and by letter, for a book treating on the elements of agriculture.

Careful examination of all the books on the subject I could find, satisfied me that although many of them were excellent, none exactly met the needs of my questioners.

Some of the books on the subject have been published many years, and, as many of the most important investigations in this direction have been made in the past few years, these books are out of date.

Some books of this class were well adapted for the student who was acquainted with the elements of chemistry and physiology, but could not be understood by those who had no knowledge of these sciences. Other books were so large and expensive that they exceeded the limits of the average farmer's time and purse.

In others the attempt has been made to condense the subject into such small space, that it had been impossible to treat it in a clear or satisfactory manner.

The great difficulty in the production of such books has been the fact that the men who have fitted themselves for their preparation, by lives spent in scientific research, have, by the necessities of the case, been so separated from the great body of the farmers of the country, that it was impossible for them to understand their needs.

The only special fitness that I claim for the preparation of a work of this character, is an intimate acquaintance with the farmers of our country, a strong attachment to the occupation of agriculture, and an earnest desire to see it lifted to its proper place as one of the most honorable, pleasant, and intellectual occupations that can be followed by man.

It is not the design of this book to lay down rules concerning the amount of manure to apply to an acre —nor the exact depth to which grain should be planted, nor the number of pounds of hay that should be fed to a cow. These are things which constantly vary with locality, season and circumstance, and which each farmer must, to a certain extent, determine for himself.

This book teaches the laws and principles that underly the practical work of the farm, a knowledge of which will enable a farmer to intelligently construct his own rules.

I have not attempted to write a book that can be read merely for entertainment, without mental effort —as a novel, or a fairy tale. It would not be possible to write such a book and convey the information desired. There is no "primrose path to learning."

The important scientific knowledge that is now proving of such great value to the farmer was all obtained by patient toil. They who would get the benefit of this knowledge must be willing to give for its acquirement at least a moderate amount of mental labor.

I have earnestly endeavored to make every portion of the work so clear that it *can* be understood by any who are willing to expend as great amount of mental effort as is needed in the acquirements of other studies. Greater simplicity than this can only be obtained by the sacrifice of value.

Each chapter in this book prepares the way for that which follows, and it would be as unwise to expect to understand the latter chapters before mastering those which precede it,—as it would be to expect a schoolboy to work a sum by the rule of three, before he understood the multiplication table.

I have not attempted to avoid the use of scientific names and terms, my object has been to enable the student to understand not only this book, but the writings of others. I have therefore first explained the meaning of scientific terms and then made use of them.

The book is not one of mere theory. It gives the results of long continued and careful experiments made by the most competent men in the world.

No attempt has been made to explain the methods by which the facts given have been ascertained, nor space used in aruguments to prove that they are facts. The aim has been to give the facts themselves, leaving the explanation of the methods by which they have been ascertained for books intended for scientific men.

It may be that some readers who have had the advantages of a liberal education, may consider the book too simple, and that too much pains have been taken to explain that which can be understood without explanation.

I would ask such to remember that this book is designed for men, many of whom have not had the opportunities for the higher education that is given to the young people of to-day.

It is a book intended to be studied—by the farmer and his family around the fireside, in the district school, in the grange hall, and farmers' club.

If, by its study, some are enabled to see more of the beauties, and understand more of the mysteries connected with science in farming, and inspired to greater zeal in their efforts to lift the occupation of agriculture to the honored place which is of right its own, I shall feel repaid for the days and nights of labor that have been expended in its preparation.

R. S. T.

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AUTHOR'S ACKNOWLEDGMENTS.

Had the writer paused at every step of his progress to explain the sources whence his information had been obtained, as much space would have been occupied in acknowledgments as in statement of facts, and the design of the work—as a condensed text-book of information—would have been defeated.

In addition to the standard text-books of science, special acknowledgments are due to those two valuable works of Johnson's, How Crops Grow and How Crops Feed; also to Harris' Talks on Manures, and to Warrington's Chemistry of the Farm—a book that contains a great amount of valuable information in small space.

Acknowledgments are also due to friends who have kindly aided the work with good words and valuable suggestions all the way, among whom should be named W. I. Chamberlain, Secretary of the Ohio State Board of Agriculture, Professor N. W. Lord, analytical chemist of the Ohio State University, L. N. Bonham, agricultural editor of the Cincinnati Commercial, Waldo F. Brown, author of Success in Farming, J. W. Ogden, and others.

CHAPTER I.

SCIENCE IN FARMING.

1. **Definition of Science.**—Webster defines science as "Truth ascertained"—"that which is known"—"knowledge duly arranged."

According to this definition, facts ascertained and duly arranged constitute science, and study of science consists in studying established facts, their arrangement and mutual relationship. A mere compilation of facts, without arrangement and without regard to the relations existing between those facts, is not science.

2. **Science and Practice.**—A distinction is often made between scientific and practical knowledge. Strictly speaking, all scientific knowledge is practical, as it is a knowledge of facts, and practical knowledge becomes scientific when duly arranged.

3. Scientific knowledge is the result of careful experiments conducted with an intelligent purpose.

4. In common language, practical knowledge is the knowledge of a fact, and scientific knowledge the knowledge of the principles and causes on which that fact depends.

5. **Illustration.**—A farmer learns by experience that the manure produced by cattle fed on clover hay

is more valuable than that produced by cattle fed on straw. This is practical knowledge. Afterwards he learns that this difference is due to the fact that clover contains a larger amount of a substance called nitrogen, than straw, and that this nitrogen is valuable as a manure. This is scientific knowledge, and this enables him to know that manure produced by cattle fed on any other substance containing much nitrogen will also be of special value, and he can consider this fact in making his selection of foods.

6. The Farmer a Manufacturer.—The business of the farmer is to produce certain articles such as wool, cotton, beef, pork, butter, cheese, etc. These can only be produced by bringing together other substances already in existence, and by combination and re-arrangement changing them into the substances desired. The farmer is therefore as truly a manufacturer as the man who makes plows or sewing machines.

7. The soil and air are the sources from which the farmer draws his supplies of raw material, and the plant and animal are the machines by which he works up this raw material into useful manufactured products.

8. If the farmer would be successful, he must therefore have a knowledge concerning the substances from which his manufactured goods are to be produced, and of the sources from which he is to obtain them. He also needs to be well acquainted with the machinery he is using, and with the laws that govern its working. This knowledge is the "science of farming."

9. In the earlier days, when the virgin soil was ready to produce a crop if the opportunity were provided—when the customs of life were simple, and the farmer's needs were few, it was possible for men to obtain a living from the soil though they knew but little of the "science of farming." But with the change in the condition of our soil, the customs of society, and in the manner of life upon the farm—it has become necessary that a better knowledge of this science should be diffused among the people, and the day is rapidly drawing near when none can hope for success in farming without a knowledge of science in farming.

10. **Chemistry.**—An acquaintance with the elements of chemistry is the key which opens the door to the mysteries of agriculture—for the growth of the plant and the life of the animal are the result of operations controlled by chemical laws.

As well might the child expect to read without learning his letters, or the musician to understand music without learning the notes, as the farmer to understand his occupation without having first learned the elements of chemistry. Letters are not reading; notes are not music, and chemistry is not farming; but as the child cannot read without a knowledge of his letters, neither can the farmer understand the science of his occupation without a knowledge of the elements of chemistry.

11. **Agricultural Chemistry.** — Strictly speaking, there is no such science. Chemistry and its laws are the same, whether applied to the arts, to manufactures or the farm, and the thorough student must learn these laws and principles without expecting to see an immediate application.

12. But although a certain knowledge of the laws and principles of chemistry is an essential preparation

for the study of agriculture, there is much of the details of this science which may, without detriment, be omitted.

In the treatise on chemistry contained in this work, only that is given which is of importance to the farmer.

All that is given should be studied and understood, for it is the key, not to this book alone, but to the books and writings of scientific men.

13. The complaint is often made that the writings of scientific men are beyond the comprehension of the people. The reason is that people have not studied the elementary principles of science.

14. Therefore these elements of science are of the utmost importance. They are not only important in themselves, and full of beauty and interest, but they also prepare the way for wider, deeper, and more interesting researches.

CHAPTER II.

SCIENCE IN ITS ELEMENTS.

§ 1. *Terms Used.*

In order to understand scientific facts we must first know something of the terms used by scientific men.

15. Matter.—Everything that has weight or bulk. Thus, iron is matter, and so is wood, or gold or air. Different parts of matter are called bodies or substances. Matter can change its form — a solid may become a liquid or a gas, and a gas may become a liquid or a solid — or one substance may enter into combination with another, and both lose their former characteristics and gain new ones. But in all these changes matter is neither created nor destroyed. A house is built by bringing and fastening together wood and iron and stone and brick and mortar, but the house was built, not created—there was no more stone and brick and wood and iron in existence after the house was built than before. So when a plant or animal grows, different substances are gathered together and combined to form the plant or animal; but nothing is created. There are no more of these substances in existence than before. Matter has only changed its form.

16. If a house is torn down, and the material of which it was built scattered, the bricks and wood and stone and iron are still in existence. So if, after the plant is grown we put it on the fire and burn it, the matter in the plant changes its form, but is not destroyed. If we should carefully collect the ashes and smoke and vapor and gas produced by burning the plant, we would find they weighed the same as the plant before it was burned. It is impossible to create the smallest particle of matter, and equally impossible to destroy it.

17. Solids, Liquids, Gases.—Matter exists in three forms. A solid is a substance the particles of which are firmly held together so that they will not move upon each other. Iron is a solid. Liquids are substances in which the particles readily move upon each other and which yet have some attraction for each other. Water is a liquid. A gas is a substance in which the particles seem to have no attraction for each other. The air we breathe is a gas, or rather a mixture of gases.

18. Atoms.—It is supposed that all substances are composed of exceedingly small particles, so small that no microscope has ever been able to reveal them to the eye, and which are called atoms. Between these atoms there exists a force that draws them together, and another that tends to separate them. One is called the attractive, the other the repulsive force. When the attractive force is the strongest, matter exists in the form of a solid. When the two are about equal, in the form of a liquid; and when the repulsive force entirely overcomes the attractive, the substance is called a gas.

19. Force is whatever acts on matter to change it. Thus the force of heat can change a piece of ice into water. Chemical force may cause two substances to combine, producing a different one. The force of gravity will cause a substance when not supported to fall to the ground. Like matter, force can neither be created nor destroyed. This will be further explained in the chapter on Heat and Energy.

20. Properties of Matter.— Those characteristics which serve to distinguish one kind of matter from another. Thus it is a property of flint to be hard, of wax to be soft, of snow to be white, of charcoal to be black.

21. Element.— In chemistry is a substance that cannot be separated into other substances. Thus gold is an element; you may divide it into very minute portions, but each piece, no matter how minute, is still gold. Common table salt is not an element, but can be separated into two very unlike substances which are elements. There are only a little over sixty elements known to chemists to-day.

The term element is often used to represent one of the ingredients in a complex compound — as in the expression, "The elements lacking in the fertilizer were ammonia and potash" — though neither ammonia nor potash is an element in the chemical sense of the term.

§ 2. *The Foundation of Science.*

22. All science is founded on the principle that matter is subject to certain definite and unchangeable laws, which may be ascertained, and when ascertained will enable us to know positively the results of certain causes. Science may be said to rest on the principle that every effect must have a cause, and that the same cause, under the same circumstances, will always produce the same effect. If it were not for this principle, scientific progress in any work would be impossible.

23. If a substance is left unsupported, we know it will fall directly toward the earth. No other action is possible. The fact that wood will float in water, and smoke ascend in the air, is not an exception, as the wood is supported by the water, and the smoke by the air.

24. If a farmer gets 30 bushels of wheat per acre on one field, and only 10 bushels per acre on another, the difference is not due to an accident, or a whim of the crop; but to a different condition of circumstances in the two fields. If he can learn what was the cause of the good crop in the one field, and secure that cause in the other, he will be certain of as good a crop. Of course, in practice it is not possible for the farmer to control all the circumstances that affect a crop, but just so far as he can control those causes he can control the result.

25. A knowledge of science is therefore a knowledge of the properties of bodies, of the laws that govern their action upon each other, and the relations that exist between cause and effect.

§ 3. *Arithmetic.*

26. Science being exact, much of its results are to be determined only by careful calculations, and it will be difficult, if not impossible, for the student to master any science without knowing something of the rules of arithmetic. We shall assume, therefore, that the readers of this book are at least moderately familiar with arithmetic, and call their attention to two divisions of it only.

27. **Per Cent.**—By per cent is meant the number of parts in a hundred. Thus, in 100 lbs. of good milk there are about 87 lbs. of water; so we say that milk is 87 per cent water.

28. The percentage composition of a substance is the number of parts of each constituent in 100 parts of the substance. A great many scientific tables are prepared, giving the percentage composition of substances.

29. When we know the per cent of any constituent and wish to learn the exact amount of that constituent there would be in a given amount of the substance, we multiply the amount of the substance by the per cent of the constituent, and divide by 100.

Thus we find that fat forms about 32 per cent of the whole carcass of a fat ox. Now, if we wanted to know how many pounds of fat there were in a fat ox weighing 1,475 lbs., we would proceed thus: To divide by 100, we only need to strike off the two last figures to the right, and call them hundredths, and so we get the answer, that an ox weighing 1,475 lbs., whose carcass was 32 per cent fat would contain $471\frac{90}{100}$ lbs. fat

$$\begin{array}{r} 1475 \\ 32 \\ \hline 2950 \\ 4425 \\ \hline 471.90 \end{array}$$

30. **Decimals.**—It is found very convenient in scientific calculations to use principally decimal fractions—that is fractions represented in tenths, hundredths, thousandths, and so on. Decimals are written by putting a period after the figures denoting the whole numbers, and to the right of this the figures representing the number of tenths, hundredths, thousandths, as the case may be. One figure to the right of the period stands for tenths; two figures for hundredths, and three for thousandths.

Thus 1.9 would be read "one and nine-tenths;" 1.93 "one and ninety-three one-hundredths;" and 1.016, "one and sixteen one-thousandths." A cipher annexed to the right of a decimal does not change its value; thus, 1.90 would read "one and ninety one-hundredths," which of course is the same as one and nine-tenths. A cipher placed to the left of a decimal reduces its value to one-tenth what it was in the former place; thus, 1.09 would be read "one and nine one-hundredths."

31. It frequently happens that a decimal is used without a whole number; thus, it is said that a good soil contains .25 per cent of nitrogen, which means that it contains twenty-five one-hundredths of one per cent, or a quarter of a pound of nitrogen in a hundred pounds of soil.

CHAPTER III.

SCIENCE IN HEAT AND ENERGY.*

§ 1. *Their Nature.*

32. The Same Principle.—Heat and energy are different manifestations of the same principle. Heat is said to be a mode of motion. Heat can be changed into energy, and energy may be changed into heat.

33. Illustrations.—If a bar of iron is hammered on an anvil, the energy that was used will be expended, and the bar of iron will become hot, and the amount of heat in the iron will be in exact proportion to the amount of energy expended in the blows. If heat is applied to a steam boiler, and the steam produced used in running an engine, the heat of the fire will be expended, but instead we have the motion of the machinery. If a brake is applied to some part of the machinery and the motion is stopped, the brake will become hot, and the heat will be in exact proportion to the amount of energy that had to be overcome..

If a pound of ice at 32 degrees is broken and mixed with a pound of water at 174 degrees, the ice will be entirely melted, and the temperature of the two pounds of water will be but 32. One hundred and forty-two degrees of heat will have been lost by the

*The word energy is here used to represent what might be called active force, force producing work.

pound of water, and the temperature of the pound of water produced from the pound of ice will be no higher than that of the ice. The heat had been changed into the energy needed to overcome the attraction of the particles of the solid ice and change it into a liquid.

34. If heat is applied to a quantity of water the temperature of which is 32 degrees, it will gradually grow hotter until it reaches 212 degrees; then the water will begin to boil or be changed into steam, but the temperature of the steam will be no higher than that of the water had been. If the heat is uniform, it will take five and a half times as long to change the water into steam as it did to raise the water from the freezing to the boiling point. This heat has been changed into the energy needed to overcome the attraction of the particles of water for each other and change the liquid into a vapor.

35. When water is poured on quicklime, they unite chemically, and the water becomes part of the solid slaked lime. The energy that had before kept the atoms of water separated is now changed into heat, and the mixture is hot, though both the lime and the water were cold before mixing.

36. Place a pan of hot water out of doors on a cold winter day. The temperature of the water will fall until it reaches the freezing point and the water begins to freeze. Then it will remain unchanged until all the water is frozen. The energy that has before been keeping the atoms of water separated is converted into heat, as the water becomes solid, and prevents the further fall of temperature until all the water is changed into a solid.

37. Cannot be Destroyed.—Heat and energy can neither be destroyed nor created. In an elementary work, such as this, it would be impossible to fully explain and illustrate this fact; but it is an important one. Heat and energy must always be derived from some source where they have previously been stored. The energy that moves our locomotives and keeps our factories running, was received from the sun long ages ago, in the form of heat and light, stored up by growing plants, and is now changed into energy in the furnaces and fire-boxes.

38. The heat that keeps an animal alive, the force which he expends in work and motion, are not created by the animal, but are obtained from the food, and were originally gathered from the sun. This last fact will be more fully explained in the chapter on Animal Life.

39. Specific Heat.—If a pound of water and a pound of mercury are both exposed to a uniform source of heat, it will require thirty times as long to raise the temperature of the pound of water a given number of degrees as to raise the temperature of the pound of mercury the same number of degrees. That is, the water requires thirty times as much heat to raise its temperature a given number of degrees as would be required by an equal weight of mercury. Each substance requires a particular amount of heat, peculiar to itself, and this amount is called the specific heat of the substance.

The reason for this cannot be explained in this work.

§ 2. *Transference of Heat.*

40. Heat moves, or is transferred from one place to another by three methods, called conduction, convection and radiation.

41. Conduction.—If one end of a bar of iron is placed in the fire, the heat will pass through the iron, and the other end will become hot. This is called *conduction.*

42. Difference in Conduction.—If two similar rods, one of copper and one of iron, are heated at one end, it will be found that the heat will pass through the copper more rapidly than through the iron, and the copper is said to be the better conductor. Substances through which heat passes readily are called good conductors; those through which it passes slowly are called bad conductors. All metals are good conductors. Liquids and gases are very poor conductors, so poor that they are often called *non*-conductors. Snow is a very poor conductor; hence when the ground is covered with snow, the heat it contains does not escape, and thus snow protects the crops.

43. Convection.—When heat is applied to the bottom of a vessel containing water or some other liquid, the particles in immediate contact with the vessel become heated; this causes them to expand and become lighter, and they rise to the upper part of the vessel while the colder portions sink, and in this manner all the liquid in the vessel becomes heated. This is called convection. Gases are heated in the same manner. The portion in immediate contact with the heated substance becomes warm and rises, and a circulation is thus established.

44. Radiation.—If we stand near a stove or other heated body, we feel the heat from it, though it is not conveyed to us either by conduction or convection. All bodies are constantly throwing off heat in straight lines, like light. This is called radiation, and heat thus transferred is called radiant heat. Radiant heat passes through the air or any gas without imparting warmth to it.

45. Radiation is influenced by the color and surface of the body—a dark, rough surface radiates heat more rapidly than a white or polished one. Hence a brightly polished coffee-pot will keep coffee hot longer than one that is dark and rough.

46. Absorption of Heat.—When radiant heat strikes a body it is, to a greater or less degree, absorbed by that body, and warms it. The same surfaces that radiate heat readily also absorb it readily. If a black cloth and a white one are spread on the snow in the sun, the black one will rapidly absorb the sun's heat and melt the snow beneath it, while the white one will not. So a black hat is warmer in the sun than a white one, and a black soil gets warm more quickly in the spring than one of a lighter color.

§ 3. *Practical Application.*

47. If a jug of water in the harvest field is covered with a thick cloth soaked with water, the heat of the sun and air will be converted into energy to change the water in the cloth into vapor, and the water in the jug will remain cool until the water in the cloth has been evaporated.

48. A wet cloth worn inside the hat protects from the sun's heat. The British troops in India were enabled to endure the heat only by constantly wearing a wet cloth over the head. A shawl or woolen cloth hung in the window of a room and kept wet, will lower the temperature several degrees. Sprinkling the walks, grass and trees around a house imparts a delightful coolness to the air on a summer day. These effects are caused by the conversion of heat into energy, required to change water into vapor.

49. Perspiration protects from heat in the same manner. If an animal in winter is caused to perspire unduly by the use of food containing an excess of water, heat is wasted.

50. When the ground is filled with water, the heat of the sun, instead of warming the soil, is converted into the energy required to convert that water into vapor, or in other words, the heat is used for pumping instead of for warming. Hence advocates of drainage tell us that it lengthens the season.

51. If a room is heated by an open fire, the radiant heat from the fire does not warm the air of the room, which can only be warmed by coming in contact with the walls and furniture that have been heated by the fire. Hence a grate or fire-place warms a room but slowly, and the fire may feel uncomfortably hot while the air of the room is yet cold.

A stove radiates heat less rapidly than an open fire, but warms the air by convection. Hence an open fire is better for warming the walls and furniture of a room and so removing dampness; but a stove warms the room more uniformly.

52. The sun's rays pass through the air without communicating any warmth to it. The air is warmed only by contact with the soil. Hence the soil is often several degrees warmer than the air.

53. Though gases allow radiant heat to pass through them readily, yet the minute particles of water suspended in the air will not. The partially condensed vapor always present in the air prevents the heat that has been absorbed by the earth from being radiated off into space. If it were not for this protection the earth would be uninhabitable.

54. In the same way, and to a greater extent, clouds prevent the radiation of heat into space, and so in a cloudy night in fall and spring there is little risk of frost. Thus it is that the intensely cold nights of winter are usually those when there are no clouds and the air is very dry.

55. In fruit-growing districts crops are often saved on nights when frost is threatened, by building fires that will produce a heavy mass of vapor and smoke that hangs like a cloud over orchards and vineyards. In some places arrangements have been made by the government weather stations by which warning of approaching frosts is sent to the fruit-growers who have their fires built ready to be lighted if needed.

CHAPTER IV.

CHEMISTRY.

§ 1. *Its Nature and Language.*

56. Chemistry treats of the composition of bodies, the changes that are occasioned by their combination, or the separation of those already combined, and the laws that control those changes.

To understand chemistry, it is first necessary to learn something of the language and terms used.

57. Chemical Combination.—The word combination in chemistry means something more than it does as usually employed. It indicates not only a bringing together of certain substances, but such a union of those substances that their whole nature and character is changed.

58. For example, quicklime is a white, caustic solid; oil of vitriol is an oily liquid, intensely sour, and burns and corrodes whatever it touches. If 56 lbs. of quicklime, 98 lbs. oil of vitriol and 18 lbs. of water are mixed, they will combine chemically and we will have 172 lbs. of land plaster, which bears scarcely any resemblance to the substances of which it was made. In this combination 116 lbs. of liquids were added to 56 lbs. of a solid and the result is a perfectly dry solid. This is the result of chemical combination, which is entirely different from a simple mixture.

The air we breathe is a mixture of two gases, but were those two gases to enter into chemical combination, all life would perish from the earth.

59. **Chemic Force.**—The power that causes substances when brought together to enter into chemical combination is called chemism, or chemic force, or affinity. The last term is however less used now.

60. This force does not apply equally to all substances—there are some that cannot be compelled to enter into chemical union at all, while others unite as soon as brought together.

61. When two substances are united and a third is added, it may displace one of the others. Thus, if quicklime is exposed to the air, it will, in time, unite with the carbonic acid contained in the air, forming carbonate of lime. If to this vinegar is added, it will combine with the lime and set the carbonic acid free.

62. **Acids and Bases.**—It would be impossible to explain the strict chemical definition of these terms to the unscientific reader without devoting to it more space than can be given in this work. The statement that an acid is a compound of a non-metallic element with hydrogen and oxygen, and that a base is a compound of a metal with hydrogen and oxygen, is very nearly the scientific definition.

In popular language the term acid is applied to any substance that has a sour taste, and that readily enters into combination with the oxides of the metals, and a base is a metallic oxide. Both acids and bases in their ordinary condition contain the elements of water.

63. Acids and alkalies are distinguished by the

fact that acids turn blue litmus paper red, and alkalies restore the blue color. Litmus paper is made by soaking blotting paper in a solution of litmus and drying it. Litmus is a blue substance obtained from a lichen. Litmus paper is the common test to determine whether a substance is acid or alkaline.

64. Exceptions.—Ammonia, which is not the oxide of a metal, possesses so distinctly all the characteristics of an alkali that it is universally recognized as such, and hydric chloride, though containing no oxygen, has all the properties of an acid, and is commonly known as muriatic acid.

65. Salts.—Compounds produced by the union of an acid and a base. According to chemical language common table salt is not a salt.

66. Solution.—When sugar is placed in water it gradually disappears, and we say it is dissolved. When finely powdered chalk is stirred up with water it remains for a time mixed with, or suspended in the water; but if the mixture is allowed to remain undisturbed, the chalk will finally settle to the bottom. The first case is an instance of solution; the second, of mixture or suspension. Rivers often carry, suspended in their waters, large quantities of mud and sand, and also, in solution, salts that have been obtained from the soil.

67. A substance that will dissolve in water, such as salt or sugar, is called soluble. One that will not dissolve in water, such as sand or chalk, is called insoluble. Many substances that are commonly called insoluble, are really soluble, though only to a slight extent.

68. Some substances will dissolve in one liquid but not in another. Common resin will not dissolve in water, but readily dissolves in alcohol.

69. Water containing other substances in solution will sometimes dissolve substances that are ordinarily insoluble. Thus water containing carbonic acid and certain organic acids will dissolve many substances that are usually quite insoluble, and thus present them as food for plants. This is commonly the result of chemical action. Thus chalk will not dissolve in pure water, but if vinegar is added, the chalk is dissolved. In this case the vinegar combines with the lime in the chalk, forming a soluble compound.

70. Substances when not combined are called "free." Thus we speak of the free nitrogen of the air, and the combined nitrogen in albumin.

71. Organic Substances.—Compounds that are produced under the influence of animal or vegetable life, are called organic compounds. Thus sugar, starch and gum are organic substances. So also are albumin, fat, etc. In general, the term organic is applied to all animal and vegetable substances.

§ 2. *Chemical Laws.*

72. Combining Proportions.—Substances may be mixed together in all proportions, but chemical combination always takes place in fixed and definite proportions. This may be illustrated in three of the most common elements—carbon, oxygen and hydrogen. Hydrogen and oxygen will combine by weight in the proportions:

Oxygen	16 parts.
Hydrogen	2 parts.

Or,

Oxygen	32 parts.
Hydrogen	2 parts.

If 16 lbs. of oxygen were mixed with 3 lbs. of hydrogen and the mixture caused to unite chemically, the oxygen would combine with 2 lbs. of the hydrogen, forming 18 lbs. of water, and the 1 lb. of hydrogen would be left uncombined.

73. Carbon and oxygen will unite in the proportions:

Carbon ..... 12 parts,	Oxygen .... 16 parts.
Carbon ..... 12 parts.	Oxygen .... 32 parts.

74. Carbon and hydrogen combine in numerous proportions, but they are all such as:

Carbon...... 12 parts.	Hydrogen ...... 4 parts.
Carbon...... 24 parts.	Hydrogen ...... 4 parts.
Carbon...... 24 parts.	Hydrogen ...... 2 parts.

It will be seen that in all these cases carbon enters into combination in the proportion of 12, 24, and so on; hydrogen, 1, 2, 3, and so on, and oxygen, 16, 32, 48, and so on. Every element has some definite proportion in which it always enters into combination.

75. Atomic Theory.—This property of matter is explained by what is called the atomic theory. It is supposed that the atoms of which each element is composed (18) are always of exactly the same weight, but that the atoms of different elements have different weights. When elements unite chemically, it is due to a union of the atoms. One atom of an element may combine with one, two, or more atoms of another element; but as an atom is something that cannot be divided, it is impossible for atoms to combine with fractions of atoms.

76. If an atom of carbon weighed 12 ounces, and an atom of oxygen 16 ounces, and an atom of hydrogen 1 ounce, it follows that a combination of oxygen and carbon must be in the proportion of 12 to 16, or 12 to 32; that a combination of hydrogen and oxygen must be in the proportion of 1, or 2, or 3, or 4 of hydrogen to 16 or 32 of oxygen, and this is the case. We cannot know what is the actual weight of an atom, but the relative weights of the atoms of all the elements have been ascertained, and as the atom of hydrogen is the lightest of all, it is taken as the standard, and the weight of the atom of an element, as compared with the weight of an atom of hydrogen, is called the atomic weight of that substance. And thus we say that the atomic weight of hydrogen is 1, of carbon 12 and of oxygen 16.

77. Molecular Weight.—When the atoms of two or more elements combine, they form a compound atom called a molecule.* Of course the weight of this molecule will be that of the combined weight of all the atoms of which it is composed. Thus carbon dioxide is composed of:

1 atom carbon weighing..........................	12
2 atoms oxygen weighing 16 each.................	32
Making 1 molecule carbonic dioxide weighing.....	44

This is called the "molecular weight" of the compound. When compound bodies enter into combination, they always do so in the proportion of their molecular weight. Thus, the molecular weight of carbonic dioxide, is as we have seen 44; that of calcic oxide (quicklime) 56, and when these two combine it will be in the proportion of 44 parts, by weight, carbonic dioxide, and 56 parts, by weight, calcic oxide, forming 100 parts of calcic carbonate—or carbonate of lime.

78. Equivalents.—In the older chemistries, the word equivalent was used to represent the same idea that is now represented by the words atom and molecule.

*The word is derived from a Latin word meaning a little mass.

Thus, carbonic dioxide was said to be composed of one equivalent of carbon and two equivalents of oxygen, instead of one atom of carbon and two atoms of oxygen; and calcic carbonate was said to be composed of one equivalent of carbonic dioxide and one equivalent of lime instead of one molecule of carbonic dioxide and one molecule of lime. The word equivalent was also used to represent atomic and molecular weight. Thus it was said that the equivalent of carbon was 12, of carbonic dioxide 44, and so on. The term is about discarded, but is still occasionally seen.

79. Application.—A knowledge of the atomic and molecular weight of bodies enables us to know the proportions in which these substances are contained in their compounds. Thus we learn that tricalcic phosphate (commonly called bone phosphate) is composed of three molecules of lime, and one molecule of phosphoric acid. The molecular weight of lime is 56, of phosphoric acid 142 (when in combination) so we know the composition of tricalcic phosphate to be:

3 molecules lime weighing 56 each	168
1 molecule phosphoric acid..................	142
Making 1 molecule tricalcic phosphate	310

And we know that the phosphate contains $\frac{142}{310}$ths of its weight of phosphoric acid.

A knowledge of these facts also enables us to know in what proportion chemicals should be used to secure certain results.

§ 3. *Chemical Symbols and Formula.*

80. Symbols.—For convenience in representing the composition of bodies, chemists have adopted certain signs, each of which represents an element, and is called its symbol. Usually the first letter of the name is used—thus C stands for carbon, O for oxygen, H for hydrogen. When the names of two elements begin with the same letter, the two first letters of one are used—as Ca for calcium. Sometimes the first letter of the Latin name of the element is used, as K for potassium, the Latin name of which is kalium.

81. A compound is represented by writing together the symbols of all the elements it contains. Thus CO would represent a compound of carbon and oxygen. HSO a compound of hydrogen, sulphur and oxygen.

82. The symbol not only represents the element, but exactly one atom of that element. Thus CO would represent a compound composed in the proportion of one atom of carbon and one atom of oxygen. When it is desired to represent more than one atom of an element, it is done by placing a small figure after the symbol and a little below it. Thus CO_2 represents a compound of one atom of carbon and two atoms of oxygen. The symbols representing the composition of a substance are called its formula. Thus CO_2 is the formula of carbonic dioxide. In this way the chemical composition of a substance can be stated with an accuracy, clearness and brevity not otherwise possible. When more than one molecule is to be represented, it is done by placing a large figure before the formula of that molecule, thus $CaSO_42(H_2O)$ represents a compound containing one molecule of calcic sulphate, and two molecules of water.

§ 4. *The Elements.*

83. Of the sixty-three elements known to chemists agriculture deals with only fifteen. We give the list of these with their symbols and atomic weights:

Name.	Symbol.	Atomic Weight.
Oxygen	O	16
Hydrogen	H	1
Nitrogen	N	14
Chlorine	Cl	35.5
Carbon	C	12
Phosphorus	P	31
Sulphur	S	32
Silicon	Si	28
Potassium	K*	39.1
Sodium	Na†	23
Calcium	Ca	40
Magnesium	Mg	24
Aluminum	Al	27.5
Iron	Fe‡	56
Manganese	Mn	55

The first four are gases, the next four non-metallic solids, and the last seven metals. This being a work on agriculture, and only treating on chemistry so far as necessary to a comprehension of the science of farming, we devote no space to the other elements, and consider the fifteen named specially in view of their importance to the farmer.

84. Oxygen.—A gas that forms about one-fifth of the atmosphere. It very readily unites with a great number of other substances. It was formerly called "vital air," as without it animals could not live and fires could not burn. Any substance that will burn in the air will burn more readily in this gas, and even substances that will not usually burn at all, such as a piece of iron wire, or a steel watch spring, will burn brilliantly in a jar of this gas. An animal when drowned dies from lack of oxygen, and fires are checked by excluding oxygen. An animal confined in the pure gas becomes excited and feverish, and soon dies from over excitement. Oxygen causes the decay of animal and vegetable substances, and with-

*From Kalium. †From Natrium. ‡From Ferrum.

out it fermentation and decay cannot take place. Fruit keeps in air-tight cans and ensilage in silos because the oxygen of the air is excluded. Though the promoter of fermentation and decay, it is also the great purifier, for where oxygen is supplied in abundance decay is rapidly carried so far that the material is reduced to harmless forms. Oxygen is necessary not only for animal but also for vegetable life. It is one of the most abundant of all elements, forming one-fifth of the atmosphere, eight-ninths of the water, and a large proportion of all rocks.

85. **Hydrogen.**—The lightest known substance. A cubic foot of it weighs only one-sixteenth as much as a cubic foot of oxygen. It can be breathed without injury, but an animal confined in the pure gas would die from lack of oxygen. It burns with a blue flame, and with air or oxygen gas forms a very explosive mixture. It is never found in nature except in combination.

86. **Nitrogen.**—This gas forms about four-fifths of the air. It will not burn, and though not poisonous an animal confined in the pure gas will die from lack of oxygen. It does not readily enter into combination with other elements, and except in the air is not abundant. It is an essential element however, in many organic substances.

87. **Chlorine.**—A greenish yellow, heavy, poisonous gas, never found in a free state in nature. One of the elements of table salt. Used for bleaching and as a disinfectant.

88. **Carbon.**—Well known in three forms: charcoal, black lead and diamond. The first two are nearly pure, the last perfectly pure carbon. Contained in nearly all organic matter. It forms more compounds

than any other element. At ordinary temperatures it will not enter into combination with any other element, and is completely insoluble. When uncombined it is therefore without value as food for either plant or animal. When heated in the air it takes fire and burns, combining with the oxygen of the air to form carbonic dioxide—which readily enters into further combination and is the source from which the carbon in all its compounds is obtained.

89. Phosphorus.—A waxy yellow substance that burns so readily it is usually kept under water. Used in commerce in the manufacture of friction matches. Combined with oxygen and hydrogen it forms phosphoric acid, a substance of great agricultural importance.

90. Sulphur. — Well known as "brimstone," or "flowers of sulphur." It is contained in some organic substances. With oxygen and hydrogen it forms sulphuric acid.

91. Silicon.—A brown solid, known only in combination.

92. Potassium, Sodium, Calcium and Magnesium.— Metals known only in their compounds, which will be described in the next section.

93. Aluminum.—A hard white metal of considerable value in the arts. In combination with silicon and oxygen it forms common clay.

94. Iron.—In some form iron is necessary to the life of plants and animals. It forms two compounds with oxygen—one called the black oxide, the other the red oxide. Substances containing the first oxide are injurious to vegetation, and soils containing it are therefore unproductive. By exposure to the air the black oxide is converted into the red oxide, which is of much value.

85. **Manganese.**—A metal resembling iron, but of much less importance. Its compounds cannot take the place of those of iron in the soil.

§ 5. *The Compounds.*

96. In describing compounds we shall use the chemical symbols and formula, for the double reason that they can be more clearly and briefly represented in that way than in any other, and that it will be good practice for the student. It will be well for the student to refer to the table of atomic weights, and calculate for himself the proportion of each element contained in a compound. Thus we shall give the composition of sulphuric acid as H_2SO_4. A molecule of it is therefore composed of

2 atoms of hydrogen, weighing 1 each	2
1 atom of sulphur, weighing	32
4 atoms of oxygen, weighing 16 each	64
Making one molecule of sulphuric acid, weighing	98

Sulphuric acid is therefore composed, by weight, of $\frac{2}{98}$ths hydrogen, $\frac{32}{98}$ths sulphur, and $\frac{64}{98}$ths oxygen.

The formula of starch will be given as $C_6H_{10}O_5$. From this we learn a molecule of it contains

6 atoms carbon, weighing 12 each	72
10 atoms hydrogen, weighing 1 each	10
5 atoms oxygen, weighing 16 each	80
Making one molecule of starch, weighing	162

Which shows the proportion of each element contained in starch.

Suppose, for example, the reader wishes to know how many pounds of nitrogen are contained in a ton of sodic nitrate, commonly called nitrate of soda—a popular fertilizer. Its formula is given as $NaNO_3$. It is therefore composed of

1 atom sodium, weighing	23
1 atom nitrogen, weighing	14
3 atoms oxygen, weighing 16 each	48
Making one molecule sodic nitrate, weighing	85

A ton of it therefore contains $\frac{14}{85}$ths of a ton of nitrogen, and the number of pounds of nitrogen in a ton would be determined by multiplying 2000 (the number of pounds in a ton) by the numerator of the fraction, and dividing by the denominator. Thus:

$$\begin{array}{r} 14 \\ 2000 \\ \hline 85)28000(329 \\ 255 \\ \hline 250 \\ 170 \\ \hline 800 \\ 765 \\ \hline 35 \end{array}$$

A ton of pure nitrate of soda therefore contains $329\frac{35}{85}$ lbs. of nitrogen.

97. Water.—H_2O. Mol. Wt. 18.* Water is the great natural solvent by which plants and animals obtain their food. Its elements are also contained in a large number of organic and inorganic substances. It is commonly referred to in four forms: water of combination — as it exists in land plaster, which contains a little over one-fifth of its weight of water in combination; "hydrostatic water," which means water that will flow out of the substance containing it, if opportunity is afforded; capillary water, that which is retained within the pores of a substance and will not flow out, but is still perceptible to the senses; and hygroscopic water, that which is not perceptible to the senses, but can be driven out by heat. Nearly all substances that have been dried in the air contain hygroscopic water.

*Henceforth we shall use the abreviation At. Wt. for atomic weight, and Mol. Wt. for molecular weight.

98. **Ammonia.**—NH_3. Mol. Wt. 17. A colorless gas, with a peculiar, pungent odor, often perceived about stables and manure heaps. It is very valuable as a fertilizer, and will be further considered in succeeding chapters. Being a gas, it readily escapes into the air and is lost. Water absorbs it readily, and a strong solution of it forms the "aqua ammonia," "spirits ammonia" of the drug stores. In this form it is valuable in the household. It is useful in place of soap, in cleaning paint, removing grease, etc. A little added to the water for the bath has a very refreshing effect. A few drops, given in water, makes an excellent stimulant in cases of fainting, poisoning, etc. A tea-spoonful added to a quart of water, is an excellent fertilizer for pot plants, but caution should be exercised not to use too much. It is often retailed at 5 or 10 cents an ounce, but can be bought at wholesale at from 4 to 6 cents a pound.

99. **Carbonic Dioxide.**—CO_2. Mol. Wt. 44. Commonly called carbonic acid. A gas with a sour taste. About one-half heavier than the air, which contains about $\frac{1}{2500}$th of its weight of this gas. When breathed in quantity it is highly poisonous, but the small amount present in the air is not injurious to animals, and is essential to vegetable life. It is given off in the breath of all animals, and by the fermentation or decay of organic matter. When wood or coal is burned, the carbon it contains unites with the oxygen of the air, producing this gas. Hence, if the smoke and gas from a fire are allowed to escape into a room, the air becomes poisonous. Lamps burning in a poorly ventilated room soon produce an injurious amount of this gas. It is the amount of this gas given off in the breath that makes the air grow foul in crowded rooms unless

abundant ventilation is provided. Water absorbs this gas freely, and though poisonous when breathed, its solution in water is both palatable and wholesome. Spring water owes its sparkling to the presence of this gas. The water in the soil always contains this gas in solution. Water containing this gas will dissolve many substances not otherwise soluble, and thus prepare them for the food of plants. Hard water usually owes its hardness to limestone, which will dissolve in water containing cabonic acid, but not in pure water. As boiling the water drives off the gas, kettles in such regions of country soon become crusted with a coating of lime. Carbonic dioxide forms many compounds with bases, which are called carbonates.

100. Phosphoric Acid.—H_3PO_4. Mol. Wt. 98. This is really a compound of phosphoric pentoxide (P_2O_5) with three molecules of water, and is sometimes written thus: $P_2O_53(H_2O)$ Mol. Wt. 196. In its combination with bases, one, two, or three molecules of water are replaced by one, two or three molecules of a base, and the compound is called a phosphate. Phosphates containing one molecule of base and two of water are distinguished by the prefix mono; those containing two molecules of a base and one of water, by the prefix bi; and those containing three molecules of base by the prefix tri. This will be more fully explained later in this chapter. In analyses of foods and fertilizers, the term "Phosphoric acid" is used to represent P_2O_5, called by chemists phosphoric pentoxide.

101. Nitric Acid.—HNO_3, Mol. Wt. 63. Known in the drug stores as "aqua fortis." It is formed to a small extent in the atmosphere by the direct combination of its elements under the influence of electricity, and combines with the ammonia in the air, and is washed out by the rains. It is also formed to a considerable extent in the soil under certain circumstances by the oxidation of ammonia and organic substances containing nitrogen. Its compounds with bases are called nitrates.

102. Sulphuric Acid.—H_2SO_4. Mol. Wt. 98. A heavy, oily liquid, commonly known as oil of vitriol. A pint weighs a little over 1¾ lb. It is very corrosive, burning and destroying most forms of organic matter. It should always be handled with great care. When mixed with water great heat is produced, and it is a dangerous experiment when incautiously done. In making the mixture, the acid should always be poured into the water, and *never* the water into the acid. It is usually sold in large glass vessels called carboys, and costs from 1½ to 3 cents a pound. Its compounds with bases are called sulphates.

103. Silicic Dioxide.—SiO_2. Mol. Wt. 60. Commonly called silica and sometimes silicic acid. It is commonly known as quartz, flint, etc. Nearly all rocks contain it. Water containing certain organic substances dissolves it to a small extent, and it is thus taken up by the plant with its food. Its compounds with bases are called silicates.

104. Potassic Hydrate.—KHO. Mol. Wt. 56.1. An exceedingly caustic substance sold in the drug stores as caustic potash. It is always present in good soils, and is essential to vegetable life. It is a large constituent in ashes, and gives them their value as a manure. It is contained in many rocks, which, by their decay, supply it to the soil. A mineral called kainit contains it in large quantities and is now extensively used as a fertilizer. The term "potash," as used in giving the analysis of foods and manures, means K_2O, called by chemists potassic monoxide, a substance usually known only in combination.

105. Sodic Hydrate.—$NaHO$. Mol. Wt. 40. Caustic soda. It is used by plants to but a small extent, and cannot take the place of potash in the soil.

106. Sodic Chloride.—$NaCl$. Mol. Wt. 58.5. Common table salt.

107. Calcic Oxide.—CaO. Mol. Wt. 56. Quicklime. Obtained by burning chalk or limestone, (calcic carbonate.) This is a compound of lime and carbonic dioxide, and when exposed to heat the latter is driven off and the lime remains. Quicklime readily unites with water, forming slacked lime, with the formula H_2CaO_2. When quicklime is exposed to the air, it gradually absorbs water and falls into a white powder —slacked lime. It also gradually absorbs carbonic dioxide and returns to its original condition of calcic carbonate. Hence, when lime is kept, it is necessary to exclude the air as much as possible. When applied to the soil it is very rapidly converted into carbonate of lime, but in a much finer powder than it could possibly be reduced to by any other means. Lime is of value as food for plants, and it also has other properties which will be more fully considered in the chapter on fertilizers. It has a strong "affinity" for all acids, and when mixed with a salt, will frequently combine with the acid it contains and set free the base with which it had been previously combined. Thus, if sulphate of ammonia and quicklime are mixed, the result will be sulphate of lime and free ammonia, which, being a gas, will escape. Hence, lime should not usually be mixed with the manure heap.

§ 6. *Compounds of Acids and Bases.*

108. **Nitrates.**—Nearly all the compounds of nitric acid are soluble. The only ones of importance to the farmer are potassic nitrate, (KNO_3, Mol. Wt. 101.1) commonly known as nitrate of potash, or saltpeter, and sodic nitrate, ($NaNO_3$, Mol. Wt. 85,) commonly called nitrate of soda, or Chili saltpeter.

Nitrate of potash occurs in abundance in the soils of some tropical countries, and is also produced artificially in what are called "saltpeter plantations." Heaps of soil and organic matter containing nitrogen, are made, with lime or potash in some form, and left for many months to decompose — being kept constantly moist. The nitrogen in the organic matter combines with oxygen from the air, forming nitric acid, which combines with the potash or lime in the soil, forming nitrate of potash or lime. This is afterwards dissolved out by water, and when purified becomes the saltpeter of commerce. It is too expensive for use as a fertilizer, but its formation naturally in the soil is a matter of great importance.

Chili saltpeter derives its name from the fact that it is imported in large quantities from South America. It is largely used as a fertilizer to supply nitrogen to the soil. It contains about fifteen per cent of nitrogen.

109. **Sulphates.**—Calcic sulphate dihydrate, $CaSO_4$ $2(H_2O)$, is commonly known as gypsum, or land plaster. It is used as a manure, and furnishes both sulphuric acid and lime to the plant. The method of its action as a fertilizer is not well understood. When added to matter containing carbonate of ammonia, an exchange takes place—resulting in sulphate of ammonia and carbonate of lime. This makes it valuable for use in the manure heap and about stables to pre-

vent waste of ammonia. When gypsum is heated it parts with the two molecules of water, and is converted into calcic sulphate ($CaSO_4$) or plaster of Paris.

Ammonic Sulphate, $2(NH_4)SO_4$, Mol. Wt. 132,—Sulphate of ammonia. Largely used as a fertilizer on account of the large proportion of nitrogen it contains, amounting to about 21.2 per cent.

Ferrous sulphate, commonly known as sulphate of iron, copperas, green vitriol. Valuable as a disinfectant. When it is present in the soil in considerable quantity, it is poisonous to vegetation. The addition of lime results in the formation of carbonate of iron and sulphate of lime.

110. Phosphates.—The important compounds of phosphoric acid are those it forms with lime.

Tricalcic phosphate, $Ca_3P_2O_8$, Mol. Wt. 310. Bone phosphate. Forms about 55 per cent of all bones. Is also found in minerals called coprolite, apatite and phosphorite, of which there are large natural deposits in South Carolina, Canada, England, Spain, and some other countries. It is insoluble, and only available as plant food as it undergoes decomposition in the soil.

Bicalcic phosphate, $Ca_2H_2P_2O_8$. Mol. Wt. 272. Obtained from the tricalcic phosphate by a process that will presently be described. Is slowly soluble, and can be used as food by plants.

Monocalcic phosphate, $CaH_4P_2O_8$. Mol. Wt. 234. Is readily soluble, and immediately available as plant food.

111. Preparation of Phosphates.—To understand the preparation of the bicalcic and monocalcic phosphates, it may be well to represent their composition in this way—keeping in mind that phosphoric acid (using that term to represent P_2O_5, called by chemists phosphoric pentoxide when not in combination) is usually in combination with 3 molecules of water, or some base.

Tricalcic phosphate, $Ca_3P_2O_8$, is equal to

$$\left.\begin{matrix} CaO \\ CaO \\ CaO \end{matrix}\right\} P_2O_5$$

or three molecules of lime and one of phosphoric acid.

Bicalcic phosphate may be represented

$$\left.\begin{matrix} CaO \\ CaO \\ H_2O \end{matrix}\right\} P_2O_5$$

or two molecules of lime, one of water, and one of phosphoric acid.

Monocalcic phosphate may be represented

$$\left.\begin{matrix} CaO \\ H_2O \\ H_2O \end{matrix}\right\} P_2O_5$$

or one molecule of lime, two of water, and one of phosphoric acid.

Sulphuric acid, H_2SO_4, may be represented

$$H_2O \quad SO_3.$$

If we put together one molecule tricalcic phosphate one of sulphuric acid and two of water, they may be represented thus:

$$\overbrace{\left.\begin{matrix} CaO \\ CaO \\ CaO \end{matrix}\right\} P_2O_5}^{\substack{\text{1 Molecule} \\ \text{Tricalcic Phosphate}}} \qquad \overbrace{\begin{matrix} SO_3 \\ H_2O \end{matrix}}^{\substack{\text{1 Molecule} \\ \text{Sulphuric Acid}}} \qquad \overbrace{\begin{matrix} H_2O \\ H_2O \end{matrix}}^{\substack{\text{2 Molecules} \\ \text{Water.}}}$$

By re-arranging these we can get

$$\overbrace{\left.\begin{matrix} CaO \\ CaO \\ H_2O \end{matrix}\right\} P_2O_5} \qquad \overbrace{CaO\ SO_3 \left\{\begin{matrix} H_2O \\ H_2O \end{matrix}\right.}$$

By adding the elements under the first bracket, it will be found they constitute bicalcic phosphate, and by adding those under the second bracket, it will be found they constitute calcic sulphate dihydrate, and thus by mixing bone phosphate, sulphuric acid and water, we get, as the result of the chemical action, bicalcic phosphate and gypsum.

If we add to the tricalcic phosphate double the proportion of sulphuric acid and water, the result will be one molecule of monocalcic phosphate and two molecules of calcic sulphate dihydrate. The process of manufacture of the bicalcic and monocalcic phosphate differs only in the amount of sulphuric acid and water used. The principle is the same in both cases. To aid the student in comprehending the principle, we will represent the process of making the monocalcic phosphate by words, instead of by symbols.

One Molecule Tricalcic Phosphate.	Two Molecules Sulphuric Acid.	Four Molecules Water.
Phosphoric acid	Sulphuric acid*	Water
Lime	Sulphuric acid	Water
Lime	Water	Water
Lime	Water	Water

This gives us one molecule phosphoric acid, three of lime, two of sulphuric acid* and six of water. They can be re-arranged thus:

One Molecule Monocalcic Phosphate	One Molecule Gypsum	One Molecule Gypsum
Phosphoric acid	Lime	Lime
Lime	Sulphuric acid*	Sulphuric acid*
Water	Water	Water
Water	Water	Water

This subject is of importance because it explains the

*Properly speaking, sulphuric oxide, SO_3, sulphuric acid being composed of one molecule sulphuric oxide combined with the elements of one molecule of water.

conversion of bones and rock phosphate into superphosphate. The practical application, proportions needed, etc., will be given in the chapter on Fertilizers.

112. Carbonates.—Carbonic dioxide is readily displaced from its compounds by other acids; and carbonates can usually be recognized by the fact that they boil up or effervesce when an acid is poured on them, the effervescence being caused by the escape of the carbonic dioxide in the form of gas.

The carbonates that interest the farmer are calcic carbonate (carbonate of lime), and ammonic carbonate (carbonate of ammonia). Calcic carbonate is well known as chalk and limestone; it is of some value in the soil. Soils that contain it in considerable quantity are called calcareous, and may be recognized by effervescing when vinegar or some other acid is poured on them.

Ammonic carbonate is a white solid produced by the combination of ammonia and carbonic dioxide. It very readily passes into the form of vapor. It has the pungent odor of ammonia. As manure in decomposing gives off carbonic dioxide as well as ammonia, the ammonia in manure usually exists in the form of carbonate unless some stronger acid is present to combine with the ammonia.

113. Ammonic Chloride.—NH_4Cl. Mol. Wt. 53.5. Commonly called sal ammoniac. It is used as a fertilizer to supply nitrogen of which it contains rather more than ammonic sulphate.

§ 7. *Organic Chemistry.*

114. Organic chemistry treats of those substances that are produced under the influence of animal or vegetable life. As these compounds all contain carbon, this division of chemistry is frequently called the Chemistry of the Carbon Compounds.

115. All organic substances are composed from the elements named on page 38 with the exception of silicon and aluminum. Silicon is not found in animal substances, and seems to be present in vegetable matter rather as an accident than as an essential element; and aluminum is not found in any form of organic matter. Besides these thirteen elements, very minute portions of a few others are sometimes found.

116. Isomerism.—A large number of organic substances are found to be composed of the same elements, combined in the same proportion. Thus starch and cellulose, though quite unlike, are composed of the same elements combined in the same proportions. Such substances are said to be isomeric, and this particular property can only be accounted for on the supposition of a different arrangement of atoms.

117. Organic substances are divided into nitrogenous and non-nitrogenous. The non-nitrogenous comprise the

Carbohydrates, or amyloids;
The pectose group;
Fats;
Vegetable acids.

The nitrogenous comprise the

Albuminoids;
Amides;
Alkaloids.

118. Carbohydrates are so called because they all contain hydrogen and oxygen in the proportion to form water. Many of them are isomeric. Most of them can be changed from one form to another, either —when isomeric, by a re-arrangement of their atoms, or when not isomeric, by the addition or subtraction of the elements of water.

119. Cellulose. $C_{12}H_{20}O_{10}$, forms the solid substance of most plants. It is not soluble in water but dissolves in weak acids. As the plant becomes older, another substance is deposited with the cellulose, called lignose, the exact chemical composition of which has not been ascertained, but which probably contains a larger proportion of carbon than cellulose. It is harder and less readily dissolved.

120. Starch. $C_6H_{10}O_5$.* This is contained in nearly all plants. It is insoluble in water, but readily changed into soluble substances, and hence is easily digested. Inulin is a modified form of starch found in some parts of plants. It is more readily soluble than starch. Dextrine has the same composition as starch and inulin, but is readily soluble. Starch is converted into dextrine by the application of heat.

121. Gums are a class of substances found in most plants. They are similar to starch in composition and general properties, but are mostly soluble.

122. Sugars. There are quite a number of vegetable substances possessing the general characters of sugar, and differing but little in composition. The most important are: cane sugar (sacharose) $C_{12}H_{22}O_{11}$; fruit sugar (lævulose) $C_6H_{12}O_6$, and grape sugar (glucose) $C_6H_{12}O_6$.† Cane sugar is found in

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*The exact formula for these organic substances is not in all cases fully determined. Some authorities give starch as $C_{12}H_{20}O_{10}$. It will be observed that the proportions of the elements are the same in either case. There is no question as to the percentage composition of these substances.

†Strictly speaking, grape sugar is called dextrose, and the term glucose includes both lævulose and dextrose, but in practice the term glucose is principally used to describe dextrose artificially produced.

the juice of the sugar cane, in the sugar beet, and in many other plants. Fruit sugar is as sweet as cane sugar, but differs from it in that it does not granulate. It exists in honey and in many fruits. Grape sugar (glucose) has the same composition as fruit sugar, but differs from it in being only one-third as sweet. It can be granulated.

Grape sugar differs in composition from starch only by the elements of a molecule of water. If we take

1 molecule of starch	$C_6\ H_{10}\ O_5$
Add 1 molecule water	$H_2\ O_1$*
We have 1 molecule glucose	$C_6\ H_{12}\ O_6$

As the proportionate weights of the molecules of starch and water are 162 and 18, it follows that if we could take 162 lbs. starch and 18 lbs. water and cause them to unite, we should have 180 lbs. glucose.

By boiling starch or cellulose with water and an acid, it is caused to combine with the water, producing glucose. The acid does not enter into the combination, and at the close of the process remains unchanged in quantity and quality. The combination of the starch and water is effected by the *presence* of the acid, only. *How* some substances thus induce changes in others by their presence is not understood. The property is called catalysis.

Glucose is now made on a great scale, and used for adulteration of sugars and syrups and the manufacture of candies and alcohol. Starch, sulphuric acid and water are mixed in the proportions of 1,000 lbs. starch, 21 lbs. acid and 150 gallons water. The mixture is boiled until the starch has been converted into

*When one atom of an element is intended, it is not usual to place the figure 1 after the symbol, as that stands for one atom. We do so in this case to make the addition more clear.

glucose. Chalk is then added, which combines with the acid, forming sulphate of lime or gypsum, which is separated by settling and straining.

When pure, glucose is not unwholesome, but it is often carelessly made, and contaminated with the sulphuric acid and chalk used in its manufacture.

123. The Pectose Group.—These comprise a large number of substances that are found in plants and especially fruits. They are called pectin, pectose, pectic acid, etc. Their exact chemical composition has not been definitely determined, but they are not true carbohydrates, as the oxygen they contain bears a larger proportion to the hydrogen than it does in water. This group of substances forms the vegetable jellies—which differ from the animal jellies in not containing nitrogen.

124. Vegetable Acids.—These are a very numerous class of substances, and differ from carbohydrates in containing a larger amount of oxygen. In analyses of foods, both the pectose group and the vegetable acids are frequently included in the estimate of the soluble carbohydrates.

125. Fats.—The various oily, fatty and waxy substances found in organic matter are divided into two classes: "volatile" oils, such as oil of peppermint, which give the fragrance to plant and flower, and which will evaporate like water; and "fixed" oils, which will not evaporate, but leave a greasespot. The latter class are the only ones we need to consider in this work.

Animal and vegetable fats are of the same general character, and consist principally of mixtures in varying proportions of three fatty principles: stearin—contained largely in tallow and the firmer fats; palmitin, contained in palm oil, butter, beeswax, etc., and olein, which forms the liquid substance in fats and oils. The striking difference between fats and carbohydrates is the much larger proportion of carbon and hydrogen, and the much smaller proportion of oxygen contained in the fats. This is illustrated in the following table, giving the amount of each element contained in 10,000 parts of starch, pectin and olein:

	Starch	Pectin	Olein
Carbon	4,444	4,067	7,740
Hydrogen	617	508	1,180
Oxygen	4,939	5,425	1,080
	10,000	10,000	10,000

It will be remembered that starch fairly represents the carbohydrates, pectin the vegetable jellies, and olein the fats and oils.

126. **Albuminoids.**—This term is applied to a large number of important substances, including all nitrogenous organic compounds except the amides and alkaloids. Most, if not all of them contain a small quantity of sulphur. Animal and vegetable albuminoids differ but little in composition. Their exact chemical formula has not been positively determined, but their composition, in 10,000 parts, is about as follows:

Carbon	5,350
Hydrogen	700
Oxygen	2,240
Nitrogen	1,550
Sulphur	160
	10,000

By comparison with the table in paragraph 125, it will be seen that they contain a larger proportion of carbon and hydrogen than the carbohydrates and less oxygen, holding an intermediate position between them and fats.

127. Animal albumin is found nearly pure in the white of an egg. In its natural state it is soluble; but heat, alcohol or acids change it into an insoluble form, or "coagulate" it. This is the change that takes place in cooking an egg. Musculine constitutes the substance of the muscles. Fibrine forms the "clot" in blood. Gelatine is obtained from the skin and bones of animals by the application of hot water. It is commonly seen in glue, and the finer and purer forms are sold as gelatine, isinglass, etc. Gluten is contained in wheat and most grains. It is not a simple albuminoid, but a mixture of several. Keratin is the general name applied to the substances of which horn, hair and wool are formed. Animal casein is found in milk, and forms the substance of cheese. Vegetable casein, which closely resembles it, is found in peas, beans and other leguminous plants.

128. Amides.—These vegetable nitrogenous compounds are not well understood. They exist principally in roots and immature plants. In the plant they are convertible into albuminoids, but animals have not the power to effect this transformation.

129. Alkaloids are a class of nitrogenous vegetable substances that exist in the plant in but small quantities. Tobacco owes its effects to an alkaloid called nicotine; opium to an alkaloid called morphine; tea and coffee derive their stimulating effects from an alkaloid called theine, or caffeine. These substances, though of much general interest, are of little practical importance to the farmer.

130. Transformation of Organic Substances.—The general similarity of organic substances renders their change from one form into another very simple. In the natural laboratories of the plant and animal this is constantly being done. Carbohydrates are changed into each other, either by a re-arrangement of their atoms, or by the addition or removal of the elements of water. By the removal of oxygen, carbohydrates are converted into fats, and fats again by the addition of oxygen, are changed back into carbohydrates. Out of carbohydrates and nitrates the plant manufactures albuminoids, and the animal can remove the nitrogen and part of the oxygen from the albuminoid and produce fat. These transformations will be more fully considered in the chapters on Plant Growth and Animal Life.

§ 8. *Combustion and Decay.*

131. The rapid union of any substance with the oxygen of the air, producing light and heat, is called combustion. In common language, it is said the substance burns. The light and heat are produced by the union of the atoms of oxygen with the atoms of the substance, the force that had before been keeping them apart being converted into heat. Substances that will burn are called combustible; those that will not are called incombustible.

When a carbohydrate such as cellulose burns, the hydrogen and oxygen being in the proportions to form water, pass off as watery vapor, while the carbon combines with oxygen from the air, forming carbonic dioxide. As there are 12 atoms of carbon in a molecule of cellulose, and as one atom of carbon unites with two atoms of oxygen in forming carbonic dioxide, it follows that in the combustion of a molecule of cellulose it unites with 24 atoms of oxygen from the air.

The process and its results may be thus shown:

Cellulose	Oxygen	Result.
C_{12} H_{20} O_{10}	O_{24}	$12(CO_2)$ $10(H_2O)$

The student will quickly see that there are the same number of atoms of each element on each side of the brace. The proportions by weight would be

1 molecule cellulose, weighing	324
24 atoms oxygen, weighing 16 each	384
Total material	708

Resulting in

12 molecules carbonic dioxide, weighing 44 each	528
10 molecules water, 18 each	180
Total product	708

That is, when 324 parts of cellulose are burned, there is a combination of 144 parts of carbon with 384 parts of oxygen; or, when 1,000 lbs. of cellulose are burned, there is a union of 444 lbs. carbon with 1,269 lbs. oxygen, making 1,713 lbs. of the two elements.

When fat is burned, the proportions are somewhat different. Instead of the hydrogen and oxygen in the fat being in the proportion to form water, there is a great excess of hydrogen, so that not only does a thousand lbs. of fat contain more carbon than a thousand lbs. of cellulose, but when it burns, a large part of the hydrogen it contains also unites with oxygen from the air. In burning 1,000 lbs. olein, there would be a union of

Carbon	771 lbs.
Hydrogen	105 lbs.
With oxygen	2,929 lbs.
Total elements uniting	3,805 lbs.

So that in the combustion of 1,000 lbs. of oil, the weight of the elements that enter into combination is more than twice as great as in the combustion of 1,000 lbs. of cellulose. Hence the much greater amount of heat produced.

132. Decay.—When organic matters are exposed to warmth, air and moisture, the same chemical changes that take place rapidly in combustion, occur slowly, the result being the same in the end. This process of decay is called by chemists "eremacausis," which means slow combustion. During decay heat is produced, as in combustion, but being developed much more slowly, is less noticeable. The products of the decay of non-nitrogenous organic matter are carbonic dioxide and water. If the substance contains nitrogen, either nitric acid or ammonia will also be produced.

The chemistry of respiration will be explained in the chapter on Animal Life.

CHAPTER V.

SCIENCE IN AIR.

§ 1. *Its Composition and Characteristics.*

133. Composition.—The atmosphere is a mixture of oxygen and nitrogen, with a variable quantity of watery vapor, and a small amount of carbonic dioxide. Its average composition, by weight, in 100,000 parts is as follows:

Nitrogen	78,492
Oxygen	20,627
Watery vapor	840
Carbonic dioxide	41
	100,000

This composition is commonly expressed as four parts nitrogen and one of oxygen.

In addition to these substances the atmosphere always contains a small amount of ammonia, dust, and other impurities. The proportions in which these exist are so minute that although their presence can be detected, it is extremely difficult to estimate the amount.

134. The proportion of oxygen and nitrogen in the air in the open country never varies. In a close room where many persons are gathered, or in the crowded streets of large cities, the proportion of oxygen may be slightly reduced. The proportion of carbonic dioxide is also nearly uniform except in places where from local influences this gas is produced more rapidly than it can be diffused. The proportion of watery vapor varies greatly. It may be said therefore, that with the exception of water, the composition of the great bulk of the atmosphere is the same at all places and all seasons.

The different gases of which the atmosphere is composed are simply mixed together, and are not in chemical combination (57).

135. Diffusion of Gases.—If a jar containing hydrogen is placed above one containing carbonic dioxide, and the two are connected by a small tube, the carbonic dioxide gradually rises through the tube and diffuses itself through the hydrogen, which at the same time descends diffusing itself through the carbonic dioxide, and although the latter gas is twenty times as heavy as the hydrogen this process will continue—the heavy gas ascending and the light one descending, until both jars contain a mixture of the two gases in exactly the same proportion. Whenever two gases are mixed, in any proportion, they will diffuse through each other until in time the composition of all parts of the mixture is the same. If the specific gravity* of one of the gases composing the mixture is

*Specific gravity is the proportionate weight of a substance —that is the relation that the weight of a given bulk of one substance bears to the weight of an equal bulk of some other substance taken as a standard. Thus a pint of oil weighs less than a pint of water, and so we say that the specific gravity of oil is less than that of water. A cubic foot of oxygen weighs more than a cubic foot of nitrogen, and we say that its specific gravity is greater. In practice, solids and liquids are compared with water as a standard, and gases with air. Thus the specific gravity of lead is 11.44, by which is meant that a given bulk of lead weighs eleven and forty-four one-hundredths times as much as an equal bulk of water. The specific gravity of hydrogen is .069, by which is meant that a given bulk of hydrogen weighs sixty-nine one-thousandths as much as an equal bulk of air.

greater than the other, more time will be required to effect the diffusion, but it will be as thoroughly effected. When different gases have thus been mixed, they do not again separate, however great may be the difference in specific gravity. This is called the Law of Diffusion of gases.

It is this law that secures the uniformity of composition of the atmosphere. Although the specific gravity of oxygen is greater than that of nitrogen, yet through the working of this law, the lower portions of the atmosphere contain no more oxygen than the upper portions. Although the specific gravity of carbonic dioxide is much greater than that of the other constituents of the atmosphere, yet it never separates, and settles into the low places and valleys, but the air on the highest mountain peaks contains as much as that at the level of the ocean. Owing to this law also, injurious gases poured into the air are soon diffused through the whole bulk of the atmosphere, and by their great dilution become harmless. If it were not for this, cities would soon become uninhabitable by the accumulation of carbonic dioxide and other injurious gases, and every low place would be filled with poisonous gas.

136. Apparent Exceptions.—Occasionally there is such an accumulation of carbonic dioxide in cellars, dry wells and old pits that persons entering them incautiously, lose their lives. In the island of Java there is said to be a place called the Valley of Poison, containing an accumulation of this gas. The ground is covered with the bones of animals which have been suffocated while passing through. These exceptions are only apparent. In such cases the gas is being produced in the well, pit or valley, more rapidly than it can be diffused through the air.

When there is reason to suspect that carbonic dioxide—or "choke damp," as it is popularly called, exists in dangerous quantities, a lighted candle should be lowered into it. If the gas is present in sufficient quantity to be dangerous the candle will be extinguished. The best method of removing this gas from pits and cellars is by the use of quicklime. One hundred pounds of quicklime will absorb about 675 cubic feet of the gas.

The air near a large city contains a larger proportion of ammonia than that in the country, but this also is owing to the fact that the ammonia is produced in the city more rapidly than it can be spread through the surrounding atmosphere by diffusion. The winds assist in securing the uniform diffusion through the atmosphere of gases developed in special localities.

§ 2. *Importance of Each Constituent.*

No estimate can be made of the comparative value of the different constituents of the atmosphere, as each one is essential.

137. Oxygen sustains life and combustion. It is essential to germination. It unites with organic matter in the soil, giving rise to new compounds that can be used as food by plants. It combines with impurities and poisonous gases in the atmosphere, changing them into harmless forms. It acts upon the rocks and rocky particles of the soil and reduces them to such a condition that plants can use them. It is the great purifier and disinfectant, as it converts dangerous organic compounds into harmless inorganic ones. Without oxygen neither plant nor animal could live; and the action of oxygen on the soil is essential to maintain its fertility.

138. The nitrogen of the air serves to dilute the oxygen, and prevent its too energetic action. Being itself perfectly harmless, and in many respects inert, it is excellently adapted for this purpose. Although it is essential to plant growth, the plant has no power to use the free nitrogen of the air; it must be in combination with some other element before it can be appropriated by the plant. There is a probability that under certain circumstances the nitrogen of the air contained in the pores of the soil is oxidized and made available for plant food. The free nitrogen of the air is oxidized to a small extent through the influence of electricity, forming nitric acid, which combines with the ammonia in the air, forming nitrate of ammonia, which is washed out by the rains. The quantity supplied to the soil in this way varies, but probably the average does not exceed from 6 to 9 lbs. of nitrogen per acre in a year,

139. Although the proportion of carbonic dioxide in the atmosphere is small, (only one part in twenty-five hundred,) yet the volume of air is so great that the actual amount of this gas is very considerable. It is calculated the air over an acre of ground contains 28 tons of this gas. This is a sufficient quantity to supply the needs of vegetation for many years, even were there no more produced; but the processes of combustion, respiration and decay are constantly pouring this gas into the atmosphere.*

The carbonic dioxide contained in the air supplies all the carbon for the plant. Careful experiments have shown that plants cannot grow and increase in

*The amount of this gas absorbed by the leaves of plants equals that produced, and the balance is thus constantly maintained.

weight in an atmosphere containing none of this gas. The constant motion of the winds causes an immense amount of air to touch the leaves of plants, thus enabling them to obtain an abundant supply of carbon. The farmer, therefore, need have no anxiety about providing carbon or carbonaceous manures to the roots of plants.

140. Water vapor is always present in the air, but the amount varies greatly. The warmer the air the greater amount of water it is able to retain. When the air contains all the water it can hold at that temperature, it is said to be saturated. When air that is partly saturated is cooled, a temperature will be reached at which it will be saturated, and any further decrease of temperature will cause the formation of mist or dew. The temperature at which mist or dew begins to form is called the "dew point." Suppose the temperature of the air in a room was 70 degrees, and it contained enough water to saturate it at 60 degrees; if then the temperature was reduced to 60 degrees, any further reduction would result in the formation of mist or dew, and 60 would be the dew point. The nearer the air is to saturation the closer will the dew point approach to the temperature of the air. Therefore a high dew point shows that the atmosphere is nearly saturated. When a pitcher is filled with ice-water in summer, drops of dew soon begin to collect on the outside, and, in popular language the pitcher is said to "sweat." The expression is incorrect. The drops of water do not come through the pores of the pitcher, but the cold surface reduces the temperature of the air touching it below the dew point, and the water contained in the air is condensed on the sides of the pitcher. On a clear night the leaves of plants, the surface of the soil and other objects radiate into space the heat they have absorbed from the sun during the day. As soon as they are by this process cooled below the dew point, the moisture of the air is condensed on them, and we say the "dew falls." Strictly speaking, the dew does not fall, as it collects as readily on the under surface of an object as on its upper surface. As clouds check this radiation of heat into space (54), we rarely have dew on cloudy nights.

141. As air is warmed, its capacity for water is increased, it *feels* dry, and will absorb water from whatever it touches, although the actual amount contained is the same as before. This is the reason why the air of a "stove room" is injurious to the lungs, and destructive to house plants, unless provision is made for increasing the amount of moisture in the air.

The vapor of water in the air is not usually absorbed by the plant, but an increase in the amount present refreshes the plant by checking evaporation from the leaves. The soil absorbs a considerable amount of moisture from the air, and in this way it becomes of use to the plant.

142. The quantity of ammonia in the air is very small. A portion of this is absorbed directly by the leaves of plants, a portion is washed out by the rains, and a portion is absorbed by the soil. The amount of nitrogen brought down by the rains in nitric acid and ammonia has been given (138). What amount is absorbed by the leaves of plants and by the soil has not yet been determined, and varies so much under different circumstances, that it will be difficult to secure an average. The amount absorbed is greatly influenced by the character and condition of the soil.

The source of ammonia in the air has not been positively ascertained. Some of it is produced by the decomposition of organic matter; some by the burning of coal. There is always a larger amount brought down by rains in the neighborhood of cities than in country districts.

§ 3. *Summary.*

143. The farmer therefore gets from the air:

Oxygen, to cause the germination of seed, the decomposition of organic matter, and the reduction of the mineral portions of the soil to a form in which they can be used as food for plants.

Nitrogen in the form of ammonia, absorbed by the leaves of plants and by the soil, and brought down by the rains, and in the form of nitric acid brought down by the rains. Also, probably, free nitrogen, to be oxidized in the soil under proper conditions into nitric acid.

Carbon, in the form of carbonic dioxide. The farmer can use the plant for the purpose of collecting carbon from the air and supplying it to the soil, for the improvement of its condition.

CHAPTER VI.

SCIENCE IN SOILS.

§ 1. *Origin of Soils.*

144. Soil consists of the broken fragments of rock mixed with partially decayed organic matter. The character of the soil, therefore, varies with the kind of rock from which it was produced, the extent of the decomposition it has undergone, and the kind and amount of organic matter that is mixed with the decomposed rock.

145. Rock has been reduced to the condition of soil by various natural agencies. When the continents were under the ocean, the force of the water broke off fragments of rock, and by grinding these together, reduced them to powder. During the ages when glaciers—great rivers of ice—covered much of the earth's surface, the rocks were ground to powder. After the continents took the form they now have, other agencies continued the work. Water penetrated the crevices of rock, and, freezing, broke and crumbled it. It also gradually dissolved part of the rock. The air and water together caused the elements in the rock to separate and enter into new combinations. Thus by degrees a soil of inorganic material was formed. The rains brought down and added to it nitric acid and ammonia from the air, and on this primitive soil low orders of plants, at first, began to grow; and as they decayed upon the soil, returned to it all they had gathered from both soil and air. Fresh supplies of nitrogen were constantly brought down by the rains, and this the vegetation changed into organic forms and restored to the soil again. Thus, through long ages, the work of preparing the soil went on, and where the hand of man has not interfered, is still going on.

§ 2. *Composition and Classification of Soils.*

146. Soils are composed of three principal constituents—sand, clay, and humus.

Sand is rock reduced to a powder. The composition of each grain is that of the original rock.

Clay is the product of the chemical decomposition of rock. When perfectly pure it is a silicate of alumina. It is seldom a pure silicate, however, usually containing potash, soda, magnesia, iron, and other substances.

Humus is partially decayed organic matter. When organic matter reaches a certain stage of decay, it forms a dark colored mass, and decomposition proceeds but slowly. This dark mass is humus.

147. According to the proportion of these three ingredients, soils are known as sandy, loamy, clayey and peats.

Mixtures of sand and clay are usually classified thus:

Name of Soil.	Per cent of Sand.	Per cent of Clay.
Sand	100	—
Sandy loam	75	25
Loam	50	50
Clay loam	25	75
Clay	—	100

Soils that do not exactly agree with any of these, are classed with the one to which they approach most closely. Thus, a soil containing 60 per cent sand and 40 per cent clay, or 60 per cent clay and 40 per cent sand, is called a loam; while one containing 35 per cent clay and 65 per cent sand is called a sandy loam, and one containing 35 per cent sand and 65 per cent clay, is called a clay loam.

In swamps where a rank growth of vegetable matter is produced every year, and decay is checked by excess of water, humus accumulates in great quantity, so that the soil consists almost entirely of partially decayed vegetable matter. Such soils are called peats or swamp muck.

§ 3. *Properties of Soils.*

The characteristics of soils vary according to their chemical composition and their mechanical condition.

148. Retention of Water.—If a portion of soil is soaked with water and then allowed to drain until no more will flow from it, a considerable amount of capillary water (97) will remain. Soils differ, not only in the amount of water they can retain within their pores, but also in the readiness with which they part with this water by evaporation. In the following table the first column of figures gives the number of pounds of water retained by 100 lbs. dry soil, and the second column the percentage of this water lost by evaporation in a given time, the soils being all spread out and treated alike:

Kind of soil.	Water retained	Per cent lost by evaporation.
Quartz sand	25	88.4
Clay loam	40	52
Heavy clay	61	34.9
Loam	51	45.7
Garden mould	89	24.3
Humus	181	25.5

It will be seen that while pure sand retained only one-fourth of its weight of water, and lost nearly all of that by evaporation, in the short time (four hours) used in the experiment, humus retained nearly double its weight, and lost but one-fourth of this by evaporation in the same time. The retentive power of the garden mould was due to the large amount of humus it contained.

In general, it may be said that the larger the proportion of sand in a soil, the less power it has to retain water, and the more readily it will part by evaporation with what it contains; and the larger the proportion of humus in the soil, the more water it will be able to retain and the more slowly will it part with it by evaporation.

The coarseness or fineness of the particles of a soil has a great influence on its power to retain water. The finer the particles, the more water it can retain. A very fine sand is greatly superior to a very coarse sand.

149. Absorption of Water from Air.—Soils possess to a greater or less degree the power of absorbing moisture from the air. In this, as in the retention of water, soils differ greatly. The following table shows the number of pounds of water absorbed by 1,000 lbs.

of perfectly dry soil exposed to moist air for 24 hours, the result of one experiment:

Quartz sand	0	Clay loam	28
Heavy clay	41	Loam	35
Garden mould	52	Humus	120

Sand, especially coarse sand, has little power of absorbing moisture from the air. Clay has more power, and humus most of all.

The amount of water absorbed from the air depends on the temperature; the higher the temperature the less the absorption. The rapidity with which the absorption takes place depends on the amount of moisture in the atmosphere. A given soil at a given temperature will absorb the same amount of water from the air, whether it contain a larger or smaller amount of moisture, but a longer time will be required in proportion to the dryness of the air.

As a result of this property, soils—especially those rich in humus—that may become comparatively dry during a hot day, will absorb a considerable amount of water during the night.

150. Capillary Attraction.—When a lamp-wick, or any other porous substance, is dipped into a liquid, the liquid will ascend through the pores of the substance, and the force that causes it to ascend is called capillary attraction. The law governing the operations of this force is that the smaller the pores of the substance, the greater hight the liquid will be raised. Soil being a porous substance, possesses the property of capillarity, to a greater or less degree, according to the number and fineness of the pores. In a soil composed largely of coarse sand, the pores are large and few, and the upper part of the soil may be quite dry while there may be abundance of water but a short distance below the surface. A soil composed of fine particles contains a large number of small pores, and can draw water from considerable depths. Humus possesses this property in the highest degree; coarse sand in the lowest. Soils composed of a mixture of fine sand, clay and humus, often possess it in a very high degree.

151. **Retention of Fertilizing Elements.**—If the dark colored, offensive liquor from a manure heap is allowed to filter through a portion of good soil, the offensive and coloring matter will be retained by the soil, and the water that passes through will be free from color and odor. All soils possess this property to some degree, but certain soils possess it to a much greater degree than others.

The effect is partly mechanical. The matters in solution adhere to the surface of the particles of the soil, and are thus retained. The more porous the soil, and the greater amount of surface is thus exposed to the liquid, the greater its power in this way.

The effect is also partly chemical. Phosphoric acid, when in solution, unites with lime, alumina, and ferric oxide, forming insoluble compounds. Ammonia and potash enter into combination with the silica and alumina of clay soils, forming what are called double silicates. Calcic carbonate in some cases enables a soil to retain potash and ammonia. Humus has this retentive power in a great degree, acting both chemically and mechanically.

In general, sandy soils have the least power of retaining fertilizing elements, and the coarser the sand the less its power. Clay and humus have this power to a great degree. The power of clay is increased when it contains ferric oxide, the presence of which can be recognized by the red color it imparts to the soil.

152. Temperature of the Soil.—The warmth of the soil is derived from the rays of the sun, and is influenced by the character and color of the soil and the amount of water it contains.

Other things being equal, a dark soil absorbs warmth from the sun more rapidly than one of a lighter color (46).

Sandy soil acquires heat more rapidly than a clay, as it is a better conductor (42), and the heat received from the sun is carried down into the soil. Such a soil, therefore, gains warmth more rapidly in the spring, and is also more likely to "burn out" during a hot season.

A dry soil acquires heat more rapidly than a wet one, for the double reason that the specific heat (39) of water is much greater than that of soil, and that so large a portion of the heat received by a wet soil is expended in evaporating the water (34). It requires more than twenty times as much heat to raise the temperature of a wet soil to a point at which seed will germinate as would be required by a dry one. A well drained sandy loam, containing sufficient humus to make it dark in color, is best adapted to secure favorable results in temperature.

153. Absorption of Ammonia.—The soil possesses the property of absorbing and condensing gases within its pores, and when exposed to the air under favorable conditions will absorb ammonia. If substances are present in the soil with which this ammonia can combine, the soil can then take up a further portion from the air. If the soil contains nothing to fix the ammonia, it is liable to be again given off in the air and lost. Clay and humus possess to a greater degree than any other substance the property of absorbing and retaining ammonia. A moist soil absorbs more than one that is entirely dry. The rate of absorption depends on the amount of surface exposed to the air.

154. Adhesiveness of Soils.—The common terms "light" and "heavy" as applied to soil, have reference to its adhesiveness, or "stickiness," and not to its actual weight. A cubic foot of pure sand weighs about 35 lbs. more than a cubic foot of clay, yet a sandy soil is called "light," and a clay soil "heavy." Clay is the most adhesive of all soils, and consequently the most difficult to work. The addition of sand reduces its adhesiveness. Humus has the same effect.

155. Weight of Soil.—The following table gives the weight of the dry soil on an acre taken to the depth of one foot:

Sand	4,792,000 lbs.
Loam	4,182,000 lbs.
Common plow land	3,485,000 lbs.
Heavy clay	3,267,000 lbs.
Garden mould	3,049,000 lbs.

Sand is the heaviest and humus the lightest constituent of soils, consequently those rich in humus, such as old pastures and rich black lands, weigh less to the acre than sandy or loamy soils.

156. Wastes by Drainage.—The water that falls upon the soil and filters through it dissolves a portion of the soluble constituents, and analysis of drainage water shows that it contains nearly every element of fertility contained by the soil through which it has passed, with the exception of phosphoric acid. The amount of most substances removed by drainage is not, however, sufficient to be of practical importance.

Most of the important soil constituents are retained in the manner already explained (151). Nitric acid is the important exception to this rule. Nearly all its salts being soluble it is freely carried away by the drainage water. The Nile pours 1,100 tons of saltpeter into the sea every 24 hours, the result of the drainage of the soil.

About the only means by which the waste of nitrates by drainage can be prevented, is to keep the soil covered with a crop during the season when nitric acid is formed in the soil. The roots of the growing crops take up the nitrates as they are formed, and convert them into insoluble organic compounds.

As will be seen (163), the nitrates are produced most rapidly during the warmer months. Cereal crops, wheat, etc.,—leave the soil bare much of this time, and hence are exhaustive because they allow a waste of fertility. When clover is sown with wheat it remains after the latter has been cut, favors nitrification and saves the nitrates that are produced, by changing them into organic forms.

§ 4. *Chemical Characteristics of Soils.*

157. No two soils have exactly the same composition chemically, and it would be difficult even to get two samples of soil from different parts of the same field that would be exactly alike. All chemical analyses of soils are therefore approximate, only.

The value of chemical analysis in determining the present fertility of a soil is but small. A soil may contain, as shown by analysis, an abundance of every element of plant food, and yet be unproductive, owing to the plant food being in insoluble combinations. A soil, however, that shows by analysis a large proportion of plant food, is usually one that can be made productive by proper treatment. The following analysis is of an excellent wheat soil:

Silica	71.552
Alumina	6.935
Ferric oxide	5.173
Lime	1.229
Magnesia	1.082
Potash	0.354
Soda	0.433
Sulphuric acid	0.044
Phosphoric acid	0.430
Organic matter	10.198
Water	2.684

158. Plant Food.—The greater part of even the most fertile soils is of no value as plant food. Silica, though often found in plants, is not essential to their growth, and alumina does not enter the plant. Of the organic matter in the soil, only a small per cent is of value as plant food. It is necessary that a soil should contain all the elements found in the plant, except carbon, hydrogen and oxygen; but as some of these elements are used by the plant in such minute quantity and are so universally present in the soil, they may in practice be disregarded. The substances usually considered as plant food are:

Nitrogen	Potash
Phosphoric acid	Lime*
Sulphuric acid*	

An acre of the soil, the analysis of which has just been given, would weigh, taken to the depth of one foot, about 3,500,000 lbs., and would contain of these substances:

Nitrogen (probably)	8,000 lbs.
Phosphoric acid	15,050 lbs.
Sulphuric acid	1,540 lbs.
Potash	12,390 lbs.
Lime	43,015 lbs.

*Lime and sulphuric acid are usually present in sufficient

Few soils are as rich in phosphoric acid as the one above given, and many are much richer in sulphuric acid.

159. Exhaustion of Soils.—When crops are continuously grown and carried away, nothing being returned to the soil, the amount of plant food undergoes a steady diminution. A crop of 30 bushels of wheat and the straw will take from the land, of

Nitrogen	45 lbs.
Phosphoric acid	22.7 lbs.
Sulphuric acid	19.5 lbs.
Potash	27.9 lbs.
Lime	10.2 lbs.

If a crop of 30 bushels of wheat to the acre were grown every year, and both grain and straw carried away, nothing being restored to the land, it would exhaust the soil, the analysis of which has just been given, of these constituents as follows:

Of nitrogen in	177 years.
Of phosphoric acid in	766 years.
Of sulphuric acid in	80 years.
Of potash in	444 years.
Of lime in	4,217 years.

Practically it would be impossible to exhaust the soil of these substances, as, before it was exhausted, crops would cease to grow.

160. Rotation.—The exhaustion of the soil by a rotation of crops, especially where a large portion of the crop is fed on the farm, is much slower. Take, for illustration, a farm of eighty acres. Suppose that the crops grown are Indian corn, wheat, clover and grass; that such a rotation is adopted that twenty acres are each year devoted to each crop. Suppose nothing

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quantity, and are therfore frequently disregarded in estimating the quality and needs of soils.

is sold but wheat and animal products. We will estimate the annual average crops to be,

Wheat (400 bushels)	24,000 lbs.
Straw	48,000 lbs.
Clover hay	100,000 lbs.
Hay	80,000 lbs.
Corn (1,000 bushels)	56,000 lbs.
Corn fodder	168,000 lbs.

Calculating that in feeding the straw, hay, corn, and fodder, 10 per cent of the nitrogen, phosphoric acid and potash are taken by the animal, and 90 per cent returned in the manure, the loss of these constituents each year would be:

	Nitrogen.	Phosphoric Acid	Potash.
Wheat*	440 lbs.	191 lbs.	129 lbs.
Straw†	23 lbs.	12 lbs.	29 lbs.
Clover†	197 lbs.	56 lbs.	195 lbs.
Hay†	124 lbs.	30 lbs.	134 lbs.
Corn†	93 lbs.	34 lbs.	20 lbs.
Corn fodder†	80 lbs.	89 lbs.	161 lbs.
Total loss	957 lbs.	412 lbs.	668 lbs.

Dividing these amounts by 80—the number of acres —we get the loss per acre per annum on a farm so conducted:

Nitrogen	11.96 lbs.
Phosphoric acid	5.15 lbs.
Potash	8.35 lbs.

With this rotation, it would require, to exhaust the soil described in paragraph 158:

Of nitrogen	668 years.
Of phosphoric acid	2,922 years.
Of potash	1,484 years.

Under a proper rotation there need therefore be no apprehension of exhausting, or even of materially reducing, the amount of plant food in a fertile soil in any ordinary life time. In fact, except by allowing

*Amount contained in entire crop. † One-tenth amount contained in entire crop.

it to wash away, it would be impossible to exhaust the plant food in any fertile soil in a hundred years.

161. Condition of Plant Food in Soil.—The greater part of the plant food in the soil exists in forms of combination that cannot be used by the plant until they have undergone some chemical change. The same causes that prevent the exhaustion of the plant food by drainage, also prevent it from being immediately used by a crop. Nitrogen usually exists in insoluble organic compounds; phosphoric acid in insoluble phosphates of lime or iron; potash in combination with silica and alumina. A soil may contain enough of these constituents to produce 30 bushels of wheat per acre for five hundred years, and yet not contain enough of them in a form the plant can use to produce a single crop of 10 bushels to the acre. Some soils that are called "exhausted" or "run down" contain a great deal more plant food in an acre than others that are called extremely fertile. In the one case the plant food is available, in the other it is not. A large part of the science of farming consists in knowing how to render the plant food in the soil available, and how to secure it with a crop before it is wasted by drainage.

162. Chemical Changes in the Soil.—In order that the plant food in the soil may be rendered available, chemical action must be constantly maintained. The principal agents by which the chemical changes are effected, are the oxygen of the air, and the carbonic dioxide in the water of the soil.

By the action of the carbonic dioxide, the tricalcic phosphate is gradually changed into bicalcic phosphate, the nature of the change being similar to that described on page 49, carbonic dioxide taking the place of sulphuric acid. The same agency also changes the potash into a soluble form.

By the action of the oxygen of the air, the organic matter in the soil is changed into ammonia, water, and carbonic dioxide — and the ammonia is also oxydized producing nitric acid and water.

163. Nitrification.—By this is meant the conversion of the nitrogen contained in organic matters and ammonia into nitric acid. It is one of the most important chemical operations in the soil—as it is in the form of nitric acid—or its compounds with bases—that nitrogen becomes available for the use of a crop. The conditions necessary for nitrification are:

A porous soil.

The presence of the carbonates of potash, lime or soda in the soil.

Warmth.

Moisture.

Under these conditions and through the influence of a minute fungus plant called *bacterium*, the nitrogen of the organic compounds unites with the oxygen of the air, producing nitric acid, which as rapidly as formed combines with the lime, potash or soda present, forming nitrates.

Nitrification proceeds more rapidly the higher the temperature, and ceases altogether at the freezing point. When the soil contains an excess of water, nitrification ceases, and nitrates are sometimes decomposed with the escape of free nitrogen.

In order that nitrification may proceed rapidly and keep the growing crop supplied with available nitrogen, it is necessary that the soil be kept porous so that it presents a large amount of surface to the air, and that it be moist but not wet. These conditions are secured by drainage and cultivation. Mulching the ground favors nitrification by keeping the soil in a moist, porous condition. Part of the value of clover and other crops that shade and cover the ground is due to the fact that they thus provide the conditions favorable for nitrification.

§ 5. *Mechanical Conditions of Soils.*

164. Effects of Division.—A cube 1 inch each way, has 6 square inches surface. If it is divided once in each direction, and reduced to 8 cubes, each $\frac{1}{2}$ inch each way, these smaller cubes will have $1\frac{1}{2}$ square inches surface—or 12 square inches in all. By the division the total amount of surface has been doubled. If the division is continued until the original cube has been divided into a million cubes, the surface will be increased six hundred times. Thus the smaller the particles of the soil, the greater the amount of surface will be exposed to the air which penetrates it, to the water, and to the roots of plants.

The retention of water and of fertilizing material is due largely to adhesion to the surface of the particles of the soil; hence the smaller these particles the greater the amount of this retention. The absorption of moisture and ammonia from the air is in proportion to the surface exposed. The chemical action of air upon the soil is in proportion to the amount of surface exposed. The smaller the particles of soil the smaller and more numerous will be the pores, and hence the greater will be its capillarity.

For all these reasons, the fertility of the soil depends greatly on the fineness of its particles, and soil that in its ordinary condition is almost sterile is sometimes rendered quite productive by thorough pulverization.

165. Some soils, especially heavy clays, are so compact that the air cannot penetrate them, and the roots of plants find difficulty in doing so. Such soils "bake" into compact masses, and in that condition they are of little value. It is necessary to mix sand or humus with such soils to make them sufficiently open and porous to admit the air, and to separate their particles so as to prevent "baking."

166. Drainage.—Soil may contain water in three conditions: hygroscopic, capillary, and hydrostatic (97). When it contains hydrostatic water the particles of the soil are wet, and the pores between them are filled with water. The water prevents the air from penetrating the soil, and renders it unfit for the growth of agricultural plants,* and the chemical changes necessary to make the plant food in the soil available can not take place.

167. When soil containing hydrostatic water dries, it shrinks and hardens into compact masses. The shrinkage causes the soil to crack, often breaking the roots of plants. This is particularly the case with clay soils. The compact masses thus formed offer great resistance to the roots of plants, and as they can not readily be penetrated by the air, but little moisture can be absorbed from it. The cracks caused by the shrinkage are too large to favor capillary attraction, and moisture is not drawn up from below.

Water falling on soil in such a condition is absorbed slowly, and much of it may flow off, leaving the

*The term "agricultural plants" is used to describe those which are cultivated by the farmer. There are some others which grow under very different circumstances and obtain their food in a different manner, such as aquatics, (plants which grow in water), parasites, (those which grow on others), and fungi.

ground at the depth of a few inches unmoistened. Therefore an undrained soil, particularly if it be a heavy clay, suffers greatly in a drought.

168. When, by means of ditches or underdrains, the hydrostatic water is removed, the soil remains moist, as the capillary water cannot thus be removed. The roots of plants find sufficient moisture in the particles of the soil, and as the pores are filled with air, this supplies the oxygen necessary for their growth and health.

When a well drained soil becomes dry, it does not harden into compact masses, nor shrink and crack, but remains in a loose and porous condition. During the night the temperature of the soil is reduced by radiation, (44), and moisture is condensed from the air. If the soil is compact and impervious to air, this moisture will be condensed upon the surface only; but if by drainage it has been left porous, the moisture will also be condensed within its pores, often to a considerable depth. Drainage also favors capillary attraction in the soil, thus enabling it to draw water from below. A light rain falling on such a soil is immediately absorbed. For these reasons drainage enables the soil to withstand drought.

A loose, porous soil presents to the air many times as much surface as a hard and compact one, thus securing a larger absorption of ammonia, and providing conditions favorable for nitrification (163). In this way drainage increases the fertility of the soil.

In some parts of Minnesota the soil consists of a deep sandy loam, containing a large amount of humus. The sand is exceedingly fine. This soil seems of almost inexhaustible fertility. It is moist a few inches beneath the surface during the dryest weather, and can be worked immediately after the heaviest rain.

§ 6. *Value of Sand, Clay and Humus.*

169. Sand.—The value of sand in the soil depends on the kind of rock from which it has been reduced, and the size of its particles. White quartz sand contains no plant food, and soils containing it in large quantity are not usually fertile.

To determine the character of the sand, mix a portion of the soil with a large amount of water. After allowing time for the sand to settle, pour off the water, which will contain most of the clay and humus. By repeatedly washing the sand which remains, it may be obtained pure. If it is white, "sharp" and coarse, it is of little value in the soil. Sand from granite or limestone contains a considerable amount of plant food, which, under the influence of air and cultivation, will be slowly given up in available form for the plant. If the portion of soil used in the experiment is first dried and weighed, and the sand that remains also dried and weighed, the proportion of sand in the soil will be known.

The mechanical uses of sand in the soil are to make it loose and porous, facilitate drainage and prevent "baking." Sand alone does not absorb moisture or ammonia from the atmosphere, nor has it the power of retaining plant food. Manures applied to sand have little effect beyond the immediate crop. Sand becomes warm early in the spring, and soils containing it in excess are liable to "burn out" in hot weather. When mixed with a due proportion of clay and humus, the advantages of sand are secured without its disadvantages. The finer the sand the more value it is in the soil.

170. Clay.—Pure silicate of alumina (146), supplies no food to the plant, but clay in the soil usually contains potash, magnesia, lime, and other substances of value. Red clays contain ferric oxide, valuable not only as plant food, but also because it promotes nitrification and aids in retaining nitrates in the soil.

Clay possesses, in a high degree, the properties of absorbing ammonia from the air, and of retaining fertilizers. Lime, potash and ammonia combine with it, forming double silicates. Clay thus not only absorbs ammonia from the air, but retains it when absorbed (153). It has also in a considerable degree the power of retaining water, of absorbing moisture from the air, and of capillarity.

Clay soils are called "retentive." Manures applied to them waste but little, and often continue to produce marked effects for years.

The disadvantages of clay are its adhesiveness, making it a "heavy" soil to work, and its tendency to "bake." The addition of lime renders it less adhesive, the fine particles of calcic carbonate formed in the soil, separating the particles of clay. Burning clay entirely destroys its adhesiveness, and if the burnt clay is mixed with the soil, it has an effect similar to the addition of sand. This plan is sometimes resorted to in dealing with very "stubborn" clay lands.

171. Humus (146).—The proportion of humus in the soil varies from 2 or 3 per cent to as much as 97. To ascertain the per cent of humus, weigh a portion of the soil that has been thoroughly dried in an oven, and heat it to a dull redness, until all the organic matter is consumed. Weigh what remains, and the loss in weight will show the amount of humus.

Humus contains carbon, hydrogen and oxygen, but the plant does not obtain these from this source. It also contains nitrogen in organic combination, which cannot be directly used by the plant, but which is gradually converted into ammonia and nitric acid by the action of the air. The amount of nitrogen contained in a soil is usually in proportion to the amount of humus it contains. Humus also contains some phosphoric acid, potash, and other mineral elements of plant food.

Humus has other value in the soil besides supplying plant food. Its dark color makes the soil warmer. It has great power of retaining water and of absorbing moisture and ammonia from the air. Being very porous it possesses capillarity in a greater degree than any other soil constituent. The decomposition of humus in the soil produces carbonic dioxide which, being dissolved in the water of the soil, assists in the decomposition and solution of mineral matters.

Humus overcomes the adhesiveness of clay soils, and remedies the deficiencies of sand.

The addition of lime to humus hastens its decomposition by favoring the conversion of the nitrogen it contains into nitric acid.

§ 7. *Practical Application.*

172. The soil best adapted for most agricultural purposes is composed of fine sand, clay and humus. No one of these ingredients should be in great excess.

173. Correcting Defects in Soil.—Soils may be good in many respects and contain an abundance of most of the elements of plant food, and yet from deficiency of some one constituent, or defective mechanical condition, be unproductive. Such soils may often be rendered valuable at moderate expense by proper treatment, which can be determined by a consideration of their character and of the principles already given.

174. A soil may contain an excess of humus and yet be unproductive. The plan to pursue is to secure the decomposition of the humus, and the conversion of the plant food it contains into available forms. This can be accomplished by drainage and thorough cultivation, by which the soil is exposed to the air, and by the addition of lime. Soils of this kind are sometimes "sour" owing to the presence of organic acids produced by the slow decomposition of humus, and which are injurious to plants. Lime combines with these acids forming harmless compounds. The addition of phosphates or potash may sometimes be beneficial.* When phosphates are needed, rock phosphate—which contains no nitrogen—would be suitable, as the soil already contains an abundance of nitrogen which only needs to be rendered available. Green manuring on such a soil would be injurious rather than beneficial.

175. A sandy "leachy" soil may be improved by growing a succession of green crops, rye, buckwheat, sowed corn, clover, etc., and plowing them under. The humus thus furnished will supply those characteristics of the soil lacking in the sand. Nitrogenous manures may be used with profit, but they should be applied on the surface and at the season when the plant can make immediate use of them. After a suf-

*Whether phosphate and potash are needed can only be determined by experiment. Four portions of the field should be marked off. To one portion phosphate should be applied, to another potash, to the third both, and the fourth should receive no manure. The cultivation, drainage and liming of the four portions should be the same, and the results carefully noted.

ficient amount of humus has accumulated in the soil, the crops may be fed off and the manure produced returned.

176. A "retentive" clay is often a difficult soil to deal with, but can usually be rendered valuable by proper treatment, and as it has great capacity for retaining manures, those which are applied and not immediately used by the crop will accumulate in the soil. The first treatment indicated is thorough drainage—which will make the next step—thorough cultivation, possible. The adhesiveness may be overcome by the use of lime, by plowing under long barn-yard manure, and by green manuring. Nitrogenous manures, such as bone phosphates and guano can be used with advantage—but should not be applied at the same time with the lime, or a waste of nitrogen may be occasioned. After the condition of the clay has been sufficiently improved, the plowing under of green crops may be discontinued.

177. Thus by drainage, cultivation, green manuring and the use of lime, the farmer can to a great extent remedy natural deficiencies in the soil. Of the three great soil constituents, humus is the only one over which control can be exercised. By the use of lime and cultivation it can be reduced in quantity when in excess; and by plowing under green crops it can be increased when needed.

CHAPTER VII.

SCIENCE IN PLANT GROWTH.

§ 1. *Composition of Plants.*

178. Water.—The largest constituent of all living plants is water. The following table gives the average percentage of water in various fresh plants:

Meadow grass	72
Red clover	79
Corn fodder	81
Cabbage	90
Potatos (tubers)	75
Beets	82
Turnips	91
Pumpkins	94.5

The per cent of water is not always the same. It is greater in plants grown in a wet season than in those grown in a dry one. The ranker the growth of plants the more water they contain, hence the increased weight of crop caused by heavy manuring is often chiefly water. In some cases the amount of dry matter contained in a crop grown on a manured soil may be less than that in a crop produced without manure. The following table gives the weight (fresh and dried) of two crops of clover grown on an acre of ground each, one with, and one without manure.

	Fresh Clover.	Clover Hay.
Manured acre	22,256 lbs.	4,800 lbs.
Unmanured acre	18,815 lbs.	5,190 lbs.

It will be seen that while the crop on the manured acre was ranker and weighed more when fresh than that on the unmanured acre, it contained so much more water that the amount of hay was less.

179. Even dried plants and the seeds and grains contain a considerable amount of hygroscopic water (97). The following table gives the per cent of water contained in various plants and grains that are usually considered dry:

Meadow hay	15
Clover hay	17
Straw	15
Wheat (grain)	14
Indian corn (grain)	12
Wheat bran	14

The amount of hygroscopic water varies a little with the temperature and the condition of the atmosphere.

The term "dry substance" is used to describe all the plant except the water. Thus, fresh meadow grass contains about 28 per cent dry substance; meadow hay 85 per cent; Indian corn 88 per cent, and so on. That is, 100 lbs. meadow grass if dried at a temperature of 212, so as to drive off all the water would weigh 15 lbs.; 100 lbs. Indian corn would weigh after being dried in this manner 88 lbs. As the quantity of water in different plants varies so greatly it is often necessary in making comparisons to consider only the dry substance each contains.

180. **Ash.**—When a plant is burned, part passes off in gas and vapor, but a part remains unconsumed. This is called the ash, and the amount of it varies in different plants, and in the same plants grown under different circumstances. Plants grown on a soil rich in available ash constituents will contain more ash than the same plants grown on soil in which these substances are deficient. The following table gives the percentage of ash in the dry substance of various plants:

Wheat (grain)	2
Oats (grain)	3.3
Indian corn (grain)	1.5
Timothy	7.1
Red clover	6.7
Turnip (roots)	12

That is, if turnips were thoroughly dried at the temperature of 212, and 100 lbs. of this dried turnip burned, 12 lbs., of ash would be left. The following table gives the number of pounds of ash in a ton of various vegetable substances in their natural condition:

Name of Substance.	Ash in One Ton.
Oats (grain)	70 lbs.
Wheat (grain)	34 lbs.
Indian corn (grain)	32 lbs,
Wheat bran	122 lbs.
Clover Hay	106 lbs.
Meadow hay	124 lbs.
Wheat straw	92 lbs.
Meadow grass	40 lbs.
Green clover	30 lbs.
Potatos	20 lbs.
Turnip	14 lbs.

The ash of plants consists principally of lime, potash, phosphoric acid, sulphuric acid, soda, magnesia and iron. Chlorine is occasionally present, and silica quite frequently (158). Minute portions of other substances are frequently found, but do not seem essential to the plant.

181. Other Substances.—The remainder of the plant is composed of cellulose (119) and other carbohydrates (117), lignose (119), albuminoids (126), pectose substances (123), amides (128), vegetable acids (124), fats (125) and alkaloids (129).

§ 2. *Germination.*

182. A Seed is composed of two parts—the embryo and the endosperm. The embryo, commonly called the "chit," is the undeveloped plant. The endosperm forms the bulk of the seed, and is the provision made by Nature for the nourishment of the young plant.

183. Chemistry of Germination.—When a seed is subjected to favorable conditions of moisture, air and temperature, water and oxygen are absorbed, and certain chemical changes occur. The starch in the endosperm is converted into glucose and other soluble substances; fats, by combination with the elements of water, are changed into soluble carbohydrates; and albuminoids also become soluble. The nutriment in the seed is thus prepared for the use of the plant.

Two stems are now thrown out from the embryo; one, called the radical, turns downward into the soil, the other, called the plumule, turns upward and seeks the light. The substances in the endosperm that have been rendered soluble, are dissolved by the water absorbed, and carried through the growing plant, and in the proper places changed into cellulose and other insoluble substances.

This process continues, the young plant being supported by the nutriment stored in the seed, until that is exhausted, as it has no power to obtain any other food until the leaves are formed and exposed to the light. If the nutriment in the parent seed is exhausted before the leaves reach the light, the young plant dies of starvation.

184. Necessities of Germination.—These are oxygen, water and a proper temperature. The soil performs no part in the work except to furnish the proper conditions. Oxygen and water are both needed to effect the chemical changes by which the substances in the seed are rendered soluble, and water is necessary to dissolve them and convey them to the different parts of the growing plant.

Numerous experiments have been made to determine the lowest and highest temperatures at which germination is possible, and that at which it proceeds most rapidly. The following table gives the results with certain seeds:

	Lowest Temperature.	Highest Temperature.	Most Rapid Germination.
Wheat and Barley	41 deg.	104 deg.	84 deg.
Peas.............	44.5 "	102 "	84 "
Indian corn......	48 "	115 "	93 "
Squash	54 "	115 "	93 "

Some other seeds will germinate at much lower temperatures. It is said that rye will germinate at any temperature above the freezing point.

§ 3. *How the Plant Grows.*

185. Plant Food.—The plant has no power to create any substance. It can therefore only grow by collecting certain elements from the soil and air and forming out of these the various organic compounds. The elements used by the plant are carbon, hydrogen, oxygen, nitrogen, phosphorus, sulphur, calcium, potassium, magnesium and iron. Without these ten, no agricultural plant can be formed, and deficiency in one cannot be made up by an over-supply of another. After germination, the plant obtains its food by means of its roots and leaves.

186. The Roots gather from the soil all those substances which form the ash of the plant, and also nitrogen, usually in the form of a nitrate. These substances are taken up in solution. The roots have power, however, to attack some substances that are not ordinarily soluble. This is due to the acid sap which they contain, and which dissolves some substances when they are in direct contact with the roots. It is in this manner that plants obtain phosphoric acid —a substance that rarely exists in the soil in a soluble condition. The roots also obtain from the soil the water necessary for the growth of the plant. Soluble substances in the soil not essential to the plant, are often taken up by the roots. These are usually deposited in the older tissues, or as a crust upon the stem of the plant, and often serve a useful purpose by hardening the tissues and protecting them from injury. Carbonic dioxide is also taken up by the roots, but the amount is so small that the fact is of scientific interest, only.

187. The Leaves absorb carbonic dioxide from the air. This is taken up by the minute pores of the leaves. These pores are called stomata, and are very numerous. An ordinary apple leaf has about 100,000 to the square inch. The carbonic dioxide is decomposed in the leaf, the oxygen being given off and the carbon uniting with the elements of water to form carbohydrates. The decomposition of the carbonic dioxide in the leaf is performed in what are called the chlorophyl cells. These cells contain a green liquid called chlorophyl, and to which the green color of the plant is due.* All green portions of the plant have

*Plants which have no green color cannot obtain carbon from the air. These are chiefly parasites—which obtain their the power of decomposing carbonic dioxide, but the work is principally performed by the leaves.

The plant obtains the power by which this decomposition of carbonic dioxide is accomplished, from the sunlight. The process ceases entirely in the darkness.

All green plants are thus during the day-time constantly taking carbonic dioxide from the air and returning oxygen.

Albuminoids and amides are formed from the soluble carbohydrates in connection with nitrogen and sulphur obtained from nitrates and sulphates in the sap. Fats are produced by the removal of a part of the oxygen and hydrogen of carbohydrates, and vegetable acids by their oxidation.

The leaves absorb from the air a very small amount of ammonia, which is used by the plant in the formation of albuminoids and amides.

188. The soluble carbohydrates and other substances when formed are carried in the sap to every portion of the plant, and its tissues are built up by the conversion of these soluble substances into cellulose, lignose, and other insoluble forms. Thus every part of the plant, including the roots, is built from the carbon obtained by the leaves.

189. The plant has the power of rendering soluble substances that have been deposited in one part, conveying them to another, and changing them into new forms. If a tree is stript of its leaves, it can no longer obtain carbon from the air, but carbohydrates already deposited in other parts of the tree will be taken up by the sap and used for the production of new leaves. If these are removed as rapidly as they are produced,

carbon from the juices of the plants they live upon — or fungi, which obtain it from decaying organic matter.

the tree will continue putting forth leaves until the available supply of material is exhausted, when it dies.

During the fall the carbohydrates, albuminoids, phosphoric acid and potash contained in the leaves are largely re-absorbed and deposited in the trunk. With the coming of warm weather the sap begins to circulate, these substances are converted into soluble forms and used for the production of new leaves. The sugar in maple sap is produced from the starch stored up the previous fall.

190. Respiration.—The plant is continually absorbing oxygen through the bark and leaves. This combines with carbon in the plant forming carbonic dioxide, which is thrown off. This process continues both in daylight and darkness, and so closely resembles the respiration of animals that it has been given that name.

During the daytime the amount of carbonic dioxide absorbed is many times greater than that given off, and consequently the process of respiration is not noticeable, but in darkness when the absorption of carbonic dioxide ceases, the effect of respiration becomes perceptible. Hence it is sometimes said that plants absorb carbonic dioxide during the day, and give it off during the night. The statement is not scientifically correct as respiration continues at all times, but its effects are hidden, in daylight, by the larger amount of carbonic dioxide absorbed, and of oxygen given off.*

*From the fact that plants give off carbonic dioxide in the night, the theory has been advanced that they are injurious in bed-rooms. The amount of this gas given off is so minute that it could have no appreciable effect on the air of any ordinary

§ 4. *Formation of Seed.*

191. The Seed.—As we have seen (182), the seed contains nutritive matter in the most concentrated form, it being Nature's provision for the nourishment of the young plant until the time when it shall be able to collect food for itself. We therefore find in the seed every element needed for the life and growth of the plant. The composition of seed is more uniform than that of any other portion of the plant, and they never contain any of the unessential ash constituents sometimes taken up by the roots.

192. Annuals.—These are plants which germinate, attain maturity, and produce their seed within a single season of growth. During the early part of the life of an annual, its energies are entirely devoted to the formation and development of the organs of nutrition, the leaves and roots. When the flower is put forth this process is checked, and as the formation of the seed progresses, less and less food is gathered from the soil and air, and the energies of the plant are devoted to gathering up the nutritive matter already formed within its tissues, changing them into more concentrated forms and depositing them in the seed. The final work of storing food in the seed is done after the plant has entirely ceased to collect food from without.

Thus as seed formation in an annual progresses, the whole plant undergoes exhaustion, and, if the season is favorable, this exhaustion is very great. Consequently the straw of a crop is more valuable in a season unfavorable for the maturing of the grain.

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room. A growing plant absorbs during daylight a great deal more carbonic dioxide than it gives off in 24 hours.

The extent to which this exhaustion of the plant is carried is shown in the following tables giving the percentage of soluble carbohydrates,* albuminoids, and crude fibre† in the dry substance of various plants, before and after the formation of seed:

RED CLOVER.

	Cut in Bloom.	Cut When Ripe.
Soluble carbohydrates	36.0	24.4
Albuminoids	16.0	11.3
Crude fibre	43.0	57.6

RYE FODDER.

	Cut in Bloom.	Ripe Straw.
Soluble carbohydrates	55.0	31.5
Albuminoids	12.2	1.8
Crude fibre	26.9	63.0

INDIAN CORN FODDER.

	Cut in August.	Cut after Grain has ripened.
Soluble carbohydrates	61.2	45.3
Albuminoids	6.2	3.5
Crude fibre	26.4	46.5

The decrease in proportion of the nutritive substances—especially albuminoids, is very noticeable in each case.

It must be remembered that these tables give the percentage composition of the dry substance only, the purpose being to illustrate the exhaustion of the plant in the formation of seed. They cannot be used to compare the value of a ton of green rye fodder with a ton of rye straw, on account of the different amount of water. This part of the subject will be considered elswhere.

193. Biennials.—These are plants which grow

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*The term "soluble carbohydrates" is frequently used in analyses of foods to represent not only the true carbohydrates, but also the pectose substances (228).

†Crude fibre consists of cellulose and lignose in such forms that they cannot readily be dissolved.

through one season, producing only leaves and roots, and the next season throw up a flower stalk and produce seed. Beets and cabbages are biennials. In these plants the first year's growth is devoted to collecting nutritive matters from the soil and air and storing them, either in a fleshy root, as in the beet, parsnip and carrot, or in a leafy head, as in the cabbage. In the second season the flower stalk is thrown up and seed produced from the material that had been stored up during the first season.*

194. The tuber of the potato and the bulb of the onion are similar storehouses of food. Men and animals take advantage of these characteristics of vegetable life, and find much of the best and most concentrated food in the seeds of annuals, and the roots of biennials—gathered at the close of the first season—or if they use the whole plant do so before the production of seed begins.

§ 5. *Summary and Practical Application.*

195. Germination.—The necessities of germination are water, air, and a suitable temperature. When the pores of the soil are filled with water, germination is greatly retarded, as the water excludes the air. Too deep planting retards germination for the same reason. As moisture is essential, it is necessary that the soil should be well pulverized, otherwise the seed may fall into cavities between the lumps of soil and be unable to obtain sufficient moisture; or if dampness of the weather at the time of sowing the seed enables it to germinate, a few dry days following may

*A plant cannot take up by its roots and use organic matter in the soil, but it can take organic matter from one part of its own structure and use it for building up some other portion.

cause the young plant to perish before its roots can penetrate the soil far enough to obtain a supply of moisture. As warmth is necessary, seed sown before the ground has become sufficiently warm is liable to rot instead of germinating. Indian corn, especially, requires a considerable degree of warmth, and a "bad stand" is often the result of planting in cold ground.

As the parent seed is the only source from which the young plant can draw nourishment until its leaves reach the light, when seeds are too deeply planted, the young plant may exhaust this nutriment and die from starvation before its leaves reach the light. Hence, also, if the leaves are torn from a young plant just as germination is completed, it dies, being deprived of means of obtaining food from soil and air, and having no source of supply within itself. If the plant is allowed to grow for a time after germination, a supply of material is laid up within its own tissues which can be used for the production of new leaves. A practical knowledge among farmers of the working of this principle has given rise to the expression that "the best time to kill weeds is before they come up," by which is meant just as the process of germination is completed.

196. Plant Food.—As the plant cannot use the nitrogen contained in organic matter in the soil until it has been oxydized into nitric acid, it is necessary to expose the soil thoroughly to the action of the air, in order to secure a sufficiency of available plant food. The nitrogen in urea being available for the use of the plant without first being oxydized, urine acts very rapidly as a fertilizer. As, when one element of plant food is deficient, the plant is incapable of using other food, however abundant it may be, it is necessary to see that all the elements of plant food needed are contained in the soil and in an available condition. As the carbon in the plant is obtained wholly from the air, carbonaceous matters in manures are without value as plant food.

197. The Growing Plant.—As the whole plant, including the roots, is built up from carbon obtained by the leaves, no growth can be made after the leaves have been removed, and hence, if insects are allowed to continually destroy the leaves of trees, the trees themselves will ultimately die. Hence, also, if weeds are constantly cut down and not permitted to put forth leaves, the roots will ultimately perish. In order to kill a weed in this way, however, the leaves must be removed as rapidly as produced, for if they are allowed to remain even for a short time, they will lay up another store of surplus material.

CHAPTER VIII.

SCIENCE IN ANIMAL LIFE.

§ 1. *Composition of the Animal.*

198. General Composition.—Animal substances are composed of the same ten elements as vegetables (185) with cholorine and sodium in addition. These two last elements form in combination common table salt (106), and though not essential to plant life, are usually present in vegetable substances.

199. Organic Compounds.—These are principally Albumnoids Gelatinoids, Keratin (127) and fats. Carbohydrates do not exist in the animal body except in the form of partially consumed food.

200. Ash.—The ash consituents are principally found in the bones, of which about 55 per cent. is tricalcic phosphate. Iron and potash are also found in all parts of the system.

201. Water.—As in the plant, the larger part of the living animal is water. The following table shows the average composition of a half fat ox, weighing 1,000 lbs. exclusive of stomach and intestines:

Water	560
Nitrogenous matter	181
Fat	208
Ash	51
	1,000

202. Comparison with Vegetable Matter.—The animal contains less carbon, hydrogen, and oxygen than the plant and more nitrogen, phosphoric acid and lime. The following table shows the number of pounds of these contained in 1,000 lbs. of a fat ox, (exclusive of stomach and intestines) and in an equal weight of fresh clover in bloom:

	Fat Ox.	Fresh Clover.
Nitrogen	23.18	5.10
Phosphoric acid	16.52	1.40
Lime	19.20	4.80

§ 2. *Animal Nutrition.*

203. We have seen that the food of plants consists of gasses, mineral salts, and water, out of which it forms all of its various organic compounds. The power by which these transformations are accomplished is obtained from a source outside of the plant —the light of the sun.

The animal is unable to construct organic matter out of inorganic, nor can it obtain power for carrying on the functions of life, from any outward source. It must therefore find in its food, in forms that will require but little change, the materials it needs, for growth; and, also the source of animal heat and energy. The plant is therefore the machine by which inorganic matter is prepared for the use of the animal and the medium through which the energy derived from the light and heat of the sun is made available for the purposes of animal life.

204. Digestion.—The food of animals consists of carbohydrates, albuminoids, fat and mineral salts contained in the plant. These are fitted for animal nutrition by the process of digestion. Some of the carbohydrates, such as sugar require but little change.

Others, such as starch and cellulose must be converted into glucose. This change is begun by the action of the saliva, and is completed in the intestines. The albuminoids are rendered soluble by the action of the gastric juice secreted by the stomach, and also by the pancreatic juice. The digestion of fats is accomplished by the bile and pancreatic juice.

205. Assimilation.—After the food has been rendered soluble, or digested, it is absorbed by the minute blood vessels lining the intestines and by vessels called the lacteals, and carried by the blood to every part of the body. Each part takes from the blood the needed material for its own growth or repair, and changes it into substance like itself. This is called assimilation. Thus all parts of the body are nourished by the blood. How the tissues make the selection from the blood, of the particular materials they need, is not understood.

206. Waste of the Body.—The tissues of the body are continually undergoing oxidation and decay. The waste matter thus produced is taken up by the blood, and removed from the system through the excretory organs. This waste is repaired by the blood which serves both to bring the new material and remove that which is worn out.

207. Respiration.—By the action of the heart, the blood is forced through the lungs. Owing to the peculiar structure of these organs, it is here very thoroughly exposed to the air, and absorbs oxygen, which gives it a bright scarlet color. In the circulation of the blood the oxygen thus absorbed, combines with the carbon of the food, the process being similar to combustion (131). The carbonic dioxide formed by this process is given off by the lungs. When carbohydrates suffer oxidation in the blood the products are carbonic dioxide and water. When albuminoids or amides are oxidized the nitrogen is separated in the form of urea (CON_2H_4) a substance containing 46.67 per cent of nitrogen, and which is removed from the blood by the kidneys.

208. **Excretion** is the process by which waste or useless material is removed from the body. The principal organs of excretion are the lungs, kidneys and skin. Carbonic dioxide, water and small portions of waste organic matter are thrown of by the lungs, and skin. The kidney removes the urea produced by the oxidation of nitrogenous substances, and the mineral salts. The solid excrement is composed of the undigested portions of the food, with a small amount of bile, and secretions of the intestines.

§ 3. *Uses of Food in the Body.*

209. The principal uses of food are:

1. To furnish material which can be burned in the body for the production of heat and energy.
2. To supply material for growth.
3. To repair the waste of the body (206).
4. To produce fat.
5. The production of milk.

210. In the construction of fat, flesh, or milk, the animal must find in the food all the elements which the substances to be formed will contain. From a carbohydrate it can produce fat, because they contain the same elements, the difference being only in the proportions in which they are combined. It can also produce fat from an albuminoid, by the removal of the nitrogen, but it cannot produce an albuminoid from fat or a carbohydrate, as neither of these substances contains nitrogen, which is an essential element in the albuminoid.

Albuminoids are therefore capable of meeting all the requirements of the body, and can support life without any other food. Fats and carbohydrates can be used for the production of fat, and to furnish carbon for combustion in the blood.

The respective values of these different classes of foods will be considered in the next chapter.

211. Source of Animal Heat and Energy.—We have seen (37) that in the locomotive, energy that had been obtained from the sun by plants long ages ago, is set free, by the combustion in the fire-box, of the carbon of the coal, and that this energy is applied to useful work by the machinery of the engine. In the animal the energy derived from the sun by agricultural plants is set free by the combustion, in the blood, of the carbon of the food, and the muscles and organs of the body are the machinery by which this energy is applied to useful work. Part of it is expended in maintaining the heat of the body, part in carrying on the processes of respiration, digestion, circulation, etc., and part may be used by the animal in physical exercise or useful work. The combustion of a given amount of carbon from the food, will produce a given amount of energy and no more. If more of this energy is used for maintaining the heat of the body, less can be used in the performance of work, and if an increased amount of heat and work is needed, there must be an increased consumption of food.

§ 4. *Disposition Made of the Food.*

212. Heat and Energy.—By far the greater portion of the food consumed by the animal is used in the production of heat and energy. The heat of the body must be maintained, and even when the animal is at rest a large amount of energy is used in the processes of digestion, respiration, circulation, etc. In a fattening animal, the amount of food used in this manner is from three to ten times as great as the amount used in the production of increase. In animals that are not growing or laying on fat, the proportion of food used for the production of heat and energy is still greater. If the food contains a due proportion of carbohydrates and fat, these will be used for this purpose rather than the albuminoids.

213. Growth and Repair.—The albuminoids in the food are used for producing new tissues, and also for repairing the necessary waste. The amount required for this latter purpose is but small. An ox weighing 1,000 lbs. will require only five- or six-tenths of a pound of albuminoids per day to repair the waste of tissue. Albuminoids consumed in excess of the amount required for growth and waste, are either burned for production of heat and energy, or converted into fat. In either case the nitrogen is separated in the form of urea.

214. Production of Fat.—When more food is consumed and digested by the animal than is required for growth, the repair of waste, and production of heat and energy, the surplus will be converted into fat, and stored up to meet future demands of the system. The production of fat is in fact the one method by which the animal can dispose of food consumed in excess of immediate needs.

215. Milk.—When an animal is giving milk, a large amount of the food consumed is used in its production. Fats and carbohydrates are used in forming the fat and sugar, and albuminoids for the casein. A large amount of mineral salts are also used in milk production.

216. The mineral salts obtained in the food are largely used in the production of the bones. Those not used are removed by the kindeys.

217. Undigested Food.—The animal never digests all the food it consumes. The amount left undigested varies with the kind of food and the animal. It is seldom less than five, and sometimes as much as sixty per cent of the dry matter of the food consumed. This undigested food passes off in the solid excrement.

§ 5. *Effects of Insufficient Food.*

218. Insufficient Albuminoids.—When the albuminoids supplied to an animal in its food are but just sufficient to repair the waste of tissue, muscular growth will necessarily cease. If the amount of albuminoids in the food is insufficient to repair the waste, the animal will gradually shrink in weight, and finally die of starvation, even though abundantly supplied with non-nitrogenous food constituents. Instances are on record of children who have died from starvation while being fed on a purely farrinaceous (starchy) diet. Injury to children raised by hand, from insufficient albuminoids in their diet is more common than is usually known.

219. Insufficient Non--Nitrogenous Constituents. — When carbohydrates and fat in the food are insufficient to meet the demands for the production of heat and energy, the albuminoids will be burned for this purpose, even though growth is stopped and the wastes of the body go unrepaired. In this manner, deficiency of non-nitrogenous matter in the food may cause loss of muscular weight, although these substances are not capable of conversion into muscle. Owing to the same principle, an increase of non-nitrogenous matter in food may cause an increase of muscular development, provided the food already contains a due proportion of albuminoids. The increase in such a case is not due to the conversion of the non-nitrogenous substance into muscle, but to the fact that they supply carbon for the production of heat and energy, and thus prevent the albuminoids from being used for this purpose.

220. **Starvation.**—When the food is insufficient to meet the needs of the animal, not only is waste left unrepaired, but fat that had previously been deposited is re-absorbed into the blood and burned in place of food. If the deficiency of food continues, the muscular substances will also be attacked and absorbed. This process will continue until the animal can no longer obtain from its own tissues material to produce, by its combustion, sufficient heat and energy to maintain the vital processes, and the animal dies.

§ 6. *Effects of Exercise and Exposure to Cold.*

221. As we have already seen, the first use of food is for the production of heat and energy. When an animal is exposed to cold, the amount of heat required to maintain the temperature of the body will be increased, and a larger proportion of the food consumed by the animal must be used in its production.

222. Physical work can only be performed by means of the energy derived from the combustion of

food in the system. Consequently every increase of physical exercise increases the amount of food that must be used in the production of energy.

223. The first effect, therefore, of exposure to cold, or of exercise, is an increased appetite, by which Nature indicates that more food is needed. If the increased food is not provided, the effect on the animal will be re-absorption of fat, and, in extreme cases, waste of muscular substance.

CHAPTER IX.

SCIENCE IN FOODS.

§ 1. *Food Constituents.*

224. Food is composed of various organic substances combined in varying proportions. Vegetable substances will vary in composition according to the soil and season, and the treatment they have received. All statements of the composition of food are therefore approximate only. The nutritive constituents of foods are usually classed as:

Albuminoids.
Amides.
Fats.
Soluble carbohydrates.
Crude fibre.
Ash.

225. The term albuminoids is used to include all nitrogenous matters in food that can be used for the formation of albuminoids in the animal system. In a great many analyses all the nitrogenous substances in the food are classed as albuminoids. In many substances this is unavoidable, as the proportion of the nitrogen contained in the amides has not yet been determined in all cases.

226. Amides cannot be used by the animal for the production of albuminoids, but can be burned in the system as a source of heat and energy. They exist principally in roots and immature substances.

227. The term "soluble carbohydrates" in analyses of foods includes all non-nitrogenous substances (excepting ash and fats) that can readily be dissolved by weak acids or the juices of the stomach.

228. Crude fibre includes the coarser and harder portions of cellulose and lignose that are not readily dissolved by weak acids or the juices of the stomach

229. In many analyses of foods the division is made into flesh formers, heat producers and ash. Under the term "flesh formers" are included all nitrogenous substances, and under "heat producers" all that do not contain nitrogen. The terms, however, are incorrect and misleading.

§ 2. *Composition of Foods.*

230. The figures in the following table give the average results of a number of analyses. They represent about the composition of any ordinary lot of food, but cannot be relied on as positively accurate, as the composition of different samples of the same kind of food is rarely the same. The variation in composition is but small in seeds and grains, but in roots, straw and fodder is often quite considerable. The column of "Total nitrogenous matter" may, in most cases, be considered reasonably near the truth, but some doubt exists as to the figures in the column of "True albuminoids," owing to the uncertainty with regard to some foods, particularly roots and fodder, as to the proportion of the nitrogen that exists in the form of amides and nitrates.* In many cases it has

POUNDS OF EACH CONSTITUENT IN ONE TON OF VARIOUS FOODS.

Name of Foood.	Water.	Total Ni-trog'nous matter.	True Al-buminoid	Fats.	Soluble Carbohy-drates.	Crude Fi-bre.
GRAINS, CAKES, ETC.						
Cotton cake, decorticated	200	824	740	280	360	180
Cotton cake, undecorticated	230	492	443	124	604	416
Linseed cake	240	562	506	240	606	220
Beans	290	510	459	32	918	188
Peas	286	448	404	40	1050	128
Oats	260	258	232	120	1076	216
Wheat	288	226	203	30	1362	60
Barley	280	212	191	40	1274	142
Rye	286	220	198	40	1384	70
Indian corn	228	208	187	102	1370	60
Wheat bran	280	284	200	84	1008	222
Corn cobs	206	28	?	28	880	756
HAY AND STRAW.						
Meadow hay	286	194	155	50	820	526
Clover hay	320	246	196	44	764	520
Lucerne hay, cut in bloom	334	288	230	50	450	800
Wheat straw	286	60	?	30	652	880
Oat straw	286	50	?	40	764	800
Corn fodder	280	60	?	22	780	800
GREEN FODDER.						
Meadow grass	1600	70	?	16	384	90
Clover	1660	66	?	14	140	90
Rye	1458	66	?	18	298	146
Lucerne, in blossom	1480	90	?	14	140	250
Peas	1630	64	?	12	164	112
Hungarian grass in blossom	1312	118	?	30	300	230
Sorgum	1480	50	?	28	306	146
Indian corn	1644	22	?	10	218	94
ROOTS, ETC						
Potatos	1500	42	25	6	410	22
Mangel wurzel	1770	24	6	2	164	20
Turnips	1834	22	10	4	106	20
Pumpkins	1890	26	?	2	56	20
Sugar beets, small	1630	20	?	2	308	26
Carrots	1700	30	?	4	216	34

not been possible to give the amount of true albuminoids.

*It was formerly supposed that all the nitrogen contained in

231. The composition of straw depends very much on the season. In seasons that have been unfavorable for maturing the grain, the straw contains considerably more soluble carbohydrates and albuminoids than indicated in the table (192). Only a small portion—probably less than half—of the nitrogen in straw exists in true albuminoids.

232. The composition of hay depends greatly on the date of cutting. The following table gives the number of pounds of nutritive substances in a ton of hay made from grass cut at three different periods. The first date represents grass younger than it would usually be cut for hay, but such as cattle get on a good spring pasture. The second date represents good early cut, well cured hay. The third date represents a quality of hay cut rather late, and rather coarse and stemmy:

	May 14.	June 9.	June 26.
Nitrogenous matter	303	191	145
Fat	55	47	46
Soluble carbohydrates	700	742	743
Crude fibre	394	598	654

It will be seen from this table that grass in early spring contains a larger proportion of nitrogenous matter and fat than it does later in the season. In the more mature crop, however, a larger proportion of the nitrogen is contained in true albuminoids.

233. Root crops, as they approach maturity, contain more valuable nutritive constituents than when

foods was available for the use of the animal, and the albuminoids were reckoned by first ascertaining the amount of nitrogen contained in the food and multiplying this by 6.25. Many errors have arisen from this method, as in some foods as much as 75 per cent of the nitrogen exists in amides and nitrates. Foods have thus been supposed to have a high albuminoid ratio (255), when in fact they were very deficient in albuminoids.

immature, a portion of the fibre being converted into starch and sugar.

234. Water in Foods.—It will be noticed that potatos, the dryest of the roots, contain three-fourths of their weight of water, while turnips are nine-tenths water. This is a matter that is of considerable importance in determining the proper mixture of foods, and will be more fully considered in the next chapter.

235. Variations Caused by Soil and Season.—Foods grown in wet seasons and on heavily manured soil, usually contain more than the average per cent of water (178). Root crops grown on rather poor soil contain a larger per cent of nutritive matter than those grown on soil that has been heavily manured. The dry substance in a crop grown on soil that has been heavily manured, usually contains a larger per cent of ash and of nitrogen than the dry substance of a crop grown without manure. A larger portion of the nitrogen in the manured crop will be in the form of amides and nitrates.

236. Effect of Methods of Preparing Foods.—Hay that has been roughly handled contains a smaller proportion of valuable constituents than that which has been more carefully treated, as the finer portions of the blades and leaves, which contain more albuminoids and less crude fibre than the stems, are crumbled and broken off. Clover, especially, is liable to deterioration in this way, as the leaves, which are rich in albuminoids, crumble readily when too dry. The chemical composition of a ton of clover which had been roughly treated, would be quite different from that of a ton which had been properly cured. If grass, after cutting, is exposed to drenching rains, part of the soluble constituents will be washed out, and its composition will therefore show a larger percentage of crude fibre. Hay that has undergone fermentation in the field will have suffered a further loss of soluble carbohydrates by their conversion into carbonic dioxide and water.

When properly handled and cured, the composition of hay does not differ materially from that of the grass from which it was made.

§ 3. *Digestibility of Foods.*

237. The composition of a food cannot be taken, alone, as a trustworthy indication of its feeding value, as this will depend largely on its digestibility. Some foods are almost entirely digested, while of others more than half is sometimes rejected (217).

238. An animal does not always digest the same proportion of each constituent in a food, nor the same proportion of the same constituent in different foods. Thus, a cow will digest a much larger proportion of the albuminoids in lucerne hay than of those in clover hay, and will digest a larger proportion of the fat in clover hay than of that in lucerne hay. The digestibility of foods thus influences not only their comparative feeding value, but also their relative character. Thus the difference as an albuminoid food in favor of lucerne hay over clover is greater than indicated in the table on page 115. Likewise the table shows lucerne hay as containing a larger proportion of fat than clover; yet so much more of the fat contained in clover is digested, that as a food it is really richer in fat than lucerne. It will thus be seen that while such a table as given on page 115 is very useful for many purposes, yet, taken alone, it cannot be depended on to determine either the value of a food, or its character.*

239. The following table gives the number of pounds of digestible constituents in a ton of several different foods as determined by experiments with cattle and sheep. It will be noticed that in many respects it differs materially from the last table:

Name of Food.	Nitrogenous Matter.	Fat.	Soluble Carbohydrates.	Fibre.
Linseed cake	472	216	473	?
Beans	449	30	854	?
Oats	204	101	818	52
Barley	163	40	1108	?
Indian corn	164	87	1247	?
Wheat bran	213	42	706	82
Meadow hay	109	23	508	300
Clover hay	135	25	527	229
Lucerne hay	219	19	301	320
Oat straw	19	12	329	488
Wheat straw	12	11	254	494

240. In this table it was impossible to make any accurate calculation of the amount of true albuminoids in the digested portion of the food. It will probably be safe to assume, however, that true albuminoids formed 90 per cent of the digested nitrogenous matter in the cakes and grains—80 per cent in hay and 50 per cent in straw. Roots appear to be almost completely digested.

241. The horse digests a smaller proportion of coarse foods than ruminating animals, but on grains and concentrated food his digestion is equal or superior to theirs.

242. Pigs have great powers of digesting concentrated food, and can digest a good proportion of green foods when supplied in moderate amount, but they

*By the "character" of a food is meant its richness in any particular constituent, as albuminoids or fat.

do not successfully digest large quantities of coarse food.

243. The degree of maturity of a crop has much to do with its digestibility. Young grass is more digestible than that which is older. The number of pounds of food constituents in a ton of hay cut at different dates was given in paragraph 232. We now give the number of pounds of *digestible* food constituents in a ton of hay cut at the same three dates:

	May 14.	June 9.	June 26.
Nitrogenous matter	222	138	80
Fat	36	24	20
Soluble carbohydrates	530	459	414
Crude fibre	313	393	400

By comparison with the preceeding table, the great depreciation in the value of the crop, as it approached maturity will be noticed. Not only does the older grass contain a smaller proportion of the more valuable constituents, but a smaller proportion of what it does contain is digested.

For this reason, young grass or clover pastured, or cut and fed green gives greater returns in beef or milk than the same amount of grass allowed to mature and made into hay. This also explains why cattle do so well on spring pastures.

244. Digestibility of Food as Affected by Mixing.—To secure the most complete digestion of food, a certain proportion between the nitrogenous and non-nitrogenous constituents must be secured.

245. If, to a diet of hay or straw, a food rich in albuminoids is added, the digestibility of the whole ration is not impaired, but if to such a diet a food deficient in albuminoids is added, the proportion of the hay or straw digested will be diminished. Potatos, and other foods rich in starch, have a greater effect in reducing the digestibility of a diet with which they are mixed than mangels or other roots rich in sugar.

246. If to a diet of hay or straw, potatos or some similar food is added, and also some food rich in albuminoids, such as peas, beans, or linseed cake, the digestibility of the diet will not be reduced.

247. The results of experiments in this direction show that in order to secure the most perfect digestion of food, the diet must contain a certain proportion of albuminoids. If a diet is mixed in such a manner that it does not contain a sufficient proportion of albuminoids, a larger percentage of all the nutritive constituents in the diet will remain undigested. It is therefore important in determining on a mixed diet to consider what its albuminoid ratio (255) will be, and to so proportion the food that this ratio (calculated from the whole food) will not fall below that which secures the most perfect digestion of all the food constituents. The proper albuminoid ratio will be considered in the next chapter.

§ 4. *Valuation of Foods.*

248. For development of muscle no comparisons can be made between albuminoids and non-nitrogenous substances, as only the albuminoids in the food can be used for this purpose. If a diet is deficient in albuminoids, the addition of a sufficient quantity of them will have an effect out of all proportion to the actual value of the albuminoids.

249. As albuminoids, carbohydrates and fats can all be used for laying on fat, or can be consumed in the system for the production of heat and energy, it is easy to make a comparison of their respective values for these purposes. By careful experiments these values have been determined, as follows:

Fat	100
Albuminoids	47.4
Carbohydrates*	43.1

These figures refer to the value of the digested portions of the food. A given weight of a very digestible carbohydrate might be of more value than an equal weight of an indigestible fat, but the proportion between the value of 1 lb. of digested fat and 1 lb. of digested carbohydrate is that of 100 to 43.1. That is if a given weight of fat in a food were worth $1.00, an equal weight of albuminoids would be worth $47\frac{4}{10}$ths cents, and an equal weight of carbohydrates, $43\frac{1}{10}$th cents.

250. The rule usually adopted in comparing the value of fats with carbohydrates is to multiply the amount of fat by 2.44. That is, if one lot of food contained 100 lbs. fat and another 244 lbs. carbohydrates, they would be estimated of equal feeding value.

251. To illustrate. By reference to the table in paragraph 239 it will be seen that a ton of linseed cake contains 216 lbs. digestible fat, and 473 lbs digestible carbohydrates. To estimate the feeding value of the digestible constituents in a ton of linseed cake, we multiply the fat by 2.44 and add to this the carbohydrates. Thus:

Number of pounds	216
Multiply by	2.44
	864
	864
	432
Equal in carbohydrates to	527.04
Add carbohydrates	473
	1000.04

*This includes all digestible non-nitrogenous food constituents except fats.

By which we see that the feeding value of the digestible non-nitrogenous constituents in a ton of linseed cake is equal to 1,000$\frac{4}{100}$ths lbs. of starch or other digestible carbohydrates.

252. The rule for reducing fat to its equivalent value in starch, or other digestible carbohydrates, is: Multiply the number of pounds of fat by 244 and point off the last two figures in the product for decimals.

253. As already stated, the value of a food, providing it contains a sufficient amount of albuminoids to meet animal requirements, depends on its capacity for the production of heat and energy. By taking the digestible constituents of different foods and reducing them all to their value in carbohydrates, their respective values have been approximately determined.

254. The following table gives the result of these calculations, Indian corn being taken as the standard with which the others are compared. The first column gives the respective values of foods in their ordinary condition, the second column the respective values of the dry substance in these foods:

Name of Food.	Ordinary Condition.	Dry Substance.
Indian corn	100	100
Linseed cake*	95	96
Beans	93	96
Barley	85	88
Oats	80	81
Wheat bran	67	69
Meadow hay	59	61
Wheat straw	47	49
Potatos	30	105
Mangels	13	100

*It may appear strange that linseed cake is given a position as a food inferior to Indian corn. It must be remembered that

The figures for the last five articles are probably too high, owing to the fact that proper deduction has not been made for the amides and nitrates.

§ 5. *Albuminoid Ratio.*

255. The "albuminoid ratio" of a food is the proportion that exists between the albuminoids and the non-nitrogenous constituents.

It is customary in calculating the albuminoid ratio of a food to take into consideration the digestible portion only, as the portion undigested of course has no feeding value. When the digestibility of the different constituents of a food is not known, the albuminoid ratio must be calculated from its total constituents. A food will usually appear richer in albuminoids when the estimate is made from the table of digestible constituents than when calculated from the table of total constituents, as there is usually a larger percentage of carbohydrates, fat and fibre rejected, undigested, than of albuminoids.

256. To secure strict accuracy in the determination of the albuminoid ratio, the calculation should be made from the amount of true albuminoids only, as the amides and nitrates are without value in the production of muscle. Nearly all the older calculations are erroneous from this cause, as it is only lately that the distinction between amides and true albuminoids has been learned. It is still sometimes necessary to make calculations in this way, as, with some foods, the proportion of nitrogen which exists in true albuminoids has not been ascertained with

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this table is calculated only on the capacity of the food for producing heat and energy. Linseed cake mixed with other foods may, by increasing the albuminoid ratio of the mixed diet, have a value many times greater than that of corn, certainty. Calculations made in this manner will be reasonably correct with respect to grains and concentrated foods; but with roots and immature substances such calculations are liable to be seriously incorrect. Thus, mangels were formerly supposed to contain sufficient albuminoids to form a complete ration, their albuminoid ratio being 1 : 8, when calculated on the supposition that all the nitrogenous matter they contained was in albuminoids; but when only the true albuminoids were reckoned, the ratio was found to be 1 : 31.8 (263).

257. To determine the albuminoid ratio of a food, the feeding value of the digestible non-nitrogenous constituents is ascertained, and this is divided by the amount of albuminoids. The product is the proportion of non-nitrogenous to one of nitrogenous constituents.

258. Illustration.—Suppose the albuminoid ratio of wheat bran is desired. By reference to the table in paragraph 239, we find that a ton of wheat bran contains the following amounts of digestible constituents:

Albuminoids*	213 lbs.
Fat	42 lbs.
Carbohydrates	706 lbs.
Fibre	82 lbs.

First reduce the fat to its equivalent in starch (250):

Fat	42	lbs.
Multiply by	2.44	
	168	
	168	
	84	
The fat is equal in starch	102.48	lbs.
Add digestible carbohydrates	706	lbs.
And digestible fibre	82	lbs.
	890.48	lbs.

*In this instance it is necessary to reckon all the nitrogenous

Which gives us the feeding value of the digestible non-nitrogenous constituents of a ton of bran as equal to 890.48 lbs. To get the proportion between this and the albuminoid, we divide it by the number of pounds of albuminoids. Thus:

```
213)890.48(4.18
    852
    ---
     384
     213
     ----
     1718
     1704
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We thus get the proportion of one to four and eighteen one-hundredths, which is written thus: 1 : 4.18.

259. When the proportion of albuminoids in a food is large, it is said to have a high albuminoid ratio. When the proportion is small, that food is said to have a low albuminoid ratio. Thus the albuminoid ratio of decorticated cotton cake is 1 : 1.5; that of wheat straw 1 : 64.4; cotton cake is said to have a high, and wheat straw a very low, albuminoid ratio.

260. To Determine the Albuminoid Ratio of a Mixed Diet.—This is a matter of great importance, as it enables the farmer to know whether a mixed diet is properly proportioned to meet the desired object.

261. Rule.—Ascertain the number of pounds of each digestible constituent in the amount of each food used in the mixture; add these and calculate the albuminoid ratio of the product, the same as in any other case.

262. Illustration.—Suppose a farmer wishes to use

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matter in the bran as albuminoid, as the per cent of amides contained in the digested portion of bran has not been fully determined.

a mixed diet arranged in the following proportion:

Meadow hay	100 lbs.
Corn meal	20 lbs.
Bran	20 lbs.

By reference to the table in paragraph 239, we learn the amount of each digestible constituent in one ton of each food named, and by a simple calculation we obtain the number of pounds of digestible substance in:

	Nitrogenous Matter.	Fat.	Carbohydrates.	Fibre.
100 lbs. meadow hay	5.45	1.15	25.40	15.00
20 lbs. corn meal	1.64	.87	12.47	.....
20 lbs. bran	2.13	.42	7.06	.82
Total in whole ration	9.22	2.44	44.93	15.82

Reducing the fat to its value in starch (250), we get the value of the digestible non-nitrogenous constituents in the diet:

Fat, 2.44 lbs. equal to	5.95 lbs.
Carbohydrates	44.93 lbs.
Fibre	15.82 lbs.
Total value equal to	66.70 lbs.

From which we find by the usual rule (257) that the albuminoid ratio of the mixed diet is 1 : 7.23.*

263. The following table gives the albuminoid ratio of various foods, calculated from the digested portions only. The first column gives the ratio as determined by calculations made on the supposition that all the nitrogenous substances in the food are true albuminoids. The second column gives the ratio as determined by estimating only the true albuminoids. The figures given in the first column for cakes and grains are nearly correct. The true ratio for turnips

*It will be noticed that this calculation is made on the supposition that *all* the nitrogen is in albuminoids, and the ratio thus obtained is therefore rather above the truth.

would probably be about 1 : 12, and of wheat straw not more than 1 : 100; for clover hay about 1 : 9.

ALBUMINOID RATIO OF THE DIGESTED PORTION OF FOODS.

Name of Food	Reckoning all Nitrogenous matter as albuminoids.	Reckoning only the true albuminoids.
Cotton cake decorticated	1 : 1.5	
Cotton cake undecorticated	1 : 1.8	
Linseed cake	1 : 2.3	
Beans	1 : 2.4	
Peas	1 : 2.9	
Wheat bran	1 : 4.2	1 : 7
Oats	1 : 5.5	
Barley	1 : 7.6	
Indian corn	1 : 9	
Clover hay	1 : 5.9	
Meadow hay	1 : 8	1 : 12.4
Turnips	1 : 6.2	
Mangels	1 : 8	1 : 31.8
Potatos	1 : 10.6	1 : 17.7
Wheat straw	1 : 64.4	

264. The same food may have a different albuminoid ratio when fed to different animals, as one may digest a larger proportion of the albuminoids, and the other a larger proportion of the carbohydrates. In one experiment a horse and a sheep were fed on the same meadow hay. The portion of the hay digested by the horse had an albuminoid ratio of 1 : 6.7, while the portion digested by the sheep had a ratio of 1 : 9.1. This difference was due to the fact that the horse digested as large a proportion of the albuminoids in the hay as the sheep, but the latter animal digested a larger proportion of the carbohydrates and crude fibre.

CHAPTER X.

SCIENCE IN FEEDING.

§ 1. *General Principles.*

265. The practical objects to be attained in feeding are:

1. To cause growth—development of bone and muscle—in the young animal.
2. The production of milk.
3. The production of fat.
4. To furnish material from which the animal can derive energy to be employed in useful work.

A fifth might be added—namely, the production of manure, but this will be considered in the next chapter.

266. While food is being supplied for these purposes, a sufficient amount must also be furnished to repair the wastes of animal substance (206), maintain the heat of the body, and furnish the energy required in the vital processes (212).

267. We have seen (203) that the plant is the machine by which inorganic substances are converted into forms that can be used by the animal. To the farmer, the animal is only a machine for the conversion of vegetable substances into flesh, fat, milk, wool etc., and for the development into useful work of the energy which the plant has obtained from the sun and stored in the food.

268. If a steam engine attached to a mill requires 20 lbs. of coal per hour to overcome the resistance of the machinery and only that amount is supplied, no useful work can be accomplished. If the supply of coal is increased to 30 lbs. per hour, the energy derived from the 10 lbs. added would be available for grinding. If 40 lbs. per hour is supplied, the available power will be that of 20 lbs. of coal. Thus by the last increase of 10 lbs. the work which can be accomplished is doubled.

269. The same principle applies to the science of feeding. If an animal which requires 20 lbs. of food per day to repair the waste of tissue and carry on the vital processes receives only that amount, no part of this food can be applied to growth, production of fat or milk, or in useful work. If a larger quantity of food is supplied, the additional food can be used for profitable increase.

270. The animal is, in fact, engine and mill combined. Into the same hopper is put the grist to be ground and the fuel to drive the engine. Only that which is furnished in excess of the amount required to keep mill and engine running and in repair pays any profit to the owner. Of this excess part is ground up and worked over into profitable forms, and part is used to supply the additional energy needed for the purpose.

Underfeeding is therefore extravagance.

271. Adaptation of Foods.—It is not only necessary that the animal should have sufficient food, but it must be adapted to the object desired. If the food supplied to a growing animal is composed chiefly of non-nitrogenous matters, these cannot be converted into muscle, and either growth will be checked or an excess of food must be supplied—and a portion of the carbohydrates be wasted. If on the other hand the food contains a larger proportion of albuminoids than is needed, while the animal will not suffer, as the albuminoids will meet all its needs (210), yet as they are much more expensive than carbohydrates, the farmer's profits will be greatly diminished.

272. **Effects of Exercise.**—We have seen that the physical energy in the animal is derived from the combustion of the carbon of the food in the blood (211). The greater amount of physical effort required the greater amount of the food consumed will be used for this purpose.

It has been ascertained by experiment that a man when doing a fair day's work, gives off from his lungs one-third more carbonic dioxide than in an equal time when at rest, which proves that when at work one-third more food was burned in the system.

Hence all unnecessary exercise on the part of an animal causes a waste of food. When cows are driven long distances to and from pasture, are compelled to roam over closely cropped fields in search of food, or worried by flies, or chased by dogs and boys, the farmer may know that the energy thus expended is obtained by the combustion of food that would otherwise be converted into milk and butter.*

*The greatly increased production of butter and cheese claimed by the advocates of soiling, is partially explained by the fact just given. The cows kept in a quiet and comfortable stable, protected from annoyance by flies and spared all unnecessary exertion, can put into the pail a quantity of butter, that, were they roaming over a large pasture and fighting flies, they would be obliged to burn for the production of physical

273. **Effects of Cold.**—Exposure to cold results in loss to the farmer in much the same manner as excess of exercise. The animal heat must be maintained and food will be burned in the system in proportion to the demand for this purpose. Food which the animal should be manufacturing into fat, flesh or milk, is burned to keep the animal warm. A farmer would be considered extravagant who would put up a stove to warm his stable and feed the fire with butter, but when he leaves his cows exposed to cold and storms, they have to keep warm by burning the butter which would otherwise go into the milk pail.

274. In some experiments with sheep made to ascertain the amount of food required to produce one pound increase of live weight, it was found that 150 lbs. of turnips were required to produce this amount of increase when fed to sheep which had no protection from storms and cold, but that the same result was obtained by feeding 100 lbs. when the sheep were protected.

275. The Kansas State Board of Agriculture recently made some experiments in fattening pigs. A number were put in pens and fed and treated alike, with the exception that part of the pens were in the basement of a barn and part were out of doors. It was found that one pound of increase was made from 5.15 lbs. of corn fed to the pigs in the barn, but that

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energy. Men who have had no experience in soiling, often wonder how it is possible that the food grown on an acre should produce any more milk and butter when cut and fed to animals in the stable, than when the same animals gather it for themselves. They do not see the butter burned to enable the cow to wander after her food, and fail to appreciate that it is burned as truly as if put into the fire-box of an engine.

5.48 lbs. corn were required to make one pound of increase in the pigs fed outside.

Too great heat is also wasteful, as it occasions perspiration and food must be consumed in its evaporation.

276. **Effect of Water in Food.**—A certain amount of water is necessary to the life of the animal, but if an excess is contained in the food waste will be occasioned, as the water must all be warmed to the temperature of the animal and a part must be evaporated through the skin. Considerable food must be burned to produce the heat thus required.

277. The proper proportion of water is, for sheep about two parts to one of dry substance; for cattle, four parts to one. Cows giving milk require a still larger proportion of water.

278. In feeding grains and dry fodder, there is little probability of supplying too much water, but in feeding roots alone the quantity of water is liable to be greatly in excess of the animal's requirements. When an animal is fed exclusively on turnips, a large part of the dry substance consumed will be used in raising the temperature and evaporating the surplus water.

279. Hence, roots should usually be fed in connection with dry food, and when fed in this manner, will give much better results than when fed alone.

§ 2. *Proper Food for the Young Animal.*

280. The chief object of the food supplied to the young animal is to produce bone and muscle, as the production of a large amount of fat is not desirable. The food, therefore, should be rich in albuminoids, phosphoric acid and lime. The milk — called colos-

trum—which Nature furnishes for the young animal at birth, is exactly fitted for the purpose designed. The following table gives the analysis of the colostrum of the cow:

Water	716
Albuminoids	207
Fat	34
Sugar	25
Ash	18
	1,000

The albuminoid ratio is about 1 : 0.5. The ash, which is also in large proportion, is principally calcic phosphate. This food is therefore specially adapted for producing bone and muscle. During the first few days of its life the animal takes but little exercise; consequently the amount of carbonaceous food required is not large. The character of the milk soon changes, as the needs of the animal change. The milk contains more fat and sugar, and less albuminoids and ash. The following is the average composition of cow's milk:

Water	870
Albuminoids	40
Fat	37
Sugar	46
Ash	7
	1,000

The albuminoid ratio is now only 1 : 3.3.

The composition of milk gives the key to the proper food for the growing animal.

281. It should be readily digestible and contain a fair proportion of fat. Carbohydrates can take the place of fat; but as 2.44 lbs. carbohydrates are required to equal 1 lb. of fat, a less bulk of carbonaceous food will be required when fat is provided, and the animal will thus be able to consume more albuminoids, which are essential for the development of bone and muscle. The food must also contain a due proportion of phosphoric acid and lime.

282. By reference to the table of foods (230), it will be seen that young clover and grass are rich in albuminoids. They also contain a considerable percentage of phosphates, and therefore form a suitable diet for the growing animal. Bran makes a good addition to such a diet, and a little linseed cake will supply the fat and albuminoids.

283. Many of our best farmers have adopted the plan of putting their growing pigs on grass or clover pastures, and feeding but moderately with corn. This enables the pig to grow and develop a large, bony and muscular carcass, with capacious digestive organs. When the time arrives for fattening such an animal, it can consume large quantities of food, and produce a proportionately large amount of fat.

284. The proper albuminoid ratio for a growing animal is 1 : 5 to 1 : 7. When all the nitrogenous matter has been reckoned as albuminoid, in determining the ratio, it should not be less than 1 : 5.

§ 3. *Proper Food for Producing Milk.*

285. As milk contains a large proportion of albuminoids and phosphates, the food must contain enough of these substances to meet the demands for milk in addition to what is required to supply the wastes of tissue. If the food does not contain enough of these substances, the flow of milk will be diminished, or the cow must use her own tissues for its production. The food should also contain some readily digestible fat, as we have seen that this is contained in milk in considerable quantity (280).

286. If a food is deficient in albuminoids, the cow may be fed all she can eat, and yet be unable to yield a liberal supply of milk.

287. As the bulk which a cow can eat is limited, the food should be tolerably concentrated; otherwise it will not be possible for her to obtain a sufficient amount of nutritive substances in the quantity she is able to eat

288. For example. By reference to the table in paragraph 239, it will be seen that a ton of wheat straw contains only 12 lbs. of digestible nitrogenous matter. Not more than half of this is in the form of true albuminoids. As 25 lbs. of milk contain about 1 lb. albuminoid, it would be necessary for a cow fed on wheat straw alone, to consume (in addition to the amount required to repair the wastes of her tissues) $333\frac{1}{3}$ lbs. straw in order to produce 25 lbs. of milk. It is true that a cow could not eat such a quantity of straw in a day, but it would be as possible for her to do so as it would be for her to give a liberal flow of milk on such a diet. This explains why farmers who winter their cattle at the straw stack find it impossible to make butter in winter.*

289. Pea and bean meal, linseed and cotton cake are rich in albuminoids. Bran and clover are also nitrogenous foods and contain a considerable proportion of phosphates, Mangels supply valuable carbohydrates. A diet of good clover or meadow hay, with

*A cow could hardly keep alive, much less give milk, fed on pure wheat straw. Practically a straw pile always contains a little grain and some other substances, and the cattle "pick up" a little food besides. The usual condition in spring of cattle wintered at the straw stack, is, however, a sufficient evidence of the correctness of the scientific principles that have been laid down.

mangels, bran and a small amount of linseed or cotton cake, bean or pea meal would be a good milk diet from a scientific stand-point, and practical experience has approved it.

290. The value of young meadow grass as a milk diet is well known. The fact that cows on pasture decrease in flow of milk as the season advances, is also a familiar one. This is caused by the decrease of albuminoids in the older grass. By reference to the table in paragraph 243, it will be seen that 100 lbs. of hay, cut May 14th, contained a little over 11 lbs. of digestible albuminoids, while the same quantity cut June 26th, contained but 4 lbs. The cow cannot eat more grass in summer than in spring, and therefore if at each period she has all the grass she can eat, she will by June 25th get but four-elevenths as much albuminoids as she would May 14th.*

291. Wolf gives the albuminoid ratio of a milk diet as 1 : 5, reckoning all the nitrogenous matter as albuminoids. Reckoning only the true albuminoids, a ratio of 1 : 6 or 1 : 7 will be sufficient.

292. Meadow grass cut May 14th has a ratio of 1 : 4.14 (reckoning all nitrogenous matter). That cut June 26th has a ratio of only 1 : 10.76. The first, therefore is a rich milk diet, while the latter falls far below the requirement.

293. Analysis of aftermath hay shows that while it is no richer in albuminoids than the first crop, it is very considerable richer in fat. The following table

*This further explains the advantages claimed by the advocates of soiling. Under this system the cattle are kept constantly supplied with fresh young grass and fodder, cut at the time when it is richest in nitrogenous constituents.

gives the number of pounds of food constituents in a ton of aftermath hay:

Water	237.4 lbs.
Nitrogenous matter	196.8 lbs.
Soluble carbohydrates	845.0 lbs.
Fat	136.8 lbs.
Crude fibre	395.4 lbs.
Ash	188.6 lbs.
	2,000.0 lbs.

Such hay if fed with sufficient nitrogenous food to secure a proper albuminoid ratio, would make a better milk diet than the first crop.

294. Mr. T. Horsfall, of England, made some of the most complete experiments on the diet of milk cows. He first calculated a diet from scientific principles, and then applied to this the test of practical experiment. The ration for each cow per day consisted of:

Meadow hay	9.33 lbs.
Rape cake	5. lbs.
Malt combs	1.5 lbs.
Wheat bran	1.5 lbs.
Beans	1.5 lbs.
Green fodder	34. lbs.
Oat straw	8.33 lbs.
Bean straw	2. lbs.
Total	63.16 lbs.

The rape cake, malt combs, wheat bran, beans and bean straw made this a highly nitrogenous diet, the albuminoid ratio being 1 : 5.4. The rape cake furnished a considerable quantity of fat. In some parts of the country rape cake and malt combs cannot be obtained. Linseed or cotton cake can be substituted, and a diet fully equal to Horsfall's be obtained. If neither of these can be had, an approach to the ration could be made by increasing the proportion of bran—using clover or Hungarian grass and some corn meal.

Mr. Horsfall's cows on this diet gave a large quantity of milk, of which 16 quarts yielded from 24 to 28 ounces of butter. And the cows gained in weight.

§ 3. *The Fattening Animal.*

295. The chief constituent in the increase in a fattening animal is fat. In experiments at Rothamsted it was found that the increase of weight in a fattening sheep consisted of:

Water	22.0
Nitrogenous matter	7.2
Fat	68.8
Ash	2.0

The increase contained nearly ten times as much fat as muscle.

296. Theoretically, therefore, the fattening animal requires a diet containing but a small proportion of albuminoids. Practically, however, it is found that when the ratio falls as low as theory would indicate could be used, the digestibility of the food is impaired and the health of the animal suffers (247).

297. The albuminoid ratio* of food for a fattening animal has been ascertained to be:

For cattle	1 : 10
For sheep	1 : 9
For pigs	1 : 7

298. A diet richer in albuminoids may often be used with advantage when not too expensive. Food excessively rich in albuminoids, as cotton cake, is liable to produce disease if fed in large quantities. Such substances should always be fed moderately and in connection with other foods.

299. **Experiments in Fattening.**—The following table shows the result of some experiments made by

*Reckoning only the true albuminoids.

Messrs. Lawes & Gilbert, of Rothamsted, England, for the purpose of determining the amount of food required to produce an increase of a pound of live weight, and the relative capabilities of different animals for converting food into meat. In the experiment, the oxen and sheep were fed on linseed cake, clover hay and sweedes; the pigs on barley meal:

RESULTS OBTAINED PER HUNDRED POUNDS LIVE WEIGHT PER WEEK.

	Oxen.	Sheep.	Pigs.
Dry food received per week per hundred pounds live weight....	12.5	16.0	27.0
Which contained of digestible substance	8.9	12.3	22.0
Amount of food expended per week in production of heat and energy for each 100 lbs. live weight....	6.86	9.06	12.58
Gain in live weight per week for each 100 lbs. of live weight of animal........................	1.13	1.76	6.43

The student will understand from the above table that an ox weighing 1,000 lbs. consumed per week food containing 125 lbs. of dry substance, of which he digested 89 lbs. 68.6 lbs. of this was used in the production of heat and energy, and 11.3 lbs. stored as increase in live weight. The remainder of the digested matter was expended in repairing the wastes of the body.

300. The table also shows that a sufficient number of pigs to weigh 1,000 lbs consumed per week food containing 270 lbs. dry substance, of which they digested 220 lbs. 125.8 lbs. of the digested matter was used in the production of heat and energy, 64.3 lbs. stored up as increase, and the remainder expended in repairing waste of tissue.

301. These experiments show that the pig eats more in proportion to his weight than the ox, but he also makes a larger amount of increase in proportion to food consumed.

RESULTS OBTAINED PER HUNDRED POUNDS DRY FOOD USED.

	Ox.	Sheep.	Pig.
Received by animal	100	100	100
Digested	72.2	76.9	81.5
Used for heat and energy	54.9	56.6	46.6
Laid up in increase	9	11	23.8

By the term 100 lbs. dry food is meant an amount of food containing 100 lbs. dry substance.

302. It will be noticed that the pig digested a larger proportion of his food than the ox. This was not due to the better digestive powers of the pig, but to the fact that his food contained a larger proportion of digestible material. Calculating therefore only on the digestible portion of the food, we get the following table, showing the amount of increase in live weight produced from 100 lbs. *digested* dry substance—that is, from an amount of food containing 100 lbs. of digestible dry substance:

	Ox.	Sheep.	Pig.
Increase in live weight per 100 lbs. digested food	12.7	14.3	29.2

It will be seen that the pig produced a far greater amount of increase from a given amount of digestible food than either the sheep or the ox, showing that he is the most profitable machine which the farmer can use for the conversion of his crops into meat.

303. The table in paragraph 299 shows that even in these experiments, where the animals were carefully treated, and no unnecessary food expended in the production of heat and energy, the amount of food consumed for this purpose was far greater than that stored in the increase.

304. The fact that the pig uses a larger proportion of the food he consumes in production of increase than the ox, and less for heat and energy, explains the reason why he requires a diet richer in albuminoids.

305. The fattening animal does not make the same rate of increase, nor yield the same profit on food consumed during the whole fattening period. As the animal increases in size and weight, it can eat less food in proportion to its weight, and probably digests a smaller proportion of what it does eat. It also uses a larger proportion of the digested food for production of heat and energy and repair of waste.

306. An experiment was made at Rothamsted with 16 pigs, averaging 135.8 lbs. at the commencement of the fattening period, and 276.3 lbs. at its completion. The food consisted of 7 lbs. pea meal per day for each pig, with all the barley meal in addition that they would eat. The pigs were fed for ten weeks and weighed every two weeks. The following table gives the result. The number of pounds of food refers to the food in its ordinary condition—not to the dry substance:

	Food consumed per head.	Food consum'd per 100 lbs live weight.	Food consum'd to produce 100 lbs increase.
First two weeks	60.1 lbs.	39.7 lbs.	386 lbs.
Second two weeks ..	67.5 lbs.	36.7 lbs.	388 lbs.
Third two weeks ...	66.4 lbs.	30.9 lbs.	502 lbs.
Fourth two weeks ..	66.0 lbs.	27.4 lbs.	511 lbs.
Fifth two weeks	69.6 lbs.	26.3 lbs.	618 lbs.
Average for ten w'ks	65.9 lbs.	32.0 lbs.	469 lbs.

307. During the first two weeks 3.86 lbs. food produced 1 lb. increase; but during the last two weeks it required 6.18 lbs. to produce that amount. Calculating that 90 per cent of the increase was butcher's carcass, it required during the first two weeks only

4.29 lbs. food to produce a pound of pork; but during the last two weeks 6.88 lbs. to produce that amount. The pork made during the last two weeks therefore cost 60 per cent more than that made the first two.

308. In experiments made in feeding pigs in the United States, it was found that 5.33 lbs. corn was required to make 1 lb. increase in live weight, while in the English experiment just given, the average for the whole period was 1 lb. increase from 4.69 lbs. food. The difference in favor of the English experiment was probably due to the fact that the food used—a mixture of pea and barley meal—had a much higher albuminoid ratio than corn.

309. Corn does not contain a sufficient proportion of albuminoids to make a perfect diet for fattening pigs. Consequently the addition to a corn-diet of a small amount of some highly nitrogenous food, as linseed cake,* or bean or pea meal, greatly increases the value of the whole food.

310. Skim milk is a highly nitrogenous food. Its percentage composition is about:

Water	90.
Albuminoids†	3.7
Fat	0.8
Sugar	4.8
Ash	0.7

157.4 lbs. skim milk contains as large an amount of albuminoids as a bushel of corn. We have seen that a pig requires a diet having an albuminoid ratio of 1 : 7, and that the ratio of corn is only 1 : 9. If a pound of skim milk is fed with every pound of corn,

*Linseed cake can only be fed in small quantity, or it will injure the flavor of the pork.

†The nitrogenous matters in milk are all true albuminoids

the albuminoid ratio of the whole diet would be 1:6.4 —a ratio sufficient to secure the best results.*

311. The entire increase of live weight in a fattening animal is not useful carcass. As the animal grows the digestive organs also grow. The increase of offal is not as great proportionally as the increase of butcher's carcass, and consequently the highly fattened animal contains a larger percentage of carcass and less percentage of offal than the animal in "store" condition only.

312. In fattening a sheep, from 68 to 77 per cent of the increase is carcass.

313. Of the fatted animal, about 60 per cent of the fasted live weight is carcass in the ox, 58 per cent in the sheep and 83 per cent in the pig.

§ 4. *The Working Animal.*

314. A working animal, if it has been properly grown, will contain a large amount of muscular substance and a comparatively small proportion of fat. To replace the waste of this muscular tissue will require a fair amount of albuminoids in the food. Beyond this, carbohydrates and fat meet the requirements of the working animal. It has been found that an albuminoid ratio of 1 : 9 is sufficient for an adult horse at work.

315. It would seem that a horse not at work would require about as large an amount of albuminoids as a working horse, but a smaller amount of carbohy

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*This explains why persons who have but one or two pigs and give them the skim milk and scraps from the table, are so successful. The small quantity of food rich in albuminoids added to the corn, raises the character of the whole diet, and better results are obtained from all the food given.

drates, and that therefore the albuminoid ratio of his diet should be higher.

316. In growing an animal intended for work, the object is to produce the largest possible development of muscle, and but a small development of fat. Therefore the food for the young animal intended for work should be rich in albuminoids—bran, oats, peas, beans, clover, etc.

§6. *Summary.*

The only profit which the farmer can secure in feeding, is that from food supplied in excess of the amount required to keep the animal alive and in health.

It is not only necessary that the food be sufficient in quantity, but its character must also be adapted to the purpose desired. Lack of care and judgment in this respect is likely to result in injury to the animal, waste of some of the food constituents supplied, or the use of unnecessarily expensive foods.

In arranging a mixed diet, the effect of the mixing upon the digestibility of the food must be carefully considered, otherwise, much of the food supplied may remain undigested, causing waste and loss.

The greater the amount of food, a fattening animal can be induced to eat and digest, the greater will be the profit obtained in proportion to the amount of food consumed. Therefore the flavor of the food, and the degree in which it is relished by the stock, have an important influence on the profits of feeding.

Exertion, and exposure to cold require a large consumption of food which gives no returns in flesh or fat, therefore, economy requires that fattening stock be protected from the weather, and spared all unnecessary exercise.

The increase of weight produced from a given amount of food is greater in the young animal than in the old, and greater in the beginning of fattening than towards its close. Therefore, a careful estimate should be made of the cost of the food and the value of the meat produced, so that the farmer may know at what time to sell his stock in order to secure the largest profit on food used.

In fattening pigs, improvement in their health, and, therefore, in the profit of the farmer, has been secured by keeping them supplied with a mixture of 20 lbs. sifted coal ashes, 4 lbs. salt, and 1 lb. superphosphate of lime.

CHAPTER XI.

SCIENCE IN FERTILIZERS.

§ 1. *General Principles.*

317. A fertilizer is a substance which, if added to the soil, will increase its capacity for the production of a crop. The science of fertilization includes all methods of rendering the soil more productive.

318. The production of a good crop depends on the soil and the season. Over the former, only, the farmer has control, and it is his business to provide a condition of soil that will secure the largest crop the season is capable of producing.

The conditions of soil necessary for this are: A sufficient amount of plant food, in a form that can be used by the crop;

Such a mechanical condition of the soil as will enable the roots of the plants to reach and use the available plant food present.

319. Nature and Cultivation.—We have seen (145) that in a state of nature the amount of plant food in the soil tends continually to increase. Under cultivation where crops are carried away, the amount must decrease, unless in some manner the plant food taken away from the soil is restored.

320. Favorable mechanical conditions of the soil are obtained by cultivation, drainage, and sometimes by plowing under green crops (See "Soils," sections 5, 6, and 7).

321. Plant food in the soil is rendered available by drainage, cultivation, the use of lime, bare fallow, and by plowing under green crops (See "Soils," paragraphs 161-163).

322. The amount of plant food in the soil is increased by the addition of manures.

323. The methods necessary to secure favorable mechanical conditions of the soil also tend to increase the amount of plant food by favoring absorption from the air, and to render that which is present available, by favoring nitrification and the solution of mineral substances.

324. The methods necessary to render plant food available, also usually improve the mechanical condition of the soil, and by favoring absorption, tend to increase the total amount of plant food in the soil.

325. The addition of manures frequently improves the mechanical condition of the soil, and may also, by starting chemical action, render the plant food already present, more available.

It is therefore impossible to draw a strictly accurate line between these different methods. The farmer must usually employ all three, and in order to attain the best results, their judicious combination is necessary.

The methods of improving the mechanical condition of soils have been considered in chapter six.

§ 2. *Rendering Plant Food Available.*

326. Bare Fallow.—This is one of the oldest methods of improving the condition of soils. It is often called "resting the land," but the term is unscientific and misleading. In a bare fallow the land is allowed to remain one season without a crop, and is continually cultivated in order to keep down weeds, and expose the soil to the action of the air. Except by favoring the absorption of ammonia from the air, it does not increase the amount of plant food, but by favoring oxidation, a portion of the mineral substances is rendered soluble, and by nitrification the nitrogen contained in the humus of the soil is converted into nitric acid. Under favorable circumstances, a large amount of nitrogen—sometimes as much as 35 to 55 lbs. per acre—will be converted into nitric acid, and the soil be able to produce a double crop the year succeeding the fallow.

In some experiments at Rothamsted, one part of a field was cropped with wheat four years in succession; another part was cropped and fallowed alternately. The soil was the same and no manure was used. The following table gives the yield per acre for the four years, the field that was cropped continuously being marked No. 1, and the field fallowed each alternate year, No. 2:

	Field No. 1.	Field No. 2.
First year..................	15.87 bu.	Fallow
Second year................	13.81 bu.	37 bu.
Third year	15.81 bu.	Fallow
Fourth year.................	21.06 bu.	42 bu.
Total in four years........	66.55 bu.	79 bu.

In this experiment the field that was alternately cropped and fallowed, produced in the four years a total of nearly 12½ bushels per acre more than the other. As, in this case, one-half the seed and nearly one-half the labor of harvesting were saved, the fallowed field was the more profitable.

Producing a heavy crop alternate years by means of a bare fallow, simply draws on the supply of plant food in the soil.

If heavy rains fall on a bare fallow, much, or in some cases all, of the nitric acid formed may be washed out. The constant use of the bare fallow as a means of securing large crops therefore tends, under ordinary conditions of soil and climate, to the ultimate exhaustion of the nitrogen in the soil.

327. Lime.—The principal effect of the application of lime is to favor the decomposition of humus in the soil. The amount of plant food furnished is unimportant, as nearly all soils contain sufficient to supply the needs of any ordinary crop. The use of lime is therefore classed among the methods adopted for rendering plant food already present in the soil available. Its principal value for this purpose is on soils that are over-rich in humus (174). The persistent use of lime without other manures, therefore, tends to greatly reduce the total amount of nitrogen in the soil. While valuable when properly used, many farms have been almost ruined by its injudicious application. Lime is also sometimes useful on clay soils, by improving their mechanical condition (170). In this manner it may not only render a clay soil more easy to work, but also increase its capacity for absorbing and retaining fertilizing elements.

328. Green Manuring.—Growing green crops and plowing them under is properly classed as one of the methods of rendering plant food available. It is true that a large portion of the crop was obtained from the air, but that portion is not of value as plant food in the soil. The nitrogen* and mineral elements in the plant were obtained from the soil, and the actual quantity of these elements in the soil is, therefore, not increased.

329. Green manuring renders the plant food in the soil available:

By gathering that which is already present, forming it into organic substances which are left near the surface, and as they decay, give up to the succeeding crop that which they have gathered.

By taking up the nitric acid as rapidly as formed by nitrification, and thus preventing it from washing out in the drainage water.

By shading the soil, keeping it moist, and loose, and thus providing the circumstances favorable for nitrification.†

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*The leaves of plants absorb from the atmosphere some ammonia (142), and the nitrogen contained in this is gained by the soil when the crop is plowed under. The quantity thus obtained is, however, so small and so uncertain that it cannot be taken into consideration in practical estimates.

†Numerous experiments appear to indicate that under certain circumstances the free nitrogen of the air which is contained in the pores of the soil, may be oxidized into nitric acid. The circumstances necessary are, a porous soil, rich in humus, a certain amount of moisture, warmth, and the presence of some base with which the nitric acid can combine as rapidly as formed. The presence of ferric oxide in considerable quantity seems to aid the action by catalysis (122). Should future experiments demonstrate that this oxidation of free nitrogen can be accomplished to any considerable extent under the influences which the farmer can control, the present views of the operation of green crops will require serious modification. It will then appear possible, by green manuring, not only to change the nitrogen in the soil into more available forms, but

By attacking plant food existing in the soil in forms of combination not available for other crops. Leguminous crops (clover, peas, beans, etc.) appear to have the power of feeding on nitrogenous substances in the soil in forms that are not available for cereal crops. This nitrogen it leaves in forms of combination that readily undergo oxidation with production of nitric acid. Hence clover, even when the crop is cut for hay and seed, leaves in the roots and stubble a large amount of plant food that can be used by the succeeding crop.

§ 3. *Manures.*

330. The plant takes from the soil a large number of substances, but in practice only three have to be considered. These are:

Nitrogen.
Phosphoric acid.
Potash.

The other mineral elements of plant food are equally essential, but they are usually contained in the soil in sufficient quantity, and most manures that contain nitrogen, phosphoric acid and potash, also contain these other substances. These three are the ones to be considered in estimates of the fertility and exhaustion of soils and in the valuation of manures.

331. We have seen (158) the amount of these substances in a very fertile soil. The following table

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also to add to its quantity. With our present knowledge on this subject, however, it will not be safe for the farmer to depend on increasing his store of nitrogen by this means; whatever future discoveries may be made, the wise farmer will still carefully save and return to his soil all waste plant food.

shows the amount taken from an acre by an average crop:

	Nitrogen.	Phosphoric Acid.	Potash.
20 bushels wheat..........	22 lbs.	9.5 lbs.	6.4 lbs.
2000 lbs. straw............	9.6 lbs.	5.2 lbs.	11.6 lbs.
Total crop..............	31.6 lbs.	14.7 lbs.	18. lbs.
30 bushels barley.........	26.2 lbs.	12.1 lbs.	7.3 lbs.
18000 lbs. straw...........	9 lbs.	3.6 lbs.	17.4 lbs.
Total crop.	35.2 lbs.	15.7 lbs.	27.7 lbs.
30 bushels oats............	25.3 lbs.	7.9 lbs.	5.7 lbs.
1800 lbs. straw............	9.0 lbs.	4.5 lbs.	18.7 lbs.
Total crop..............	34.3 lbs.	12.4 lbs.	24.4 lbs.
20 bushels rye	19.7 lbs.	9.4 lbs.	6.3 lbs.
3240 lbs straw	13.0 lbs.	6.8 lbs.	25.2 lbs.
Total crop..............	32.7 lbs.	16.2 lbs.	31.5 lbs.
50 bushels Indian corn	41.4 lbs.	12.8 lbs.	10.8 lbs.
8000 lbs. cornstalks........	38.4 lbs.	42 4 lbs.	76.8 lbs.
Total crop..............	79.8 lbs.	55.2 lbs.	87.6 lbs.
2 tons meadow hay........	62 0 lbs.	15.2 lbs.	67.2 lbs.
2 tons clover hay..........	78.8 lbs.	22.4 lbs	78.0 lbs.
15 tons turnips............	54.0 lbs.	18.0 lbs.	87.0 lbs.
9000 lbs. tops	38.6 lbs.	8.4 lbs.	31.7 lbs.
Total crop..............	92.6 lbs.	26.4 lbs.	118.7 lbs.
20 tons mangels...........	76.0 lbs.	28.0 lbs.	156.0 lbs.
16000 lbs. tops	44.7 lbs.	13 3 lbs.	62.7 lbs.
Total crop..............	120.7 lbs.	41.3 lbs.	218.7 lbs.
100 bushels potatos........	20.4 lbs.	10.8 lbs.	33.6 lbs.
2000 lbs haulm.....	9.3 lbs.	3.0 lbs.	8.1 lbs.
Total crop.............	29.7 lbs.	13.8 lbs.	41.7 lbs.

332. It would require a great many years to remove all the nitrogen, phosphoric acid and potash from a soil (even were it possible to continue to grow crops until the whole amount was exhausted) but that which is in an available condition may be exhausted in a few years.

333. It is also necessary in order to produce a full crop, that the soil should contain considerably more of these substances in an available form than the crop will require, for no plant can gather all the available plant food in the soil. Thus we see that a crop of wheat of 20 bushels to the acre, contains only about 32 lbs. of nitrogen, but such a crop cannot be grown unless the soil contains at least 65 lbs. available nitrogen.

334. The means employed to supply the required available plant food, and prevent the deterioration of the soil by too heavy drafts on the supply it contains, are the application of farm-yard manures and commercial fertilizers.

335. Farm-Yard Manure consists of the excrements of the animals fed upon the farm, mixed with the straw used for litter, and other waste products of the farm.

336. Commercial Fertilizers consist of various imported and manufactured articles with the refuse from slaughter houses, etc., worked up into a condensed form ready for immediate application.

§ 4. *Farm-Yard Manure.*

337. Composition.—This varies greatly, depending on the kind and amount of litter used, the character of the animals producing it, the food used, the length of time the manure has been kept, and the treatment it has received.

338. Water forms the greater part. The remainder consists of carbonaceous matter with a small amount of nitrogenous substances and mineral salts. The following table gives the composition of one ton of average fresh farm-yard manure.

Water	1,420 lbs.
Nitrogen	9 lbs.
Phosphoric acid	4.2 lbs.
Potash	10.4 lbs.
Carbonaceous matter, lime, sand, etc.,	556.4 lbs.
Total	2,000 lbs.

This represents an *average* sample of fresh manure. It will be seen that one ton contains only 23.6 lbs., of valuable plant food. Farm-yard manure from animals fed on rich food may contain a much larger amount.

339. Fermentation of Manure.—When fresh manure is allowed to remain in a heap, decomposition soon commences. The carbon combines with oxygen from the air, producing carbonic dioxide which is given off. The nitrogen combines with hydrogen of the water forming ammonia. If the manure has become dry, this ammonia combines with the carbonic dioxide forming carbonate of ammonia (112), which escapes in vapor. If the heap has been kept moist, it combines with the organic acids formed by the decomposition of carbohydrates, producing soluble but not volatile salts.

340. Considerable heat is produced during this process, which drives off much of the water in the manure. By fermentation of the manure, the amount of water and carbon in the heap is decreased, while the amount of nitrogen and mineral salts (if the process has been properly conducted,) remains unchanged. The manure, therefore, contains a larger proportion of these substances than before fermentation, and more of the nitrogen is in an available form.

341. Manure Fermented in a Heap in Open Yard.—The following table shows the weight of a ton of manure fermented in a heap in an open yard, and the amount of nitrogen contained in the heap at different dates:

	Total Weight of Manure.	Nitrogen.
November 3rd................	2,000 lbs.	12.9 lbs.
April 30th.....................	1,428 lbs.	12.8 lbs.
August 23rd...................	1,405 lbs.	9.3 lbs.
November 15th...............	1,391 lbs.	9.2 lbs.

The manure used in this experiment contained considerably more nitrogen than that of which the analysis was given in paragraph 338. It will be noticed that during the first six months the weight of the manure was reduced nearly 29 per cent, while the loss of nitrogen was immaterial. A ton of the manure analyzed April 30th would have contained 20.2 lbs. of nitrogen. During the next 6 months the decrease of weight was very small, but the loss of nitrogen was quite serious. A ton of the manure on November 15th would only contain about 13 lbs. of nitrogen. By fermenting for six months in winter the weight of manure that would have to be handled to obtain a given amount of nitrogen was decreased, but by fermenting six months longer nitrogen was wasted and the amount of manure required to contain a given weight of it was as great as at first.

342. Manure Fermented Under Shed.—The following table shows the result of an experiment in fermenting manure under a shed:

	Total Weight of Manure.	Nitrogen.
November 3rd................	2,000 lbs.	12.9 lbs.
April 30th.....................	992 lbs.	10.2 lbs.
August 23rd...................	800 lbs.	10.2 lbs.
November 15th...............	758 lbs.	11.4 lbs.

In this case the manure lost more than half its weight in the first 6 months, but it also lost 2.7 lbs. nitrogen per ton. This was probably due to the heap having been allowed to become too dry. During the next four months the heap lost in weight but not in nitrogen. On August 23rd the heap contained nitrogen at the rate of 25.5 lbs. per ton. It will be noticed that the last date shows an actual increase in nitrogen. This must have been due to error in the analysis, unless sufficient free nitrogen was oxidized in the heap to cause the increase. We have not sufficient facts at present to warrant this last supposition.

343. Manure Spread in Barn-Yard.—The following table gives the result of an experiment with manure left spread in an open barn-yard:

	Total Weight of Manure.	Nitrogen.
November 3rd	2,000 lbs.	12.9 lbs.
April 30th	1,730 lbs.	9.2 lbs.
August 23rd	1,226 lbs.	5 lbs.
November 15th	1,150 lbs.	4.5 lbs.

In this case nitrogen was constantly lost, so that at the end of the year but little over one-third remained. The loss of nitrogen was in greater proportion than the loss of weight, so that the manure at the close of the experiment contained a smaller proportion of nitrogen than at its commencement.

344. Leaching.—When manure is exposed so that the rain which falls upon it leaches through, great loss of its most soluble, and therefore most valuable constituents is incurred. A heap of ordinary manure containing a ton of dry substance contains only 31 lbs. of nitrogen and 35 lbs. potash, while sufficient of the dark colored drainage from the manure heap to contain one ton of dry substance would contain about

166 lbs. nitrogen and 554 lbs. potash. The nitrogen in the drainage is also entirely soluble, and hence much more valuable than that which remains.

345. Evaporation of Ammonia.—We have seen (339) that the evaporation of ammonia may be prevented by keeping the heap sufficiently moist to insure the production of organic acids. It can also be prevented by the addition of gypsum or land plaster (109). Sulphuric acid diluted with water and sprinkled over the manure heap also prevents this waste by the formation of sulphate of ammonia, but it is neither as cheap nor as convenient as land plaster.

346. Care of Manure.—From the facts already given the following practical applications may be made:

By the fermentation of manure it loses carbon and water, causing considerable loss of weight and bulk, but if the fermentation is properly conducted there will be little or no loss of valuable constituents.

If the manure while fermenting is allowed to become dry, serious loss of nitrogen will ensue.

If so much water is allowed to fall on the manure that it leaches through and escapes by drainage, great loss of all the valuable constituents will result, and the exhaustion may be so complete that what remains will not be worth hauling to the field.

By the use of gypsum loss of nitrogen by evaporation can be avoided.

347.—Concentration.—It costs as much to haul and spread a ton of poor manure as a ton of the best; consequently there is economy in having manure as concentrated as possible. If a farmer has two heaps of manure, one weighing five tons and containing plant food worth $2.50, and another weighing only one ton but containg the same amount of plant food—and if the cost of hauling and spreading is 50 cents per ton, the net value of the two heaps will be as follows:

Five-ton heap containing plant food worth	$2 50
Less cost of hauling and spreading at 50 cents a ton	2 50
Net value of 5 tons	$0 00
One-ton heap containing plant food worth	$2 50
Less cost of hauling and spreading at 50 cents a ton	50
Net value of 1 ton	$2 00

§ 5. *Manure from Different Animals.*

348. There is quite a difference in the manure produced by different animals. The following table gives the average amount of water, nitrogen, phosphoric acid and potash in a ton of the fresh manure from different stock, the manure including solid and liquid excrements mixed with litter:

	Water.	Nitrogen.	Phosphoric Acid.	Potash.
Horse	1,426 lbs.	11.6 lbs.	5.6 lbs.	10.6 lbs.
Cattle	1,550 lbs.	6.8 lbs.	3.2 lbs.	8 lbs.
Sheep	1,292 lbs.	16.6 lbs.	4.6 lbs.	13.4 lbs.
Swine	1,448 lbs.	9 lbs.	3.8 lbs.	12 lbs.
Poultry*...	1,120 lbs.	32.6 lbs.	30.8 lbs.	17 lbs.

The manure from cattle and swine contains much more water than that of the horse and sheep, and consequently ferments less rapidly. In popular language, the one is said to be cold and the other warm. To secure the best results in fermenting manure, it is well, when possible, to have the manure of all the different animals mixed in one heap. This gives a composition that causes fermentation to progress favorably.

349. Solid and Liquid Manure.—There is a great difference in the composition of the solid and liquid excrement of animals. The former contains the greater part of the phosphoric acid; the latter usually con-

*Fresh, but without litter.

tains more of the nitrogen and potash. The manurial constituents in the solid excrement are mostly insoluble; those in the urine are entirely soluble.

The following table gives the amount of plant food contained in one ton of the fresh solid and liquid excrement of different animals:

	Nitrogen.	Phosphoric Acid.	Potash.
Horse, solid excrement...	8.8 lbs.	7 lbs.	7 lbs.
" Urine	31 lbs.	....	30 lbs.
Cattle, solid excrement...	5.8 lbs.	3.4 lbs.	2 lbs.
" Urine	11.6 lbs.	....	9.8 lbs.
Sheep, solid excrement...	11 lbs.	6.2 lbs.	3 lbs.
" Urine.............	39 lbs.	.2 lbs.	45.2 lbs.
Swine, solid excrement...	12 lbs.	8.2 lbs.	5.2 lbs.
" Urine	8.6 lbs.	1.4 lbs.	16.6 lbs.

The respective values of the different manures will be considered in a later portion of the chapter.

The composition of manure varies with the constitution of the animal and its food. Analyses can therefore give averages only.

§ 6. *Relation of Food to Manure.*

350. The plant food in the manure must come from that contained in the food supplied to the animal. In the animal body a portion of the carbonaceous matter is burned up, and the product thrown off by the lungs (207), but nitrogen, phosphoric acid and potash are not disposed of in this manner. All of these substances except what is used by the animal in the production of milk or increase, will be found in the manure.

351. If an ox is given food containing 100 lbs. dry substance, he will produce manure containing about 36½ lbs. dry substance, and in this manure will be the greater part of the nitrogen, phosphoric acid and potash that was contained in the food supplied. As the quantity of dry substance in the manure is much less than that in the food from which it was produced, while the quantity of plant food is nearly the same, it follows that the dry substance in the manure will contain a larger proportion of plant food than is contained in the dry substance of the food. The *amount* of plant food in the manure, however, cannot be greater than that contained in the food from which it was produced.

352. Cause of Difference in Manure.—If a ton of corn is fed to an ox, and another ton to a sheep,* and all the manure collected, there will be exactly the same amount of plant food in the manure produced by each animal while feeding on the ton of corn; but as the ox will have produced the larger *quantity*, his manure will contain the smaller proportion of plant food.

353. The difference, therefore, in the value of manure produced by different animals is due to the fact that some remove more of the carbonaceous matter from the food supplied, and leave the manure proportionally richer. But no animal can furnish in the manure any more plant food than is contained in the food it receives.

Manure produced by animals fed on poor food will therefore be poor, while that produced by those fed on rich food will be rich. A ton of clover hay contains four times as much nitrogen as a ton of wheat straw; therefore, other things being equal, the manure made by feeding a ton of clover hay will contain four times as much nitrogen as that made by feeding a ton of wheat straw.

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*In this example it is supposed that neither animal is increasing in weight.

354. Proportion of Manure to Food.—When an animal is neither increasing in weight nor giving milk, the manure produced will contain exactly the same amount of plant food that was contained in the food consumed.*

This is evident from the fact that the solid excrement contains all the nitrogen, phosphoric acid and potash of the undigested portion of the food; and all of these substances contained in the digested portion, except what is used in the production of milk, stored up in increase of weight, and used for the repairs of the waste, is carried off in the urine. If the animal is neither growing nor giving milk, the urine will contain all these constituents except the amount used in repairing waste. The wasted substance is taken up by the blood and removed by the kidneys, and exactly balances the amount used in repair.

355. When the animal is giving milk a portion of the nitrogen and phosphoric acid will be removed in the milk, and the manure produced will not usually contain more than from 50 to 75 per cent of the amount of these substances supplied in the food.

356. When an animal is growing rapidly a considerable portion of the nitrogen and phosphoric acid contained in the food is used in the production of bone and muscle, and the manure contains a proportionally smaller amount of these substances than the food.

357. The fattening animal takes comparatively little valuable material from the food, as the greater

*This, of course, includes all the manure both solid and liquid. In the manner in which manure is often saved, or rather wasted, it would contain but a small portion of the plant food furnished the animals.

part of the increase is fat, which contains no plant food. The following table shows the proportion of the nitrogen supplied in the food, that is stored up in increase, the proportion voided in the solid and liquid excrement, and in both, in fattening oxen, sheep and pigs:

	Oxen.	Sheep.	Pigs.
Per cent nitrogen stored in increase ...	3.9	4.3	14.7
Per cent nitrogen voided in solid excrement..............................	22.6	16.7	21
Per cent nitrogen voided in urine......	73.5	79	64.3
Per cent nitrogen voided in total excrement	96.1	95.7	85.3

With the fattening ox and sheep the manure contained about 96 per cent of the nitrogen supplied in the food. As the pig uses a larger proportion of the food he receives in production of increase, and less for heat and energy, the per cent of nitrogen supplied that goes into the manure is less than with either of the other animals.

358. Of the phosphoric acid and potash contained in the food of a fattening animal, from 95 to 100 per cent will be found in the manure.

359. The proportion of nitrogen received in food that is voided in solid and liquid excrement will vary with the kind of food supplied, and the table just given will therefore only be correct in this respect when the diet is the same as that on which the table was calculated. As the manurial ingredients in the digested portion of the food are voided in the liquid excrement and that in the undigested portion in the solid, the more digestible the food the larger proportion of manurial ingredients will be contained in the liquid excrement. Thus, we have seen that a ton of wheat straw contains 60 lbs. nitrogenous matter (230), but that only 12 lbs. of this is digested (239).

If an animal were fed on wheat straw alone, therefore, the solid excrement would contain at least 80 per cent of the total nitrogen voided. By the same tables it will be seen that of the nitrogenous matter in beans, 88 per cent is digested, and therefore when an animal is fed on beans, the greater part of the nitrogen voided will be in the urine.

360. As the plant food contained in the solid excrement is mostly insoluble, while that in the urine is soluble, a pound of nitrogen in urine is worth more than the same amount in the solid excrement, and therefore the more digestible the food the more valuable will be the plant food in the manure produced.

361. We obtain from the foregoing facts the following rules:

The proportion of plant food in the manure will depend principally on the proportion in which it is contained in the food supplied to the animal.

The plant food in the manure will be more valuable in proportion as the food supplied to the animal is more digestible.

Manure produced from working or fattening animals will contain from 90 to 95 per cent of the manurial constituents contained in the food.

Manure made from milk cows and young, growing animals, will contain from 50 to 75 per cent of the manurial constituents contained in the food.

362. Animal Food as Manure.—At one time rape cake was largely used in England as manure, it being sown with the seed. In this country cotton seed meal has been used for the same purpose, and some experimenters have tried bran as a manure.

363. We have already seen that the greater part of all vegetable substances is carbonaceous matter, valuable as food for animals but not as food for plants. For example, a ton of bran contains 1,044 lbs. of digestible food for the animal (239), but it only contains 138.2 lbs. manurial constituents (372). If this ton of bran is fed to fattening oxen, the manure, if all saved, would contain about 132 lbs. of manurial constituents, while the remainder of the food might produce an increase of weight in the oxen of 130 lbs. There would therefore be a gain of 130 lbs. of weight in the oxen to compensate for the loss of six pounds plant food. The plant food in the manure would also be in more available forms than in the bran, and the actual value of the 132 lbs. in the manure would probably be greater than that of the 138.2 lbs. in the bran.*

364. Plow Under or Feed.—The same principle will in some cases determine the question whether it will pay better to plow under a green crop or feed it to stock and return the manure. If on an acre of land there is a crop of clover that will make two tons of hay, it will contain plant food worth $17.52. If the clover is plowed under, this is all the value that will be obtained. If it is cut and fed to fattening cattle and the manure carefully saved and returned, the loss of plant food will be only 88 cents. The question of profit and loss will therefore be on the one hand the value of clover as food; on the other, the cost of cutting, curing and feeding the clover, and of saving, hauling and spreading the manure, and the 88 cents' worth of plant food lost.

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*It must be remembered that all such calculations as these are based on the supposition that *all* the manure is saved. Where the liquid manure is allowed to escape and the solid portion wasted by leaching and evaporation, such calculations will be very wide of the truth.

Any farmer, therefore, who can determine these points, namely:

The feeding value of the clover,
The cost of cutting and curing,
The cost of hauling and spreading manure,

Can readily determine whether it will pay best to plow under a crop of clover or feed it and return the manure.*

§ 7 *Valuation of Manure.*

365. The determination of the comparative values of different makes of commercial manures can be accomplished with reasonable accuracy, but the comparative values of farm-yard manures can be determined approximately only. They not only vary greatly in the amount of plant food contained, but the value of that plant food differs according to the form of combination in which it may exist. A pound of nitrogen contained in urine is available for the plant, and is as valuable as a pound of nitrogen in nitrate of soda, or sulphate of ammonia. But nitrogen contained in half-digested straw is but slowly available, and may remain in the soil unused for years.

366. For convenience the experiment stations of this country have adopted certain figures to represent the market value of nitrogen, phosphoric acid and potash.†

*We have seen (171) that clover when plowed under may by the production of humus, serve other useful purposes in the soil besides furnishing plant food. In all cases where more humus is needed to improve the condition of the soil, a new element enters into the calculation of the comparative profit of feeding or plowing under. In such cases it will doubtless often be more profitable to plow under until the improvement in the condition of the soil has been accomplished.

†The mistake is sometimes made of supposing that these figures represent the value that these substances will be to the

367. The valuations adopted by the Ohio State Board are:

Kind of Plant Food.	Price per lb.
Ammonia	18 cts.
Which is equal to nitrogen	21.86 cts.
Phosphoric acid in soluble compounds	12 cts.
Phosphoric acid in compounds insoluble in water but available as plant food	10 cts.
Phosphoric acid in insoluble compounds which have to undergo decomposition in the soil before they can be used by the plant	5 cts.
Potash in soluble compounds	6 cts.

The phosphoric acid in soluble compounds is called in the official analyses "soluble phosphoric acid." It is principally in the form of monocalcic phosphate (110). The phosphoric acid in compounds insoluble in water, but which can be used as food by plants, is called "reverted;" it is principally contained in bicalcic phosphate (110). The phosphoric acid in insoluble compounds is called "insoluble phosphoric acid," and is principally contained in tricalcic phosphate.

In the estimation of the value of manurial constituents in farm-yard manures, we shall adopt the following standard:

PLANT FOOD IN MIXED MANURES.

Nitrogen	15 cents.
Phosphoric acid	8 cents.
Potash	5 cents.

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farmer when applied to his field. No general estimate of this value can be made, as it depends on soil, season and circumstance. A hundred pounds of nitrogen applied to the soil might in some cases be worth to the farmer a dollar a pound, under other circumstances it might not be worth a dollar for the hundred pounds, or might even prove a detriment. Therefore when the statement is made that nitrogen is worth 22 cents a pound, the meaning is that it can usually be bought in the market for that price in forms that are immediately and entirely available for plant food. Whether the nitrogen will be worth that amount to the farmer in every particular case must be determined by other considerations.

PLANT FOOD IN SOLID EXCREMENT.

Nitrogen	10 cents.
Phosphoric acid	6 cents.
Potash	4 cents.

PLANT FOOD IN URINE.

Nitrogen	22 cents.
Phosphoric acid	12 cents.
Potash	6 cents.

PLANT FOOD IN FOODS.

Nitrogen	15 cents.
Phosphoric acid	8 cents.
Potash	5 cents.

368. Plant food in ordinary barn-yard manure is not worth as much as in nitrate of soda, sulphate of ammonia, superphosphate, etc., on account of being in forms that are less readily available to the plant. The constituents of urine being already in solution are of the highest value. The determination of the value of the manurial constituents in foods is a matter of difficulty and one in which strict accuracy is impossible. The more digestible the food the more valuable are the manurial constituents it contains. Therefore in the table in paragraph 372 the estimated value of poor and indigestible foods is liable to be too high, while that of rich foods is probably below the truth.

369. Tables of Values of Farm-Yard Manures.—These tables represent approximately what the same quantities of nitrogen, phosphoric acid and potash in equally available forms would cost in commercial fertilizers:

VALUE OF 1 TON FRESH FARM-YARD MANURE.*

Nitrogen	9 lbs,	@	15 cents	$1 35
Phosphoric acid	4.2 lbs.	@	8 cents	34
Potash	10.4 lbs.	@	5 cents	52
Total value 1 ton				$2 21

*As usually found in the barn-yard; composed of the mixed excrements of different stock with the straw used as litter.

WELL ROTTED FARM-YARD MANURE.*

Nitrogen	11.6 lbs.	@	15 cents†	$1 74
Phosphoric acid	6 lbs.	@	8 cents	48
Potash	10 lbs.	@	5 cents	50
Total value 1 ton				$2 72

FRESH HEN MANURE.‡

Nitrogen	32.6 lbs.	@	15 cents	$4 89
Phosphoric acid	30.8 lbs.	@	8 cents	2 46
Potash	17 lbs.	@	5 cents	85
Total value of 1 ton				$8 20

AIR DRIED HEN MANURE.

Nitrogen	65.2 lbs.	@	15 cents	$9 78
Phosphoric acid	61.6 lbs.	@	8 cents	4 93
Potash	34 lbs.	@	5 cents	1 70
Total value 1 ton				$16 41

FRESH SOLID EXCREMENT, HORSES.

Nitrogen	8.8 lbs.	@	10 cents	$ 88
Phosphoric acid	3.4 lbs.	@	6 cents	20
Potash	7 lbs.	@	4 cents	28
Total value of 1 ton				$1 36

FRESH SOLID EXCREMENT, CATTLE.

Nitrogen	5.8 lbs.	@	10 cents	$ 58
Phosphoric acid	3.4 lbs.	@	6 cents	20
Potash	2 lbs.	@	4 cents	08
Total value of one ton				$0 86

FRESH SOLID EXCREMENT, SHEEP.

Nitrogen	11 lbs.	@	10 cents	$1 10
Phosphoric acid	6.2 lbs.	@	6 cents	37
Potash	3 lbs.	@	4 cents	12
Total value of one ton				$1 59

*The manure from which this analysis was made must have been rotted in an open yard, and exposed to waste both by leaching and evaporation, otherwise it would show a higher value in proportion to the fresh. It is however, probably a fair representation of the rotted manure that will be found in most barn-yards.

†If the nitrogen in the fresh manure is worth 15 cents a pound that in the rotted manure (if fermentation is properly conducted) is worth more.

‡Manurial constituents in hen manure are probably more soluble and therefore really worth more per pound than in the mixed farm-yard manure.

FRESH SOLID EXCREMENT, SWINE.

Nitrogen	12 lbs.	@	10 cents	$1 20
Phosphoric acid	8.2 lbs.	@	6 cents	49
Potash	2.6 lbs.	@	4 cents	10
Total value of one ton				$1 79

FRESH URINE, HORSES.

Nitrogen	31 lbs.	@	22 cents	$6 82
Potash	30 lbs.	@	6 cents	1 80
Total value of one ton				$8 62

FRESH URINE, CATTLE.

Nitrogen	11.6 lbs.	@	22 cents	$2 55
Potash	9.8 lbs.	@	6 cents	59
Total value of one ton				$3 14

FRESH URINE, SHEEP.

Nitrogen	39 lbs.	@	22 cents	$8 58
Phosphoric acid	0.2 lbs.	@	12 cents	02
Potash	45.2 lbs.	@	6 cents	2 71
Total value of one ton				$11 31

FRESH URINE, SWINE.

Nitrogen	8.6 lbs.	@	22 cents	$1 89
Phosphoric acid	1.4 lbs.	@	12 cents	17
Potash	16.6 lbs.	@	6 cents	1 00
Total value of one ton				$3 06

370. These tables should have careful study. Farmers who allow their liquid manure to drain away but carefully preserve the solid may be surprised to learn that while a ton of the solid excrement of a horse is worth only $1.36, a ton of urine is worth $8.62.

It is true that these figures represent only the commercial value of these substances, and not their value when applied to the soil, but the proportion will be correct, even if the actual value differs. Thus if a ton of solid horse manure under certain circumstances is worth to the farmer one-half more than the figures given, under the same circumstances a ton of the urine will also be worth one-half more than the figures given. If under certain circumstances the ton of urine is not worth $8.62, then, under the same circumstances a ton of solid will not be worth $1.36.*

Urine being rich in nitrogen in a form that is immediately available, renders it specially valuable as a top dressing for crops requiring this substance.

371. Valuation of Foods as Manures.—The knowledge of the manurial constituents of foods and their value, is of considerable practical importance, as it has much to do with the profits of feeding and the choice of foods. Two foods may have equal feeding value and cost about the same, but the manure produced from one be worth more than that produced from the other. By knowing the feeding value of each food and the value of the manure produced from it, a farmer can often make a calculation whether it will pay to sell some article of food and buy another.

The question is often asked whether it will pay to sell straw, the opinion being held by many that a farmer who sells straw will impoverish his farm. By reference to the following table it will be seen that the plant food in a ton of straw is worth $2.44, while that in a ton of bran is worth $13.25. Then if a farmer can sell straw for $2.44 per ton and buy bran at $13.25 a ton, there would be no loss as far as elements of fertility are concerned. There would be in fact a slight gain, as the plant food in the manure produced by feeding the bran would be in a more available condition than that in the straw.†

372. Sir J. B. Lawes, of England, many years ago prepared a table giving the value in money of the

*An exception to this rule may arise from difference in the character of the two manures. Urine is rich in nitrogen and potash, but contains no phosphoric acid. When this latter substance is the one needed by the soil, the solid manure will have the greater proportional value.

†In this we have considered only the value of the plant food

manurial constituents in different foods. Since its publication this table has been the standard in this country as well as England. The following table is calculated on the basis of valuation given in paragraph 367, and differs slightly from that of Lawes:

AMOUNT AND VALUE OF MANURIAL CONSTITUENTS CONTAINED IN ONE TON OF DIFFERENT FOODS.

Name of Food	Pounds Nitrogen	Pounds Phosphoric acid	Pounds Potash	Value.
Linseed cake..........	90.0	39.2	29.4	$18 10
Cotton cake, decorticated..................	132.0	62.4	30.0	26 29
Cotton cake, undecorticated	78.0	45.8	40.2	17 37
Beans	82.0	23.2	24.0	15 36
Peas	72.0	17.6	19.6	13 18
Bran.................	44.0	64.6	29.6	13 25
Oats	41.2	12.4	9.0	7 62
Barley	34.0	14.6	9.8	6 76
Indian corn	33.2	12.2	7.2	6 32
HAY AND STRAW.				
Clover hay............	39.4	11.2	39.0	8 76
Meadow hay..........	31.0	7.6	33.6	6 94
Wheat straw..........	9.6	5.2	11.6	2 44
Barley straw..........	10.0	4.0	19.4	2 79
Oat straw.............	10.0	5.0	20.8	2 94
Pea straw, cut in bloom	45.8	13.6	46.4	10 28
Pea straw, ripe........	20.8	7.0	20.2	4 69
Cornstalks	9.6	10.6	19.2	3 25
GREEN FODDER.				
Grass.................	10.8	3.0	9.2	2 32
Red clover............	10.2	2.8	8.8	3 37
Peas	10.2	3.0	10.2	2 50
Oats	7.4	3.4	15.0	2 73
Rye	10.6	4.8	12.6	2 60
Corn	3.8	2.6	8.6	1 21
Hungarian	20.0	2.5	17.0	4 05
Sorgum	8.0	1.6	7.2	1 69
ROOTS.				
Potatos	6.8	3.6	11.2	1 87
Mangels	3.8	1.4	7.8	1 07
Carrots	3.2	2.0	6.4	96
Turnips	3.6	1.2	5.8	5 77

373. From this table and the rules laid down in

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contained in the straw. When straw is used as an absorbent, paragraph 361, a farmer can calculate the value of the manure produced by feeding a given quantity of any kind of food to any class of stock.

Thus, a ton of hay with half a ton of corn meal, and 500 lbs. mangels contains plant food worth $10.62. If this were fed to fattening oxen, 95 per cent of the plant food would be contained in the manure produced, which would therefore be worth $10.09. A ton of corn meal fed to fattening cattle would produce manure worth $6.00. Fed to fattening pigs the manure produced would be worth $5.37. Fed to milk cows the manure produced would not be worth more than $4.74.*

§ 8. *Commercial Fertilizers.*

374. The use of commercial fertilizers has greatly increased during the past few years. Their composition is often very uncertain, and in localities where there is no efficient fertilizer law in force, they should be purchased with caution. In Ohio and some other states the manufacturer is required to print the analysis on every package, and a heavy penalty is imposed if the composition does not agree with the printed analysis.

375. Bone Dust.—This is bones reduced to a powder, and when pure the composition is the same as bones. One ton contains:

Nitrogen	76 lbs.
Phosphoric acid	364 lbs.

The phosphoric acid is in the form of tricalcic phos-

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and prevents the waste of liquid manure, it has a practical value greatly in excess of the plant food it contains. Thus, if a farmer sells a ton of straw, and in consequence of the lack of sufficient absorbents allows a ton of horse urine to be wasted, the total loss, direct and indirect, would be $11.06.

*All these calculations are made on the supposition that *none* of the manure produced is wasted.

phate, and is therefore not available as plant food until it has undergone decomposition in the soil. Grinding the bones by increasing the amount of surface exposed (164) facilitates this decomposition, but the action is comparatively slow, and the effect of a dressing of bone dust is spread over several years. On account of its insolubility, bone dust may sometimes be used with advantage on soils that possess but little power of retaining fertilizers.

376. Guano is the excrement of sea fowls, that has in some places been accumulating for ages. It is principally obtained from the islands of the Pacific. The valuable constituents are phosphoric acid and nitrogen. That which comes from countries where no rain falls, contains a large amount of nitrogen, sometimes as much as 240 lbs. to the ton. Where it has been exposed to rain the nitrogenous matter has been mostly washed out, and little but the phosphoric acid remains. Phosphatic guanos are often converted into superphosphates by treatment with sulphuric acid.

Owing to the uncertainty of its composition no analysis of guano can be given that would apply to more than one sample. It should always be bought on the analysis of the particular brand.

377. Rock Phosphate.—Large deposits tricalcic phosphate are found in some places, (110) and are called "rock phosphate." These deposits are the remains of marine animals. The organic matter has wasted, and the calcic phosphate of the bones become compacted into a mass like rock. This is ground to a powder, as fine as flour, and in this condition used as a fertilizer. It is most valuable on soils rich in humus, as the organic acids they contain assist in its decomposition and solution. It is also rendered more soluble by composting with barn-yard manure. It contains no plant food of value, except phosphoric acid. Rock phosphate is often converted into superphosphate by treatment with sulphuric acid.

378. Salts Containing Nitrogen.—Those in common use as fertilizers are the sulphate and chloride of ammonia, and nitrate of soda, (108, 109 and 113). They are valuable only for the nitrogen they contain. Being entirely soluble they act very rapidly and will give nearly all their effect the same year they are applied. Lawes and Gilbert found that 45 to 50 per cent of the nitrogen in these salts was recovered in the increased crop the first year, when applied to wheat and barley; but that the following year showed very little effect from their application.

Owing to their solubility these salts are very liable to be washed out in the drainage water, if applied at a season when the crop cannot make immediate use of them. They are best applied as a top dressing in the spring.

379. Superphosphate.—The composition of superphosphate and the principles of its manufacture have already been given (111). Commercial superphosphate is a mixture of monocalcic phosphate with gypsum. It also usually contains some free phosphoric acid, and bicalcic, and tricalcic phosphate. When prepared from bones it also contains a considerable per cent of nitrogen. To increase the amount of nitrogen, blood, shoddy, leather waste, and the refuse of slaughter houses are frequently added. The character and composition of any particular brand can only be determined by analysis.

Many of the commercial superphosphates contain a large per cent of nitrogen and potash, while others, especially those made from rock phosphate contain only phosphoric acid.

The advantage of converting bones and rock phosphate into superphosphate is due to the greater solubility of the monocalcic phosphate. No plant food is added by the process.

380. Manufacture of Superphosphate.—The principles of the manufacture have already been given (111). In practice it will rarely prove profitable for the farmer to manufacture his own. The proportions would be, theoretically:

Bones	100 lbs.
Sulphuric acid	35 lbs.
Water	13 lbs.

Which would produce 148 lbs. dry superphosphate. In practice, several times as much water would be needed to make it possible to mix the mass. The bones should be put in a wooden vessel, and the water poured over them. The acid should then be added, a little at a time. If all the acid is added at once the mixture will be so strong that it will be liable to destroy the wooden vessel. Therefore time, between each addition of acid, must be allowed for it to combine with the bones. The decomposition of whole bones by sulphuric acid is a slow and tedious process.

§ 9. *Adaptation of Manures to Crops.*

381. Different crops require very different supplies of food. The table in paragraph 331 shows the amount of different manurial ingredients removed by different crops, but the proper manure for each crop cannot be determined by such a table. Thus, it will be seen that a crop of clover removes from the soil more than twice as much nitrogen as a crop of wheat, and yet wheat specially needs nitrogenous manures, while clover does not. The reason of this is some crops have greater ability to obtain certain substances from the soil than others.

It was formerly taught that all the constituents of plant food contained in a crop must be added in the manure. This is no longer considered necessary. If each crop is manured with the particular substance most needed for its successful growth, and a judicious system of rotation followed, the best results will be obtained in proportion to the manures used, and no undue strain will be made on the capabilities of the soil.

382. Cereal Crops.—These crops, in general, are specially benefitted by nitrogenous manures. In the experiments at Rothamsted it was found that from forty to eighty pounds of available nitrogen to the acre secured a maximum crop. Potash is usually of little value. Phosphoric acid when used alone seldom produces much effect, but is beneficial in connection with nitrogen.*

383. Indian Corn.—No satisfactory experiments have yet been made to determine the best manures for corn. Phosphoric acid appears to be beneficial in many cases, and when combined with nitrogen, good results are usually obtained. Land plaster is a favorite manure for this crop.

384. Grass—Requires all the elements of plant food, and well rotted stable manure applied as a top

*It is the opinion in many parts of this country that phosphoric acid is the manure specially needed for wheat. This opinion is probably due to the fact that throughout the West the superphosphates used have been mostly prepared from bones, and contain nitrogen, often in considerable quantity. The general result of experiments with purely phosphatic manures are that, unless combined with nitrogen, they are seldom of much value for cereals.

dressing to old meadows or pastures supplies this need. Bone-dust is also especially valuable for this crop, and can be sown broadcast.

385. Clover.—Although clover contains a larger amount of nitrogen than almost any other crop grown on the farm, it does not seem to need nitrogenous manures. Potash and lime are the most valuable manures, the lime being best applied in the form of land plaster.

386. Turnips—Require nitrogen and phosphoric acid. They seem to have little ability to appropriate the phosphoric acid existing in the soil in insoluble combinations; hence fresh applications of superphosphate in connection with farm-yard manure have a remarkable effect. In England superphosphate is chiefly used for turnips, which are one of the most important crops grown there. Nitrogen without phosphoric acid will not secure a full crop.

387. Mangels—Obtain much less benefit than turnips from phosphoric acid, and require more nitrogen. Mixed farm-yard manure is suitable.

388. Potatos—Are similar to turnips, giving best results from use of phosphoric acid and nitrogen. In soils deficient in potash this is an essential constituent in the fertilizer used; but soils that have been manured with farm-yard manure usually contain sufficient potash.

§ 10. *Summary.*

The problem of maintaining the fertility of the farm can only be satisfactorily solved by a consideration of all the principles taught in this chapter.

The farmer who drains and cultivates, but fails to restore to his land, in a measure at least, the elements of fertility that have been removed in the crops, will, sooner or later, reduce the amount of available plant food in his soil to such a degree that the production will be seriously decreased.

The farmer who carefully saves all his manure and returns it to the soil, but pays no attention to draining, and but little to cultivation, who allows weeds to grow and rob the plants, will probably complain that manuring does not pay—for no amount of manuring will secure good crops on soil that needs draining, or where the proper mechanical conditions are not provided.

The farmer who builds his barns and stables on a side-hill, allows all the liquid manure to escape into a creek, and keeps the solid portion where the drippings from the roofs will fall upon and leach through it, will be very likely to reach the conclusion that manure is of little value and will not pay for hauling to the field. And his conclusion will probably be correct with reference to the manure he uses.

It has been shown (160) that when a judicious rotation is followed, a good proportion of the crops fed on the farm, and all the manure carefully saved and returned, that the drain upon the soil will be but small.

It would seem, in fact, that under such circumstances, there is no need, at least at present, for procuring plant food from sources away from the farm. The farmer is not required to make provision for contingencies that may arise from seven hundred to three thousand years hence. If he uses care and judgment, he may not only produce on his farm the material needed for maintaining the fertilitity of his soil, but, by rendering soluble the plant food it already contains, actually increase its fertility. It should be ever borne in mind that it is not alone the amount of plant food in the soil that determines its fertility, but also the forms of combination in which that plant food exists.

Most soils contain a great amount of plant food, and hence treatment such as drainage, cultivation, lime, fallow, and green crops, which do not add plant food, but only change the condition of that already present, are often successful in changing a comparatively barren soil into a fertile one. And if, after fertility has thus been obtained, the greater part of the crops grown on such a soil are fed on the farm and the manure produced returned to the soil, the fertility may be long maintained without the addition of plant food from sources outside the farm.

If, however, it is desirable to rapidly bring a poor soil to a condition of fertility, there can be no doubt of the value of commercial fertilizers, as these will enable the farmer to grow large crops with which to make much manure that can be brought back to the soil.

When the farmer wishes to make the growing of grain, to be sold off the farm, his principle business, the use of imported fertilizers will sooner or later become a necessity.

In many cases one of the most economical methods of obtaining plant food from outside sources, is to buy bran, linseed or cotton seed cake, etc., and feed it to stock, carefully saving the manure.

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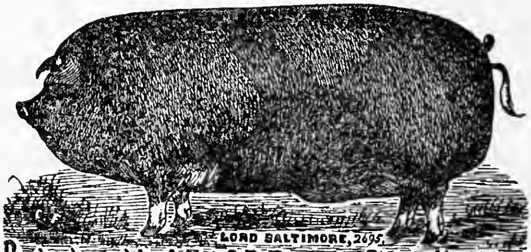

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