JOHNSTON'S ELEMENTS

OF

AGRICULTURAL CHEMISTRY

AN ENTIRELY NEW EDITION

JOHNSTON'S ELEMENTS

OF

AGRICULTURAL CHEMISTRY

FROM THE EDITION BY

SIR CHARLES A. CAMERON, M.D.

REVISED, AND IN GREAT PART REWRITTEN

BY

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'Farmyard Manure,' &c.

SEVENTEENTH EDITION

WILLIAM BLACKWOOD AND SONS
EDINBURGH AND LONDON
MDCCCXCIV

TO

BERNARD DYER, Esq.

D.Sc., F.I.C., F.L.S.

THE SEVENTEENTH EDITION

OF THIS WORK

IS DEDICATED,

BY HIS SINCERE AND OBLIGED FRIEND,

THE EDITOR.

Dec. 1893.

TO

JOHN BENNET LAWES, LL.D., F.R.S.

AND

JOSEPH HENRY GILBERT, PH.D., F.R.S.

WHOSE RESEARCHES,

OF MORE THAN FORTY YEARS' DURATION,

HAVE EXTENDED THE BOUNDARIES OF

NEARLY EVERY PROVINCE

OF THE DOMAIN OF SCIENTIFIC AGRICULTURE,

THE TENTH EDITION

OF THIS WORK

IS DEDICATED.

Sept. 1877.

DEDICATION OF THE TWELFTH EDITION.

TO

JAMES DEWAR, Esq.,

M.A., F.R.S.,

FULLEREAN PROFESSOR OF CHEMISTRY IN THE ROYAL INSTITUTION
OF GREAT BRITAIN, AND JACKSONIAN PROFESSOR OF
NATURAL SCIENCE, CAMBRIDGE UNIVERSITY.

My dear Dewar,—

To no one could I with greater pleasure dedicate this book than to you.

I know of no British worker in science who has within the same period of time done more than you have to widen its boundaries.

It is men like you who have won for Scotland its reputation as a country of original thinkers and hard workers.

Believe me,

My dear Dewar,

Yours very faithfully,

CHARLES A. CAMERON.

Sept. 1881.

PREFACE TO THE SEVENTEENTH EDITION.

THE great advance Agricultural Chemistry has made during the last few years has rendered an entirely new edition of this text-book necessary. The work has consequently been subjected to most careful revision. Large portions of the book have been entirely rewritten, and much new matter added. The only portion which has been practically left unaltered is the geological section. It is especially hoped that the Chapters on Milk and Dairy Products, in which a short summary of some of the more important results of recent investigations is given, may add to the value of the new edition.

As the work does not claim to be a text-book of pure Chemistry, students unacquainted with that science are referred to any of the many excellent chemical text-books. While, therefore, it is highly desirable that those using this work should possess some knowledge of the elements

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For a more elaborate treatment of the important subject of soil-fertility and the nature and functions of manures, I would refer readers to my work on 'Manures and the Principles of Manuring,' which is published simultaneously with this work.

In conclusion, I have to thank my friend Dr Bernard Dyer for having kindly read the proof-sheets, and for many valuable suggestions.

C. M. AIKMAN.

ANALYTICAL LABORATORY,
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December 1893.

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ELEMENTS

OF

AGRICULTURAL CHEMISTRY.

CHAPTER I.

INTRODUCTORY.

Objects of the Farmer.—The farmer's object is to raise from a given extent of land the largest quantity of the most valuable produce at the least cost, in the shortest period of time, and with the least permanent injury to the soil; the rearing and fattening of stock in the most efficient and economical method; and the production of dairy produce. Chemistry, Geology, Botany, and Physiology throw light on every step which he takes, or ought to take, in order to effect these.

There are certain definite objects which, in their connection with agriculture, these sciences hope to attain. Thus, without distinguishing the special province of each, they propose generally:—

1. *To collect, to investigate, and, if possible, to explain all known facts in practical husbandry.*—This is their first

duty—a laborious, difficult, but important one. Many things which are received as facts in agriculture prove to be more or less untrue when investigated and tested by experiment. Many ascertained facts appear inexplicable to the uninstructed—many even opposite and contradictory—which known principles clear up and reconcile; yet there are many more which only prolonged research can enable us to explain!

2. *From observations and experiments made in the field or in the laboratory, to deduce principles which may be more or less applicable in all circumstances.*—Such principles will explain useful practices, and confirm their propriety. They will also account for contradictory results, and will point out the circumstances under which this or that practice may most prudently and most economically be adopted.

Armed with the knowledge of such principles, the instructed farmer will go into his fields as the physician goes to the bedside of his patient,—prepared to understand symptoms and appearances he has never before seen, and to adapt his practice to circumstances which have never before fallen under his observation.

To deduce principles from collections of facts is attended with much difficulty in all departments of knowledge. In agriculture it is an unusually difficult task. This difficulty is largely due to the wide differences which exist in the conditions under which agriculture as an industry is pursued. Soils differ so widely in their nature that what is good treatment for one soil is not good treatment for another. Crops suited for one part of the country, similarly, are not equally suited for other parts. Again, to apply potash as a manure to certain soils is simply to throw away the money it costs. To multiply examples of this is easy, but it is not required. The above instances will serve to indicate the great variety of the conditions of agriculture, and emphasise the difficulty of discovering general principles to guide the farmer in his ordinary work.

Observations and experiments in the field were till recently generally made with too little care, or recorded with too little accuracy, to justify the scientific man in confidently adopting them as the basis of his reasonings. Now, however, experiments are being more largely carried out, and by their aid the advance of sound agricultural knowledge cannot fail to be greatly promoted.

3. *To suggest improved and perhaps previously unthought-of methods of fertilising the soil.*—A true explanation of twenty known facts or results, or useful practices, should suggest nearly as many more. Thus the explanation of old errors will not only guard the practical man from falling into new ones, but will suggest direct improvements he would not otherwise have thought of. So, also, the true explanation of one useful practice will point out other new practices which may safely and with advantage be adopted.

4. *To analyse soils, manures, and vegetable products.*—This is a most laborious department of the duties which agriculture expects chemistry to undertake in her behalf.

a. *Soils.*—The value of soil analyses to the practical farmer, from having been overrated in the past, has during the last few years become underrated. It is extremely difficult, nay, impossible, to estimate exactly what quantity of plant food is present in a soil in a condition available for the plant's immediate needs. This is really best ascertained by experimenting with the plant itself. Nevertheless, a soil analysis is calculated, in many cases, to be of great service to the farmer in guiding him as to the best treatment for his soil. Even a very partial analysis may be of great service in showing a soil's deficiency in some most important ingredient, such as lime, &c. Thus, in many cases, certain wants of the soil are directly pointed out by analysis; in others, modes of treatment are suggested by which a greater fertility is likely to be produced,—and as our knowledge of the subject extends, we may hope to obtain, in every case, some useful directions for the improvement or more profitable culture of the land.

b. *Manures.*—Were the discovery and introduction of artificial manures the only service which agricultural chemistry had rendered the farmer, it were sufficient to lay the latter under lasting obligation to the former; for unquestionably the use of artificial fertilisers has become a necessary condition of our modern system of husbandry. Of the manures we employ, therefore, too much cannot be known. An accurate knowledge of these will guard the practical man against an improvident waste of any of those natural manures which are produced upon his farm—thus lessening the necessity for foreign manures by introducing a greater economy in the use of those he already possesses. It will also protect him against any imposition on the part of the manure manufacturer.

c. *Vegetable products.*—In regard to the products of the soil, few things are more necessary than a rigorous analysis of all their parts. If we know what a plant contains, we know what elementary bodies it takes from the soil, and consequently what the soil *must* contain if the plant is to grow upon it in a healthy manner—that is, we shall know to a certain extent how to manure it.

On the other hand, in applying vegetable substances to the feeding of stock, it is of equal importance to know what they severally contain, in order that a skilful selection may be made of such kinds of food as may best suit our purposes, and that no nutritive materials be relatively deficient or excessive.

5. *To explain how plants grow and are nourished, and how animals are supported and most cheaply fed.*—What food plants require, and at different periods of their growth, whence they obtain it, how they take it in, and in what forms of chemical combination. Also, what kind and quantity of food the animal requires, what purposes different kinds of food serve in the animal economy, and how a given quantity of any variety of food may be turned to the best account. What questions ought more to interest the practical farmer than these?

Then there are certain peculiarities of soil, physical, chemical, and biological, which are best fitted to promote the growth of each of our most valuable crops. There are also certain ways of cultivating and manuring, and certain kinds of manure, which are specially favourable to each, and these again vary with every important modification of climate. Thus chemical physiology has much both to learn and to teach in regard to the raising of crops.

Recent researches have shown what important functions are performed in all departments of agriculture by micro-organic life. Whether it be in the soil, where bacteria abound in teeming millions and where they are active as preparers of plant food, or in certain dairy products such as milk, butter, and cheese (the ripening of which is due to their agency), their *rôle* in the agricultural economy is a most important one. This shows the important bearing which the science of Bacteriology has in throwing light on many agricultural customs and processes.

So, too, different kinds and breeds of domestic animals thrive best upon different kinds of food, or require different proportions of each, or to have it prepared in different ways, or given at different times. Among animals of the same species also, the growing, the full-grown, the fattening, and the milking animal, respectively require a peculiar adjustment of food in kind, quantity, or form. All such adjustments the researches of chemistry and physiology alone enable us accurately to make.

6. *To test the opinions of theoretical men.*—Erroneous opinions lead to grave errors in practice. Such incorrect opinions are not unfrequently entertained and promulgated even by eminent scientific men. They are in this case most dangerous and most difficult to overturn; so that against these unfounded theories the farmer requires protection, no less than against the quackery of manufactured manures. It is only on a basis of often-repeated, skilfully conducted, and faithfully recorded experiments, made by instructed persons, that true theories can ever be successfully built up. Hence the importance of experiments in practical agriculture.

Such are the principal objects which chemistry, aided by geology and physiology, either promises or hopes to attain. In no district, however, will the benefits it is capable of conferring upon agriculture be fully realised unless its aid be really sought for, its ability rightly estimated, and its interference earnestly requested. In other words, what we already know, as well as what we are every day learning, must be adequately diffused among the agricultural body, and in every district means must be adopted for promoting this diffusion. It is in vain for chemistry and the other sciences to discover or suggest, unless their discoveries and suggestions be fully made known to those whose benefit they are most likely to promote. In a word, the true key-note of all agricultural progress is to be found in the motto of the greatest agricultural society in the world—viz., *Practice with Science.*

Organic and Inorganic Matter.—In the prosecution of his art two distinct classes of substances engage the attention of the practical farmer—the *living* animals and crops which he raises, and the *dead* soils from which the latter are gathered. If he examine any fragment of an animal or vegetable, either living or dead,—a piece of flesh or wood, for example,—he will observe that it exhibits pores of various kinds (tubes, cells, &c.) arranged in a certain order; that it has a species of internal structure; that it has various parts, or *organs;* in short, that it is what physiologists term *organised.* If he examine, in like manner, a lump of earth or rock, he will perceive no such structure. To mark this distinction, the parts of animals and vegetables, either living or dead—whether entire or in a state of decay—are called *organic* bodies; while metallic, earthy, and stony substances are called *inorganic* bodies.

Organic substances are more or less readily burned away and dissipated by heat in the open air; inorganic substances are generally fixed and permanent in the fire.[1]

There is a higher group of substances than organic bodies—namely, those termed *organised.* Woody fibre, muscle, nervous tissue, are all examples of organised structures. These bodies have not been formed artificially, and they never exhibit a crystalline structure. Organic bodies—such as, for example, urea, sugar, and tartaric acid—resemble in the definiteness of their composition and their tendency to assume a regular or crystalline form, the inorganic or mineral compounds. Many organic compounds are capable of being artificially produced from inorganic materials; and it is diffi-

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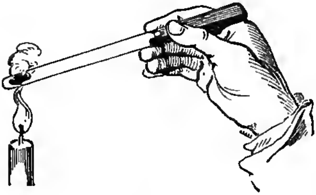
[1] The majority of those compounds which make up the mass of vegetable and animal matter are decomposed at a comparatively low temperature—viz., 250° C. (482° F.)

cult, if not impossible, to divide by a sharp line the organic from the inorganic compounds.

Now the crops which grow upon the land, as well as the soil in which they are rooted, contain a portion of all these classes of substances. In all fertile soils there exists more or less vegetable or other matter, of *organic* origin. If we heat a portion of such a soil to redness in the open air, as in fig. 1, this organic matter will burn away, leaving the inorganic or mineral matter behind.[1] By this burning, most soils are changed in colour, but if previously dried, are not materially diminished in bulk. The inorganic matter forms by far their larger part.

Fig. 1.



All vegetables, again, as they are collected for food, leave, when burned, a sensible quantity of ash; but of them it forms only a small part. Wood contains about from ¼ to ½ per cent, grain on an average between 2 and 3 per cent, straw from 4 to 8 per cent, roots and tubers about the same, hay on an average about 7 per cent; and it is only in leaves that it amounts to over 20 per cent of the weight of the vegetable substance. There is a considerable variation in the percentage of ash constituents even in the same kinds of plants. Much depends on the age and part of the plant. In succulent plants, or in the more succulent parts of the plant (as in the leaves), the percentage of ash is found to be most

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[1] To apply the term *inorganic* to the ash constituents of a plant is not, strictly speaking, correct, as a certain proportion of these form an essential part of the plant tissue, and therefore may be regarded as belonging to the organic portion.

abundant; while in drier portions of the plant it is found to be least. As a general rule the lower parts of the plant are less rich in ash constituents than the upper portions, and as growth develops this difference increases owing to the accumulation of the mineral ingredients in the extremities of the plant. So, also, the outer portions are richer than the inner portions—the husk and chaff of oats, wheat, barley, &c., containing more ash than the rest of the seed. It may be stated as a general rule that the proportion of ash of the entire plant diminishes as the plant grows older, being greatest in the young plant and least in the matured one, although certain parts of the plant, such as the leaves, contain more ash when old than young. Hence, when a handful of wheat, wheat-straw, hay, &c., is burned in the air, a comparatively small weight of matter only remains behind. Every one is familiar with this fact who has seen the small bulk of ash that is left when weeds, or thorn-bushes, or trees are burned in the field, or when a hay or corn stack is accidentally consumed. Yet this ash is very important to the plant, and the study of its true nature throws much light, as we shall hereafter see, on the practical management of the land on which any given crop is to be made to grow. It strikes us also as being important in quantity, when we consider how much may be contained in an entire crop. Thus the quantity of ash left by a ton of wheat-straw is sometimes as much as 330 lb., and by a ton of oat-straw as much as 200 lb., though not generally more than 120 in each case. A ton of the grain of wheat leaves on an average about 45 lb., of the grain of oats about 80 lb., and of oak-wood only 4 or 5 lb.

Animal substances also leave a proportion of ash when burned in the air. Dry flesh and hair leave about 5 per cent of their weight of ash; dry bones more than half their weight. The burnt ashes of a human adult average only 3½ lb.

Generally, therefore, the soil contains little organic and much inorganic or mineral matter; the plant much organic and little mineral; the animal, in its soft parts little, in its hard or solid parts much, mineral matter.

CHAPTER II.

CHEMICAL NOMENCLATURE AND NOTATION.

Elements and Compounds.—The various kinds of organised, organic, and inorganic matter of which soils, plants, and animals consist, are divided by chemists into two groups. Those which, by the agency of heat, or by any chemical or other means, can be separated into two or more unlike kinds of matter, are called *compound* bodies; those which cannot be so separated are called *simple* or *elementary* bodies.

The Chemical Elements.—By the process of *analysis* chalk may be resolved into a white substance termed lime, and a gas called carbonic acid gas, or carbon dioxide. In its turn lime yields a metallic substance (calcium) and a gas termed oxygen, identical with an important constituent of the air we breathe. Carbonic acid gas in its turn is convertible into oxygen gas, and a black substance known as carbon, which latter is identical in composition with the diamond. Chalk (calcium carbonate) therefore contains the compounds lime (calcium oxide) and carbonic anhydride (carbon dioxide), and its ultimate constituents are calcium, carbon, and oxygen.

All attempts to resolve calcium, carbon, and oxygen into simpler forms of matter having failed, these bodies are considered to be simple, elementary, or undecomposable substances. Some bodies once regarded as simple are now known to be compound, and probably some of the so-called elements of our time may in the progress of knowledge be decomposed. It is, however, convenient to consider all substances that resist decomposition as elements.

Seventy elements at least are at present known to exist; and either alone or combined with each other in various proportions, they constitute all animal, vegetable, and mineral substances.

Chemical Symbols.—It is often found convenient to use a symbol instead of a name when referring to an element. The symbol is the first letter—with sometimes a second added—of the name of the element. O is the symbol for oxygen, C for carbon, Cl for Chlorine, Ca for calcium, &c. Many of the symbols are taken from the Latin or Latinised names of the elements. For example, Fe from *ferrum*, the Latin name of iron, and Ag from *argentum*, silver.

Definition of Atom and Molecule.—The elements unite with each other, not in every proportion, but in fixed and unvarying quantities. For example, 1 part of hydrogen unites with 35½ parts of chlorine, but never with, say, 43 or 51 parts. The smallest quantity of an element which enters into combination is supposed to be the *relative* weight of its smallest divisible particle, or *atom.* The relative weight of an atom of oxygen is 16, of sulphur 32, of carbon 12—assuming, for the purpose of comparison, that the weight of the atom of hydrogen is 1. Several atoms of one element may unite with one or more atoms of another element or of several elements. Thus an atom of carbon combines with 2 of oxygen to form carbonic anhydride, and 2 atoms of hydrogen, 4 of oxygen, and 1 of sulphur combine to produce oil of vitriol.

It is believed that most of the elements are incapable of existing in the state of free atoms, and that when their atoms are not in union with those of other elements they enter into combination with each other. Hydrogen in the free state exists in pairs of atoms, and each pair of atoms is termed a *molecule.* H represents the atom of hydrogen, HH or H_2 its molecule. Certain metals, such as, for example, mercury, can exist in the state of free atoms; hence their atomic and molecular weights are identical.[1] On the other hand, the molecules of phosphorus and arsenic contain each four atoms. The molecule of a *compound* is the smallest quantity which can exist, since it must contain at least two atoms. Although the term atom of a compound often occurs in books, it is not a correct one.

Molecular Volume.—Although there is great diversity in the atomic weights of the elements, there is a remarkable simplicity in their combinations by volume. 1 part of hydrogen unites with 35·5 parts of chlorine, but the two elements combine in equal volumes.

Molecular volumes of the elements, and even of compounds, are with a few exceptions (explainable or likely to be explained) the same. A molecule of hydrogen (HH, or H_2) occupies exactly the same space as a molecule of chlorine gas, hydrochloric acid, or alcohol vapour.

In the case of compounds, it is found that one molecule of an acid is capable of doing as much work as two or three molecules of another acid. Thus it requires three times as many molecules of nitric acid to unite with bodies to form neutral salts as it does of citric acid, and twice as many as compared with sulphuric

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[1] Such is the case also with sodium, cadmium, and zinc.

acid. Nitric acid is *monobasic*, sulphuric acid is *dibasic*, and phosphoric acid is *tribasic*.

Chemical Nomenclature.—When a non-metallic element unites with a metal, the compound is named in such a way as to indicate its composition. Thus oxygen and iron in combination produce iron ox*ide*; iodine and lead, lead iod*ide*; sulphur and sodium, sodium sulph*ide* —and so on. Acids are compounds containing hydrogen, and indeed may be regarded as salts of that element. Sulphuric acid is said to be hydrogen sulphate; and when the latter and one atom of oxygen—a molecule of water (H_2O)—are removed, the remaining portion of the compound is termed sulphuric anhydride (SO_3). The substance well known under the name of carbonic acid is really not an acid until it is dissolved in water. In the dry state it is, properly speaking, carbonic anhydride. Every acid has its anhydride, though in a few instances the anhydrides have not been isolated. Sulphuric anhydride, combined with the oxides of iron, calcium, magnesium, &c., produces sulphate of iron, calcium, magnesium, &c. Phosphoric anhydride and potash produce potassium phosphate; nitric anhydride and soda, sodium nitrate. The table on pages 14, 15, shows the old and new names given to well-known compounds. The formula of each compound is given, but the water of crystallisation, &c., which they sometimes contain, is omitted. Occasionally, however, in the following pages the ordinary or common names of compounds will be used—sulphate of ammonia for ammonium sulphate, oil of vitriol for sulphuric acid, sulphuretted hydrogen for hydrogen sulphide, &c.

Oxygen, sulphur, and other non-metals unite with the metals in more than one proportion. Those compounds which contain the larger proportion of the non-metal are named thus—mercur*ic* oxide, ferr*ic* (Lat. *ferrum*,

TRIVIAL OR POPULAR NAME.	OLD NAME.	NEW NAME.	FORMULA.
Oil of vitriol	Sulphuric acid	Hydrogen sulphate	H_2SO_4
Aqua fortis	Nitric acid	Hydrogen nitrate	HNO_3
Spirits of salts	Muriatic, or hydrochloric acid	Hydrogen chloride	HCl
Vinegar	Acetic acid	Hydrogen acetate, or methyl-formic acid	CH_3CO_2H
Fixed air, or choke-damp	Carbonic acid	Carbon dioxide, or carbonic anhydride	CO_2
	Anhydrous, or dry sulphuric acid	Sulphuric anhydride, or sulphur trioxide	SO_3
	Anhydrous nitric acid	Nitric anhydride, or nitric pentoxide	N_2O_5
	Anhydrous phosphoric acid	Phosphoric anhydride, or phosphoric pentoxide	P_2O_5
	Monobasic, or metaphosphoric acid	Monohydrated phosphoric acid	HPO_3
	Bibasic, or pyrophosphoric acid	Dihydrated phosphoric acid	$H_4P_2O_7$
	Common, tribasic, or orthophosphoric acid	Trihydrated phosphoric acid	H_3PO_4
	Ammonia	Ammonia	NH_3
Spirits of hartshorn	Hydrate of ammonia	Ammonium hydrate	NH_4HO
Potash, or caustic potash	Anhydrous potassa, or oxide of potassium	Potassium oxide	K_2O
	Hydrate of potash	Potassium hydrate	KHO
Quicklime	Oxide of calcium, or lime	Calcium oxide	CaO
Milk of lime	Hydrate of lime	Calcium hydrate	$Ca(OH)_2$
Red precipitate	Protoxide of mercury	Mercuric oxide	HgO
Washing soda	Carbonate of soda	Sodium carbonate	Na_2CO_3
Pearl-ash, or salt of tartar	Carbonate of potash	Potassium carbonate	K_2CO_3
Sugar of lead	Acetate of lead	Lead acetate	$Pb(C_2H_3O_2)_2$
Common salt	Chloride of sodium	Sodium chloride	$NaCl$
Sal-ammoniac	Muriate of ammonia	Ammonium chloride	NH_4Cl
Glauber's salts	Sulphate of soda	Sodium sulphate	Na_2SO_4

Sal-enixum	Bisulphate of potash	Hydropotassium sulphate	$KHSO_4$
Gypsum, or plaster of Paris	Sulphate of lime	Calcium sulphate	$CaSO_4$
Epsom salts	Sulphate of magnesia	Magnesium sulphate	$MgSO_4$
Alum	Double sulphate of potash and alumina	Potassium aluminium sulphate	$K_2SO_4.Al_2(SO_4)_3.24H_2O$
Nitre, or saltpetre	Nitrate of potash	Potassium nitrate	KNO_3
Cubic nitre	Nitrate of soda	Sodium nitrate	$NaNO_3$
Copperas, or green vitriol	Protosulphate of iron	Ferrous sulphate	$FeSO_4$
	Per- or sesqui- sulphate of iron	Ferric sulphate	$Fe_2(SO_4)_3$
Calomel	Subchloride of mercury	Mercurous chloride	Hg_2Cl_2
Corrosive sublimate	Perchloride of mercury	Mercuric chloride	$HgCl_2$
Lunar caustic	Nitrate of silver	Silver nitrate	$AgNO_3$
Bluestone, or blue vitriol	Sulphate of copper	Cupric sulphate	$CuSO_4$
Tasteless purging salts	Common, or rhombic phosphate of soda	Hydrodisodium orthophosphate	HNa_2PO_4
	Subphosphate of soda	Sodium orthophosphate	Na_3PO_4
	Biphosphate of soda	Dihydrosodium phosphate	H_2NaPO_4
Bone phosphate	Common, or tribasic phosphate of lime	Tricalcium orthophosphate	$Ca_3(PO_4)_2$
	Subphosphate of lime	Hydrocalcium phosphate	$HCaPO_4$
Soluble phosphate	Bi-acid- or super- phosphate of lime	Tetra-hydro-calcium phosphate	$CaH_4(PO_4)_2$
	Protophosphate of iron	Ferrous phosphate	$Fe_3(PO_4)_2$
	Perphosphate of iron	Ferric phosphate	$FePO_4$
Microcosmic salt	Ammonia-phosphate of soda	Hydro-sodium-ammonium phosphate	$NaNH_4HPO_4$
	Pyrophosphate, or bibasic phosphate of soda	Sodium pyrophosphate	$Na_4P_2O_7$
	Pyrophosphate of lime	Calcium pyrophosphate	$Ca_2P_2O_7$
	Meta- or mono- phosphate of soda	Sodium metaphosphate	$NaPO_3$
	Meta- or mono- phosphate of lime	Calcium metaphosphate	$Ca(PO_3)_2$

iron) oxide; whilst the compounds containing the lower proportion of the non-metal are termed mercur*ous* oxide, or ferr*ous* oxide. There are acids which contain different amounts of oxygen united with the same metal or non-metal. Those richer in oxygen are termed phosphor*ic* or chlor*ic*; whilst the compounds which contain the lesser proportion of oxygen are called phosphor*ous* acid, or chlor*ous* acid. *Hypo*[1]sulphurous acid means an acid poorer in oxygen than sulphurous acid; and *per*[2]chloric acid is an acid containing more oxygen than is found in chloric acid. When such an acid as sulphuric unites with another substance, *ic* is changed into *ate*. Thus we have sodium sulph*ate* and potassium phosph*ate*. Sulphur*ous* acid, nitr*ous* acid, &c., form sulph*ites*, nitr*ites*, &c. There are perchlorates, chlorates, chlorites, and hypochlorites of potassium, and other metals. Latin or Greek numerals are used to indicate the proportion of oxygen, or other non-metal in combination with a metal. Iron and oxygen united in the proportion of atom for atom may be termed protoxide or monoxide; higher atomic proportions of oxygen produce *di* or *deut*oxides, *ter* or *tri*oxides, *quad* or *tetr*oxides.

Bases, Acids, and Salts.—The term *base* is frequently met with in chemical writings. It is applied to those compound bodies which are capable of neutralising acids either partly or entirely. There are four kinds of bases: 1st, Metallic oxides, such as lime; 2d, Compounds containing a metal, united with an atom of oxygen and an atom of hydrogen, such as sodium hydrate, or common caustic soda; 3d, Certain compounds, such as ammonia and trihydrogen phosphide; 4th, Many organic bodies containing nitrogen, such as strychnine or quinine. We have already seen that acids contain hydrogen. This hydrogen becomes replaced by

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[1] Greek *hypo*, less.

[2] Abbreviation of *hyper*, more.

a metal when the first class of bases is acted upon, and the oxygen of the metallic oxide and the hydrogen of the acid produce water. A similar reaction occurs when an acid acts upon a hydrate of a metal; but direct union takes place between acids and ammonia, and similar compounds and organic bases. A metal which, by union with oxygen, produces a base, is often termed a basylous radicle.

Chemical Formulæ.—By the aid of the symbols already referred to, and numerals, we can readily express the composition of substances. Chemical formulæ resemble, but are not identical with, algebraic formulæ. KCl is the formula for potassium chloride. K is not only the symbol of kalium, which is the Latinised form of the word potassium, but it represents an atom of that element. Cl represents also an atom of chlorine. K_2S is the formula for potassium sulphide: the figure placed after the symbol K, and a little below the line, means the number of atoms of potassium. $2K_2S$ means 2 molecules of potassium sulphide. $MgSO_4$ is the formula for magnesium sulphate, the figure meaning 4 atoms of oxygen. $MgSO_4,7H_2O$ shows the composition of crystallised magnesium sulphate. When it is necessary to show that several molecules of crystallised magnesium sulphate are present, we place the necessary numbers before brackets enclosing the formula for the salt: $3(MgSO_4,7H_2O)$ means 3 molecules of crystallised magnesium sulphate.

Chemical Combination and Decomposition.—If carbon, hydrogen, and oxygen be mixed together in a bottle, no change will take place; and if charcoal in fine powder be added to them, still no new substance will be produced. Or if we take the ash left by a known weight of hay or of wheat-straw, and mix it with the proper quantities of the four elementary substances

—carbon, hydrogen, oxygen, and nitrogen—we shall be unable by this means to form either hay or wheat-straw. The elements of which vegetable substances consist, therefore, are not *merely* mixed together, they are united in some closer and more intimate manner. To this more intimate state of union the term *chemical combination* is applied—the elements are said to be *chemically combined.*

Thus, when charcoal is burned in the air, it slowly disappears, and forms, as already stated, a kind of air known by the name of carbonic anhydride, or carbonic acid gas, which rises into the atmosphere and diffuses itself through it. Now this carbonic anhydride is formed by the *union* of the carbon (charcoal), while burning, with the oxygen of the atmosphere, and in this new air the two elements—carbon and oxygen—are *chemically combined.*

Again, if hydrogen be burned in the air by means of a common gas-jet (see p. 38), water is formed, and the hydrogen and a portion of the oxygen of the atmosphere disappear together. The two gases have *combined chemically* with each other and formed water.

On the other hand, if a piece of wood, or a bit of straw, in which the elements are already chemically combined, be burned in the air, these elements are separated, and made to assume new states of combination, in which new states they escape into the air and become invisible. When a substance is thus changed, and converted or separated into other substances by the action of heat, or in any other way, it is said to be *decomposed.* If it more gradually decay and perish, as animal and vegetable substances do, by exposure to the air and moisture, it is said to undergo slow *decomposition.*

When, therefore, two or more substances unite together, so as to form a third possessing properties different from both, they enter into chemical union—

they form a *chemical combination* or chemical *compound*. And when, on the other hand, a compound body is so changed as to be converted into two or more substances different from itself, it is decomposed. Thus carbon, hydrogen, and oxygen undergo a chemical combination in the interior of the plant during the formation of wood; while wood, again, is decomposed when, in the retort of the acetic acid maker, it is converted into charcoal, acetic acid, and other substances.

Plants derive their food from both air and soil. The parts of plants which are not volatile must of course be derived from the soil; but the atmosphere contributes, directly or indirectly, a large proportion of that portion of the plants which is destructible by the agency of heat—carbon, oxygen, hydrogen, and nitrogen. These elements enter the plant partly by absorption through their roots, and partly by their leaves. It was formerly believed that the plants absorbed their carbonic acid by the great number of small openings, the so-called *stomata*, especially abundant over the under surface of the leaves. It is now believed that these stomata are only for the purpose of transpiring water. The carbonic acid is absorbed by the superficial cells of the leaves. The roots bring up food from the soil, the leaves take it in directly from the air.

Now, as the pores in the roots and leaves are very minute, carbon (charcoal) cannot enter them in a *solid* state; and as it does not dissolve in water, it cannot, in the state of simple carbon, be any part of the food of plants. The same is true of sulphur and phosphorus. Again, hydrogen gas neither exists in the air nor usually in the soil; so that, although hydrogen is always found in the substance of plants, it does not enter them in the state of gas. Oxygen, on the other hand, exists in the air, and *is* directly absorbed both by the leaves and by the roots of plants. The oxygen in the free state, however, is not the source of the oxygen out of which the plant tissue is formed. This is absorbed in the form of water.

The whole of the carbon, hydrogen, and oxygen enters into plants in a state of *chemical combination* with other substances. The carbon is taken up in the state of carbonic acid; the hydrogen and oxygen in the form of water; the nitrogen chiefly in the form of nitric acid (combined as nitrates), and probably in small quantities as ammonia, and in the case of leguminous crops as free nitrogen.

We shall conclude this chapter with the following table, which shows the atomic weights of the more important elements and their symbols. The names in italics are those of non-metallic bodies; the rest are metals.

Name of element.	Symbol.	Atomic weight.[1]	Name of element.	Symbol.	Atomic weight.
Aluminium	Al	27	Iron	Fe	56
Antimony	Sb	120	Lead	Pb	207.0
Arsenic	As	75	Magnesium	Mg	24
Barium	Ba	137	Manganese	Mn	55
Bismuth	Bi	208	Mercury	Hg	200
Boron	B	10.9	Nickel	Ni	59
Bromine	Br	80	*Nitrogen*	N	14
Cadmium	Cd	112	*Oxygen*	O	16
Calcium	Ca	40	*Phosphorus*	P	31
Carbon	C	12	Platinum	Pt	197
Chlorine	Cl	35.5	Potassium	K	39.1
Chromium	Cr	52.5	*Silicon*	Si	28
Cobalt	Co	59	Silver	Ag	108
Copper	Cu	63.5	Sodium	Na	23
Fluorine	F	19	Strontium	Sr	87.5
Gold	Au	196.8	*Sulphur*	S	32
Hydrogen	H	1	Tin	Sn	118
Iodine	I	127	Zinc	Zn	65.5

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[1] The numbers given are not always the results of the most exact determinations of the atomic weights, but approximations to them sufficiently accurate for all ordinary calculations.

CHAPTER III. 3

THE ELEMENTARY CONSTITUENTS OF PLANTS AND ANIMALS.

Although there are some 70 elements, only a comparatively small number are found in animal and vegetable substances. Some of the elements have hitherto only been found in extremely minute quantities, and in but a few localities.[1] The following elements are always found in plants and animals, and appear to be absolutely essential to their existence: CARBON, HYDROGEN, OXYGEN, NITROGEN, PHOSPHORUS, SULPHUR, POTASSIUM, CALCIUM, MAGNESIUM, and IRON. SODIUM and CHLORINE are also necessary to animal life, but it is doubtful whether they are essential to plants. SILICON occurs both in plants and animals, but is probably not an essential constituent. It is found in most abundance in the stems of plants, and in the hair, wool, feathers, &c., of the animal. FLUORINE occurs in small quantities in the animal body, especially in such portions as the teeth and bones. IODINE and BROMINE are found in marine or coast plants—rarely in those which grow in inland situations. Minute traces of the rare elements, LITHIUM, RUBIDIUM, and CÆSIUM, may be found frequently in plants if skilfully sought for. COPPER, ZINC, LEAD, and TITANIUM, have all been detected in small quantities in plants; but there can be little doubt as to their presence

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[1] Composition of the earth's solid crust in 100 parts by weight:—

Oxygen	44.0 to	48.7	Calcium	6.6 to	0.
Silicon	22.8	36.2	Magnesium	2.7	0.1
Aluminium	9.9	6.1	Sodium	2.4	2.5
Iron	9.9	2.4	Potassium	1.7	3.1

being merely accidental. Copper is often found in animals, and especially in their livers. When we come to treat of Vegetable Nutrition, we shall revert to the subject, What are, and what are not, the essential constituents of plants? The following brief notes on the more important properties of the elements present in plant and animal tissue may be of service to the student of the subject. For more detailed accounts the reader is referred to any of the numerous chemical manuals.

Carbon (C). — When wood is burned in a covered heap, as is done by the charcoal-burners,—or is distilled in iron retorts, as in making acetic acid,—it is charred, and is converted into common wood-charcoal. This charcoal is the most usual and best-known variety of carbon. It is black, soils the fingers, and is more or less porous, according to the kind of wood from which it has been formed. Coke obtained by charring or distilling coal is another variety. It is generally denser or heavier than charcoal, though usually less pure. Blacklead is a third variety, still heavier and more or less impure. The diamond is the only form in which carbon occurs in nature in a state of perfect purity.

This latter fact, that the diamond is pure carbon—that it is essentially the same substance with the finest and purest lamp-black—is very remarkable; but it is only one of the numerous striking circumstances that every now and then present themselves to the inquiring chemist. Carbon in the form of charcoal is an amorphous substance; while in the form of plumbago or black-lead and the diamond it is crystalline.[1]

Charcoal, the diamond, lamp-black, and all the other forms of carbon, burn away more or less slowly when

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[1] When an element exists in two or more distinct modifications it is said to be *allotropic*. Examples of elements exhibiting allotropism or allotropy are sulphur, phosphorus, and oxygen.

heated to redness in the air or in oxygen gas, and are converted into a kind of gas known by the name of *carbon dioxide.* The impure varieties, when burned, leave behind them a greater or less proportion of ash. Carbon is the largest constituent of plant tissue.

Sulphur (S) is a well-known solid substance of a light-yellow colour, and peculiar odour. It burns with a pale-blue flame, evolving fumes possessed of the strong, pungent, characteristic odour of burning matches. These fumes consist of sulphurous anhydride (SO_2). Sulphur fully oxidised, and united with hydrogen, forms Sulphuric acid.

Phosphorus (P) is a yellowish waxy substance (giving off in the air a peculiar odour), which smokes in the air, shines in the dark, takes fire by mere rubbing, and burns with a large bright flame and much white smoke. Like sulphur, it exists in all plants and animals, though in comparatively small quantity. Like sulphur, also, it is employed largely in the arts, especially in the manufacture of lucifer-matches. It combines in several proportions with oxygen, and forms, with hydrogen and oxygen, the important substance, phosphoric acid.

Hydrogen (H).—If sulphuric acid, mixed with twice its bulk of water, be poured upon iron-filings, or upon small pieces of zinc, the mixture will speedily begin to boil up, and bubbles of gas will rise to the surface of the liquid in great abundance. These are bubbles of hydrogen gas.[1]

If the experiment be performed in a bottle, the hydrogen which is produced will gradually drive out the atmospheric air it contained, and will itself take its place. If a taper be tied to the end of a wire, and, when lighted, be introduced into the bottle (fig. 2), it

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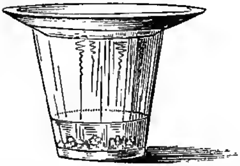
[1] The chemical changes which take place in this reaction are as follows: $H_2SO_4 + Zn = ZnSO_4 + 2H$.

Fig. 2.

will be instantly extinguished; while the hydrogen will take fire, and burn at the mouth of the bottle with a pale-yellow flame. If the taper be inserted before the common air is all expelled, the mixture of hydrogen and common air will burn with an explosion more or less violent, and may even shatter the bottle and produce serious accidents. This experiment, therefore, ought to be made with caution. It may be more safely performed in a common tumbler (fig. 3), covered closely by a plate, till a sufficient quantity of hydrogen is collected, when, on the introduction of the taper, the light will be extinguished, and the hydrogen will burn with a less violent explosion. Or the gas may be prepared in a retort, and collected over water.

Fig. 3.

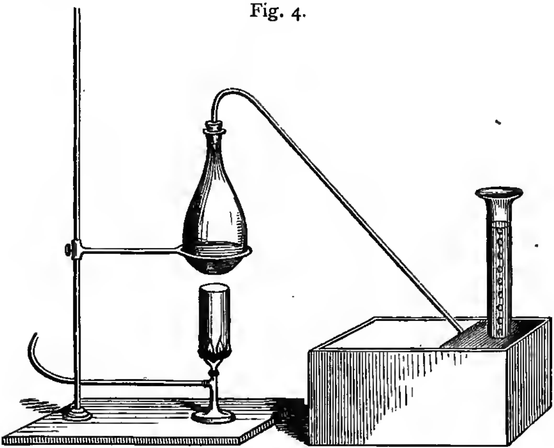


This gas is the lightest of all known substances, rising through common air as wood does through water. Hence, when confined in a bag made of silk, or other light tissue, it is capable of sustaining heavy substances in the air, and even of carrying them to great heights. For this reason it is sometimes employed for filling and elevating balloons.

Hydrogen is not found, except very rarely, uncombined with other bodies. It forms one-ninth part, by weight, of water, in which, and in many other substances, it exists in a *state of combination.*

Oxygen (O).—When strong oil of vitriol is poured upon black oxide of manganese, and heated in a glass retort (fig. 4), or when potassium chlorate, or red oxide of mercury, or saltpetre, or the black oxide of manganese,

Fig. 4.



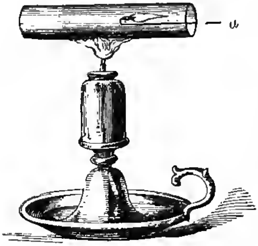
is heated alone in an iron bottle,[1]—in all these cases a kind of air is given off, to which the name of oxygen gas is given. It is obtained at a lower temperature, and with the greatest ease, rapidity, and purity, from a mixture of four parts of potassic chlorate and one of black oxide of manganese.

A very easy method of preparing the gas is to put a few grains of *red oxide of mercury* into a tube, and apply the heat of a lamp as in fig. 5. Oxygen gas will be given off, while minute globules of metallic mercury will condense on the cool part of the tube. The presence of oxygen in the tube is shown by introducing

[1] Black oxide of manganese $= MnO_2$; when heated, $3(MnO_2) = Mn_3O_4 + O_2$. Potassium chlorate $= KClO_3$; when heated, $KClO_3 = KCl + O_3$. Red oxide of mercury, HgO; when heated, $= Hg + O$.

into one end of it a half-kindled match, when it will be seen to burn up brilliantly.

Fig. 5.



Oxygen is now commercially prepared from barium dioxide (BaO_2), a white substance, which on being heated to a certain temperature gives off a portion of the oxygen it contains. On being cooled it again absorbs from the atmosphere a fresh supply of oxygen, and can be again used in a similar manner. The same material is thus capable, if certain precautions be observed, of being used over and over again.[1] Oxygen is a colourless, tasteless, and odourless gas, which, like all other gases, can be made to assume the liquid form. It is somewhat heavier than the air, of which it forms one-fifth. It has the power of uniting with almost all the chemical elements, the resulting products being known as oxides. An interesting property of liquid oxygen, which has been recently discovered by Professor Dewar, is its magnetic power.

Importance of Oxygen in Agriculture.—From an agricultural point of view, oxygen is of great importance, as it is necessary for all vegetable life. In the first place, it largely enters into the composition of vegetable tissue, which in the *dry state* contains it to the extent of about 40 per cent. In its free or uncombined state in the air it is of great importance in promoting vegetable growth. To most plants this free oxygen seems to be necessary. There are, however, lowly organised plants, such as *fungi*, of which *yeast*,

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[1] At 500° to 600° C. (dark red heat) it absorbs oxygen; at 800° C. (bright red heat) it gives it off.

the plant producing alcoholic fermentation, may be taken as an example, which can live without a supply of free oxygen, although they readily absorb it when they can obtain it. Oxygen seems to be of more importance to the plant at certain periods of growth than at others. These are, during the periods of germination and ripening. The roots as well as the leaves and stems of plants require a plentiful supply of oxygen.

Necessity of Supply of Oxygen in Soil.—The importance of having a certain amount of openness in a soil, more especially during the early period of growth, will be thus seen to be great. It is the farmer's duty, therefore, to see that the seed is not buried too deeply, or that the soil does not become impervious to the air. Fruit-trees, it may be mentioned, especially require that their roots should have free access to the air. Where, therefore, from whatever cause, the soil is not properly aerated, plants will neither grow abundantly nor develop properly. This is exemplified in the case of low-lying meadows, in marshes, and in bogs. In such cases the development in the plant of the albuminoid bodies—a class of constituents of the highest importance, as we shall see in a future chapter,—seems to be most affected; whereas the other bodies—*e.g.*, starch and sugar, of lower nutritive value—are not affected to the same extent. This is important, as throwing light on what is a well-observed fact—viz., that grains growing on wet meadows possess a lower nutritive value than others. Oxygen seems to be absorbed both during the daytime and the night by plants; but, according to experiments by de Saussure, its absorption in the case of flowering plants is greatest when the flower is fully open. It is not exactly known what the true function of free oxygen is in promoting plant growth. It would seem to be more concerned in helping in the processes of assimilation than in contributing directly to the building up of plant tissue. It is further indirectly of great importance to the plant, inasmuch as it is one of the most important factors in the formation of soils. From its tendency to unite with all bodies it is one of the most active agents in effecting "weathering," or the disintegration of the rocks out of which soils are formed, and in causing the conversion into an available form of the elements of plant food present in these rocks, or in the organic matter of the soil by decomposition or putrefaction. It is also important as one of the necessary conditions of the process known as nitrification (which will be discussed later on), by means of which nitrogen is converted from the organic form and as ammonia into nitrates.

Properties.—It is the characteristic property of oxygen, that a taper, when introduced into it, burns with great rapidity and with exceeding brilliancy, and continues to burn till either the whole of the gas disappears or the taper is entirely consumed. In this respect it differs both from hydrogen and from common air. If a living animal is introduced into this gas, its circulation and its breathing become quicker—it is speedily thrown into a fever—it lives as fast as the taper burned—and after a few hours, dies from excitement and exhaustion. This gas is not lighter, as hydrogen is, but is about one-ninth part heavier than common air. (Specific gravity, 1.1056 air =1.)

Oxygen forms about one-fifth of the air we breathe, and is the substance which supports and sustains the respiration of animals, and the combustion of burning bodies. It is necessary, as we have already pointed out, for the growth of plants, so that, were it by any cause suddenly removed from the atmosphere of our globe, every living thing would perish, and combustion would become impossible.

Ozone.—Oxygen is converted into a more concentrated form by means of the electric spark. The body produced has been called ozone, on account of its peculiar odour.[1] Ozone has very much more powerful oxidising properties than oxygen. It possesses a density 1½ times as great as oxygen. Ozone is also produced when phosphorus is allowed to oxidise slowly. This body is present in the air in very minute quantities. Its presence can be detected by its action on starch-paper soaked in potassium iodide, as it has the power of setting free the iodine.

Nitrogen (N).—This gas is very easily prepared. Dissolve a little green copperas in water, and pour the solution into a flask, or crystal bottle, provided with a good cork. Add a little of the hartshorn of the shops (solution of ammonia) till it is quite muddy, put in the cork tight, and shake the bottle well for five minutes. Loosen the cork a little without removing it, so as to allow air to enter the bottle. Cork tight again and shake as before. Repeat this as often as the loosening of the cork appears to admit any air; and after finally shaking it, allow it to stand for a few minutes. The air now in the bottle is nearly pure nitrogen gas.[2] In this experiment the condition of the iron when precipitated is such that it readily absorbs the oxygen from the air, and the nitrogen is left behind. This gas can also be obtained by removing from a limited quantity of air the oxygen it contains by burning phosphorus, when the nitrogen is obtained in a comparatively pure state. The oxygen of the air in the jar is thus removed in combination with the phosphorus as phosphoric pentoxide, P_2O_5, which dissolves in the water.

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[1] The smell of ozone is felt when an electric machine is worked.

[2] $FeSO_4 + 2(NH_4HO) = (NH_4)_2SO_4 + H_2O + FeO$; and $2FeO + O$ of air $= Fe_2O_3$.

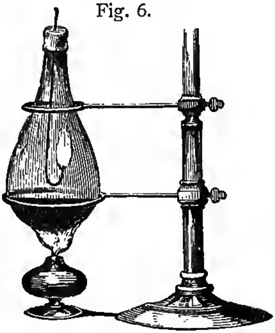
If a lighted taper be introduced into the bottle, it will be extinguished by this gas, but no other effect will follow. The gas itself does not take fire as hydrogen does. If a living animal be introduced into it, breathing will instantly cease, and it will drop without signs of life. Its function is to dilute the oxygen of the air. It is a tasteless, odourless gas, neither combustible nor a supporter of combustion.

This gas possesses no other remarkable property. It is very little lighter than common air (as 97½ to 100), and exists in large quantity in an uncombined state in the atmosphere. Of the air we breathe it forms nearly four-fifths—the remainder being chiefly oxygen. In the process above described for preparing the gas, the oxygen is absorbed by the iron, and the nitrogen left behind.

Oxygen, nitrogen, and hydrogen are incapable of being distinguished from common air, or from each other, by the ordinary senses; but by the aid of the taper they are readily recognised. Hydrogen extinguishes the taper, but itself takes fire; nitrogen simply extinguishes it; while in oxygen the taper burns rapidly and with extraordinary brilliancy.

Chlorine (Cl).—This is a greenish gas, about two and a half times heavier than atmospheric air. It cannot, even when largely mixed with air, be taken into the lungs without producing great irritation. It is soluble in its own volume of water, and its solution destroys organic colouring matters. It decomposes the offensive gases—sulphuretted hydrogen, and phosphoretted hydrogen, and also putrescent vegetable and animal matters. It is largely used as a bleaching agent and a purifier of air. It is readily obtained by pouring muriatic acid (spirits of salt) upon the black oxide of manganese of the shops, contained in a flask, and applying a gentle heat ($MnO_2 + 4HCl = MnCl_2 + 2H_2O + Cl_2$), as in the annexed figure. If the flask be of colourless glass, the colour of the gas will immediately become perceptible, and its odour will diffuse itself through the room. A burning taper plunged into it burns with a dull red smoky flame. In combination with potassium, sodium, calcium, and magnesium, it forms the *chlorides* of potassium, sodium (common salt), calcium, and magnesium; and in one or other of these states it generally enters into the roots of plants, and exists in their ash.

Fig. 6.



Iodine (I) is a solid substance of a grey colour and metallic lustre, very much resembling filings of lead. It has a peculiar odour, not unlike that of chlorine, an acrid taste, and stains the fingers a brown colour. It is distinguished by two properties—by being changed into a beautiful violet vapour when heated, and by giving with starch a beautiful blue compound. It occurs in small quantities in sea-water, and in marine and many fresh-water plants.

Bromine (Br) is a dark brownish-red heavy liquid, possessed of a strong odour, giving a yellowish-red vapour, and colouring starch yellow. It exists in sea-water, in certain salt springs, and has been detected in the ashes of certain plants. It probably accompanies chlorine and iodine into all plants, though the proportion, which is still less than that of iodine, has hitherto prevented its presence from being detected.

As *chlorine* forms *chlorides*, so *iodine* forms *iodides*, and *bromine* forms *bromides*, with the metals already mentioned.

Fluorine (F) is a very corrosive gas. It exists in small quantity in the teeth and bones of animals. With metals, it forms *fluorides;* and fluoride of calcium, or fluor-spar, is the best-known and most common of its combinations. Fluorine is never found uncombined. It is remarkable for forming no compounds with oxygen.

Potassium, or **Kalium** (K).—This metal is lighter than water, its specific gravity being only .865—water being 1. It is always found in combination with other elements, chiefly with oxygen and carbonic acid (K_2CO_3), chlorine (KCl), and iodine (KI). It instantly rusts on exposure to air, decomposes water with such energy that the hydrogen which it displaces takes fire and is reconverted into water. The metal is preserved under naphtha, which is composed of carbon and hydrogen.

Sodium (symbol Na, from *natrium*, another name of the metal).—A metal resembling potassium, but of heavier specific gravity—.97. Like potassium, it is obtained by heating to a very high temperature a mixture of charcoal and sodium carbonate ($Na_2CO_3 + C = Na_2 + 2CO$). Sodium occurs in enormous quantities in certain mines and in sea-water, as sodium chloride (NaCl). Sodium also occurs in the form of carbonate (Na_2CO_3) in kelp.

Calcium (Ca).—This metal is never met with except as a scientific curiosity. It is prepared with great difficulty by the action of sodium upon calcium chloride = $CaCl_2 + Na_2 = Ca + 2NaCl$. Combined with oxygen, it constitutes lime; with oxygen and carbon, limestone, chalk, marble, and a great variety of minerals, such as stalactite, calc-spar, &c. Gypsum and alabaster are compounds of calcium, oxygen, and sulphur. In spring and other waters calcium often occurs as chloride and sulphate.

Magnesium (Mg).—A white metal, specific gravity

1.74. It is prepared by decomposing its chloride by sodium. It burns, evolving an exceedingly brilliant white light, and forms its only compound with oxygen—*magnesia.* The rock termed dolomite is a compound of magnesium and calcium carbonates. Magnesium chloride, iodide, and bromide are present in many mineral waters; and the well-known *Epsom* salts consist of magnesium sulphate. The bitter flavour of the water of the Dead Sea is chiefly due to the large proportion of magnesium chloride which it contains. In the mineral termed *kainit,* used as a manure, magnesium chloride ($MgCl_2$) is largely present.

Iron (Fe, from the Latin *ferrum*).—This most valuable metal is found chiefly in the form of oxide, carbonate, and sulphide. Sulphur-stone, or iron pyrites, is FeS_2, and is found in many rocks, soils, and metallic ores. Of oxides there are three: protoxide, or ferrous oxide (FeO); sesqui, per, or ferric oxide (Fe_2O_3); and magnetic or ferroso-ferric oxide (Fe_3O_4).

Proportions of the Elements in Plants.—Of the one solid substance, carbon, and the three gases, hydrogen, oxygen, and nitrogen, above described, the organic part of all vegetable and animal bodies is essentially made up. In those organic substances, which contain nitrogen, sulphur and phosphorus also are present, but generally in minute proportion.

But the organic part of plants contains these four substances in very different proportions. Thus, of all the vegetable productions which are gathered as food by man or beast, in their *dry state,* the

Carbon forms nearly *one-half* by weight;
Oxygen rather more than *one-third;*
Hydrogen little more than 5 *per cent;*
Nitrogen from ½ to 4 *per cent.*

This is shown in part by the following table, which exhibits the actual composition of 1000 lb. of some varieties of the more common crops, when made *perfectly dry*:—

	Carbon.	Hydrogen.	Oxygen.	Nitrogen.	Ash.
Hay	458 lb.	50 lb.	387 lb.	15 lb.	90 lb.
Red clover hay .	474	50	378	21	77
Potatoes . . .	440	58	447	15	40
Wheat . . .	461	58	434	23	24
Wheat-straw . .	484	53	389½	3½	70
Oats . . .	507	64	367	22	40
Oat-straw . .	501	54	390	4	51

It is to be observed, however, that in drying by a gentle heat, 1000 lb. of common hay from the stack lost 158 lb. of water; of clover hay, 210 lb.; of potatoes wiped dry externally, 759 lb.; of white turnips, 900 lb.; of wheat, 145 lb.; of wheat-straw, 260 lb.; of oats, 151 lb.; and of oat-straw, 287 lb. The quantity of water depends altogether on the state of the specimens examined, hence analyses vary. 1000 lb. of young grass contain 700 to 800 lb. of water; the same, when thoroughly air-dry (as hay), about 140 lb. Straw contains about the same amount. The above table represents their composition when made perfectly dry.

The bodies of animals contain also a large proportion of water; but the dry matter of their bodies, as a whole, is distinguished from that of plants, by containing a larger proportion of nitrogen, sulphur, and phosphorus. Some parts of the bodies of animals are particularly rich in these ingredients. Thus—

Dry *lean muscle*, if free from fat, contains about 16 per cent of *nitrogen;*

Dry *hair* or *wool* about 5 per cent of sulphur; and

Dry *bone* about 12 per cent of phosphorus.

But in animals, as in plants, the chief constituents are carbon and oxygen. Thus, lean beef, blood, white of egg, and the curd of milk, when quite dry, consist in 100 parts of about—

	Per cent.
Carbon	55
Hydrogen	7
Nitrogen	16
Oxygen, with a little sulphur and phosphorus	22
	100

We shall now consider the proportion of some of the compounds used as food by plants, and from which their volatile portion is obtained.

Carbonic Acid Gas (CO_2).—If a few pieces of chalk or limestone, $CaCO_3$, or of common soda, be put into the bottom of a tumbler, and a little spirit of salt or muriatic acid (HCl) be poured upon them, a boiling up, or *effervescence*, will take place, and a gas will be given off, which will gradually collect and fill the tumbler; and when produced very rapidly, may even be seen to run over its edges. This gas is carbon dioxide.[1] It cannot be distinguished from common air by the eye; but if a lighted taper be plunged into it (fig. 7), the flame will immediately be extinguished, while the gas will remain unchanged. This kind of air is so heavy, that it may be poured from one vessel into another, and its presence in the second vessel recognised as before by the use of the taper. Or it may be poured upon a lighted candle, which it will instantly extinguish (fig. 7). This gas is exceedingly suffocating; so that if a living animal be introduced into it, life immediately ceases. It is absorbed by water—a pint of water absorbing or dissolving a pint of the gas, and acquiring a faintly acid taste.

It derives its name of acid from this taste, which it imparts to water, and from its property of redden-

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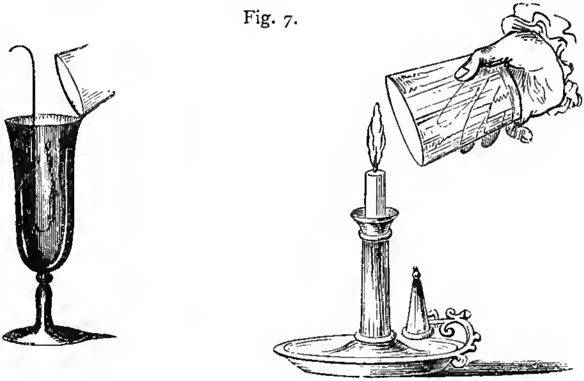
[1] The following equation gives the exact nature of the reaction which takes place: $CaCO_3 + 2HCl = CaCl_2 + CO_2 + H_2O$.

ing certain vegetable blue colours, and of combining with alkaline[1] substances to form *carbonates*. The former property may be shown by passing a stream of the

Fig. 7.



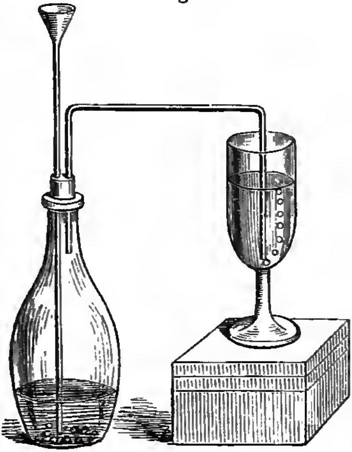
gas through an alkaline decoction of red cabbage—as in fig. 8—when the liquid will gradually become red; the latter, by putting lime-water into the glass instead of the decoction of red cabbage, when the stream of gas will render it milky, forming *calcium carbonate*.

Carbon dioxide exists in the atmosphere; it is given off from the lungs of all living animals while they breathe; and is also produced largely during the burning of wood, of coal, and of all other combustible bodies, so that an unceasing supply of it is perpetually being poured into the air. Decaying animal and vegetable substances also give off this gas. and hence it is always present in greater

[1] *Acids* are bodies containing hydrogen, which hydrogen can be replaced partly or entirely by metals. They have generally a sour taste like vinegar, and redden blue vegetable colours. Alkalies, again, have a peculiar taste called *alkaline;* they restore the colour to blue vegetable colours which have been reddened by an acid, and they unite with acids to form chemical compounds, known as salts.

or less abundance in the soil, and especially in such soils as are rich in vegetable matter. As illustrating this point it has been calculated that 1 acre of good garden land in summer evolves more than 6 tons of carbonic anhydride. Soils are very much richer in this gas than the atmosphere. It is also produced during the fermentation of malt liquors, or of the expressed juices of different fruits, such as the apple, the pear, the grape, or the gooseberry—and the briskness of such fermented liquors is due to the escape of carbonic acid gas. From fermenting dung and compost heaps it is also given off; and when put into the ground, farmyard manure imparts much carbonic acid to the soil and to the roots of plants. It serves many important ends in promoting plant growth; among others it acts as an important solvent of plant food.

Fig. 8.



Carbon dioxide consists of carbon and oxygen only, combined together in the proportion of nearly 28 of the former to 72 of the latter. Or 100 lb. of carbonic dioxide contain 28 lb. of carbon and 72 lb. of oxygen.

It combines with potash, soda, lime, magnesia, ammonia, forming potassium carbonate, sodium carbonate, &c.

Water (H_2O).—If hydrogen be prepared in a bottle, in the way already described (p. 23), and a gas-burner be fixed into its mouth, the hydrogen may be lighted, and will burn as it escapes into the air (fig. 9). Held over this flame, a cold tumbler will become covered with dew, or with little drops of water. This water is *produced* during the burning of the hydrogen; and as its production takes place in pure oxygen gas as well as in the open air, which contains oxygen — a portion of the oxygen and hydrogen alone disappearing — the water formed must contain the hydrogen and oxygen which disappear, or *must consist of hydrogen and oxygen only.*

Fig. 9.

This is a very interesting fact; and were it not that chemists are now familiar with many such, it could not fail to appear truly wonderful that the two gases, oxygen and hydrogen, by uniting together, should form water—a substance so very different in its properties from either. Water consists of 2 parts or atoms of hydrogen united to 16 parts or 1 atom of oxygen; every 9 lb. of water contain 8 lb. of oxygen and 1 lb. of hydrogen.

Water is so familiar a substance, that it is unnecessary to dwell upon its properties. When pure, it has neither colour, taste, nor odour. At 32° of Fahrenheit's scale (the freezing-point), or 0° (zero) on the Centigrade, it solidifies into ice; and at 212° Fahr. (100° C.) it boils, and is converted into steam. It possesses two other properties, which are especially interesting in connection with the growth of plants.

1. If sugar or salt be put into water, they disappear, or are *dissolved.* Water has the power of thus dissolving numerous other substances in greater or less quantity.

Hence, when the rain falls and sinks into the soil, it dissolves a portion of the soluble substances it meets with in its way, both through the air and through the soil, and rarely reaches the roots of plants in a pure state. So waters that rise up in springs are rarely pure. They always contain earthy and saline substances in solution, and these they carry with them when they are sucked in by the roots of plants.

It has been above stated that water absorbs (dissolves) its own bulk of carbonic acid at ordinary temperature and pressure; it dissolves, also, smaller quantities of the oxygen and nitrogen of the atmosphere; and hence, when it meets any of these gases in the soil, it becomes impregnated with them, and conveys them into the plant, there to serve as a portion of its food.

In nature, water never occurs in a pure state. It generally contains both gaseous and saline substances in a state of solution; and this, no doubt, is a wise provision, by which the food of plants is constantly renewed and brought within their reach.

2. Water, as we have shown above, is composed of oxygen and hydrogen, and by certain chemical processes it can readily be resolved, or decomposed *artificially*, into these two gases. The same thing takes place *naturally* in the interior of the living plant. The roots and leaves absorb the water; but if, in any part of the plant, hydrogen be required for the formation of the substance which it is the function of that part to produce, a portion of the water of the sap is decomposed either directly or indirectly, and its hydrogen worked up, while its oxygen is set free, or converted to some other use. So, also, where oxygen is required, and cannot be obtained from some more ready source, water is decomposed, the oxygen made use of, and the hydrogen liberated. Water, therefore, which abounds in the

vessels of all growing plants, if not directly converted into the substance of the plant, is yet a ready and ample source from which a supply of either of the elements of which it consists may at any time be obtained.

It is a beautiful adaptation of the properties of this all-pervading compound—water—that its elements should be so fixedly bound together as rarely to separate in external nature, and yet to be thus at the command and easy disposal of the vital powers of the humblest order of living plants.

Ammonia (NH_3).—If the sal-ammoniac $(NH_4)Cl$, or the ammonium sulphate $(NH_4)_2SO_4$, of the shops, be mixed with quicklime, a powerful odour is immediately perceived, and an invisible gas is given off,[1] which strongly affects the eyes. This gas is ammonia (NH_3). Water dissolves or absorbs it in very large quantity, and this solution of the gas in water forms the common hartshorn of the shops. The white solid smelling-salts of the shops (ammonium carbonate) is a compound of ammonia with carbonic acid.

Ammonia consists of nitrogen and hydrogen only, in the proportion of 14 parts of the former to 3 parts of the latter by weight; or 17 lb. of ammonia contain 14 lb. of nitrogen and 3 lb. of hydrogen.

The decay of animal substances is an important natural source of this compound. During the putrefaction of dead animal bodies, ammonia is invariably given off. From the animal substances of the farmyard it is evolved during their decay or putrefaction, as well as from all solid and liquid manures of animal origin.

Ammonia is naturally formed, also, during the decay of vegetable substances in the soil. This happens in one or other of two ways.

a. As in animal bodies, by the direct union of the

[1] $CaO + 2(NH_4)Cl = CaCl_2 + H_2O + 2NH_3$.

nitrogen with a portion of the hydrogen of which they consist.

b. Or when they decompose in contact, at the same time, with both air and water—by their taking the oxygen of a quantity of the water, and disposing its hydrogen at the moment of liberation to combine with the nitrogen of the air, and form ammonia.

Ammonia is also formed naturally during the chemical changes that are produced in volcanic countries, through the agency of subterranean heat. It escapes often in considerable quantities from the hot lavas, and from crevices in the heated rocks.

It is produced artificially by the distillation of animal substances (hoofs, horns, &c.), and during the burning, coking, and distillation of coal. Indeed one of the great sources of ammonia is the liquor from the gasworks, which, after being neutralised with sulphuric acid, furnishes the "sulphate of ammonia," of commerce.

Of the ammonia which is given off during the putrefaction of animal and vegetable substances, a variable proportion rises into the air, and floats in the atmosphere, till it is either decomposed by natural causes, or is dissolved and washed down by the rains. In the latter case it sinks into the ground, and finds its way, generally after being first converted into nitric acid, into the roots of plants. It is one of the most valuable fertilising substances contained in farmyard manure; and as it is usually present in greater proportion in the liquid than in the solid contents of the farmyard, much real wealth is lost, and the means of raising increased crops thrown away, in the quantities of liquid manure which are almost everywhere permitted to run waste.

Nitric Acid (HNO_3) is a powerfully corrosive liquid, known in the shops by the familiar name of *aquafortis.* It is prepared by pouring oil of vitriol (sulphuric acid) upon saltpetre (KNO_3), or nitrate of soda ($NaNO_3$), and distilling the mixture ($H_2SO_4 + KNO_3 = KHSO_4 + HNO_3$). The aquafortis of the shops is a mixture of the pure acid with water.

Pure nitrogen pentoxide (N_2O_5) consists of nitrogen and oxygen only, united in the proportions of 14 parts of nitrogen, by weight, to 40 of oxygen. Combined with water, it produces nitric acid $N_2O_5 + H_2O = 2HNO_3$. It is as nitric anhydride that the percentage of nitric acid in manures is generally stated in chemical analysis. Nitric acid occurs in the air in minute quantities, where it is produced by the union of the oxygen and nitrogen gases under the influence of electricity. The nitric acid so formed combines with the ammonia in the air, and as the ammonium nitrate thus formed is a very soluble substance, it is washed down by the rain. It is very remarkable that the union of these two gases, so harmless in the air, should produce the burning and corrosive compound which this acid is known to be. It may be recognised by the curious action it exerts on the skin, which it stains yellow; and its bleaching effect on indigo, a reaction which is made use of as a chemical test for estimating its percentage in substances. Owing to the fact that it very readily parts with its oxygen, it forms an admirable oxidising agent.[1] Its action on cellulose, the chief constituent of vegetable tissue, is of a striking nature, as it converts it into a deadly explosive compound known as nitro-cellulose, or gun-cotton. Its action on glycerine is similar, as it forms nitro-glycerine, which when absorbed by a white silicious powder known as *kieselguhr*, forms the well-known explosive compound *dynamite.* The nitrates also part with their oxygen

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[1] A substance which readily parts with the oxygen it contains is known as an *oxidising* agent, while a substance which readily combines with oxygen is known as a *reducing* agent.

easily, and are hence used as ingredients in explosives —*e.g.*, KNO_3 in gunpowder.

Nitric acid never reaches the roots or leaves of plants in this free and corrosive state. It exists and is produced in many soils, and is naturally formed in compost-heaps, and in most situations where animal or vegetable matter is undergoing decay in contact with the air; but in these cases it is always found as nitrates. With potash it forms potassium *nitrate*, or saltpetre (KNO_3); with soda, sodium *nitrate* ($NaNO_3$); with lime, calcium *nitrate*, $Ca(NO_3)_2$—and so on. All these nitrates are very soluble in water, and it is in the state of one or other of these compounds that nitric acid exists in the soil and reaches the roots of plants.

It is well known that saltpetre—called also nitre, or "nitrate of potash"—is in India obtained by washing the rich alluvial soil of certain districts with water, and evaporating the clear solution to dryness.[1] On the continent of Europe, artificial nitre-beds are formed by mixing together earthy matters of various kinds with the liquid and dung of stables, and forming the mixture into heaps, which are turned over once or twice a-year.[2] These heaps, on washing, yield an annual crop of impure saltpetre. The soil around our dwellings, and upon

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[1] These "nitre" soils are chiefly found in Bengal, and are the sites of old villages. The saltpetre is found as an excrescence on the surface of the soil, and is scraped off and collected by the *sorawallah*, or native manufacturer.

[2] These artificial "nitre-beds," or "saltpetre plantations," were formerly largely cultivated in Switzerland, Germany, France, Sweden, &c., and constituted a most important industry—to regulate which, in France, certain laws were framed called the Saltpetre Laws. These laws were abolished at the time of the French Revolution. Since the discovery of the nitrate fields of Chili, and the manufacture of saltpetre from nitrate of soda, the old method of production by artificial nitre-beds has been almost entirely abandoned (see Aikman's 'Manures and the Principles of Manuring,' pp. 151-155).

which our towns and villages stand, becomes impregnated with animal matter of various kinds through defective drainage, and the result is that nitrates are produced in larger quantity than on ordinary soil. In short, such soils are converted, to a certain extent, into nitre-beds. As every shower that falls tends to wash the nitrates downwards, they are often found in considerable traces in wells, where these are in the immediate vicinity of a town or village—a state of matters now, fortunately, very much less common than formerly.[1] The fact that we find nitrates in well waters is an indication that the soil is unable to retain them. Nitric acid in the form of nitrates, chiefly as calcium nitrate—that is, combined with lime — exists in small quantities in all soils, where it is produced by the process of *nitrification.* Nitrates are also produced in compost-heaps or whenever nitrogenous vegetable or animal matter is undergoing putrefaction in the presence of a plentiful supply of oxygen. It is only formed in the last stages of putrefaction, however, as the conditions favourable for nitrification only then obtain.

The most abundant natural deposits of nitrates are the nitrate of soda fields of Chili and Peru. Hundreds of thousands of tons of pure nitrate of soda have been annually exported from these valuable deposits for many years now. Reference will be made to them when discussing nitrate of soda.

Nitrification.—That the formation of nitrates in the the soil—or as the process is now commonly called, nitrification—is due to the action of micro-organisms, is a discovery now some fifteen years old. The important

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[1] According to the Rothamsted experiments (see 'Jour. Chem. Soc.,' 1887, p. 501), the minimum proportion of nitrogen as nitrates in the purest of well waters of Harpenden is 4.4 parts per million, while the minimum of contaminated waters is 10.7 parts per million.

bearing which this discovery has on practical agriculture cannot be too highly valued; it is, indeed, one of the most important discoveries made in the domain of agricultural chemistry of late years. As the subject of nitrification will be dealt with in a subsequent chapter, all further reference to it may be postponed till then.

Nitric acid is also naturally formed, and in some countries probably in large quantities, by the passage of electricity through the atmosphere. The air consists of oxygen and nitrogen *mixed* together; but when electric sparks are passed through a quantity of air, minute portions of the two gases *unite* together chemically, so that every spark which passes forms a small quantity of nitric acid. A flash of lightning is only a large electric spark; and hence every flash that crosses the air produces along its path a sensible proportion of this acid. Where thunderstorms are frequent, a considerable quantity of nitric acid may be produced in this way in the air. It is washed down by the rains, combined with ammonia as nitrate of ammonia. The quantity of nitric acid formed in this way is much less than was formerly believed. It varies in different parts of the earth's surface, and is doubtless very much greater in tropical countries, where electrical discharges are more frequent, than in such a country as our own, where, according to the Rothamsted experiments, the amount washed down by the rain in the course of a year on to an acre of land does not exceed 1 to 2 lb.

It has long been observed that those parts of India are the most fertile in which saltpetre exists in the soil in the greatest abundance. The nitrates have been found among ourselves, also, wonderfully to promote vegetation, when artificially applied to growing crops; and it is a matter of frequent remark that vegetation seems to be refreshed and invigorated by the fall of a thunder-shower.[1] In Europe, the value of nitrates as a plant food has been long recognised; and it is now known to be the most valuable and speedily available of all forms of nitrogen to the plant.

Urea (N_2H_4CO).—It is in the form of urea that nearly all the nitrogen of the effete tissue is excreted from the animal body. It is, in short, the final decomposition product of the oxidation of the nitrogenous compounds in the organism, and, from a manurial point of view, is the most important constituent of urine. It contains nearly a half its weight of nitrogen (46.7 per cent), and is thus one of the most rich in nitrogen of all nitrogen compounds. In human urine it may amount to from 1.4 to 2 or 3 per cent. In the urine of different animals it varies very considerably. According to Boussingault, the urine of oxen may contain from 1.8 to 1.9 per cent. Its percentage, however, in urine is intimately connected with the state of digestion and the nature of the food, and its amount has been shown to vary within very considerable limits. It is most abundant in the urine of carnivorous (flesh-eating) animals. In the urine of birds it is present in least quantity; and in that of herbivorous birds it is doubtful whether it occurs at all. The urine of oxen, which contains a larger proportion of water than that of other farm animals, is poorest in urea. A full-grown healthy man excretes daily, on an average, 30 grms. (1 oz.) of urea in his urine.[2] It is a crystalline

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[1] The first shower after a long drought generally contains all the nitrates in the air, as they are soluble in water, and are thus easily washed down.

[2] Urea may be extracted from urine by evaporating the urine down to about one-eighth of its bulk, cooling and mixing it with strong pure nitric acid. It is precipitated in pearly scales as urea nitrate, which is practically insoluble in nitric acid, and only slightly soluble in water. The urea nitrate is then collected by filtering, then dissolved in boiling water, and barium carbonate added. Urea and barium nitrate are the resulting products, and the urea may be obtained in a pure state by ex-

body, and crystallises in long rhombic crystals or needles, which have a cooling, bitterish taste, and are soluble in an equal weight of water. Urea is less soluble in alcohol, and is almost insoluble in ether. Urea acts as a weak base. A very important property of urine is its very easy decomposability. On keeping for even a short time, the urea in the urine is changed into ammonium carbonate ($(NH_4)_2CO_3$). This is effected by the combination of its elements with the elements of water.[1] Under certain conditions the decomposition of urea takes place more speedily than under others. The decomposition is effected by means of a ferment, and any condition which will weaken the action of this ferment will consequently retard its decomposition. This may be done by the addition of large quantities of water. It has been found also that certain soils (more especially clayey soils), when brought in contact with urea, effect a similar retardation in its putrefaction (Way). By the addition of some stale urine to fresh urine putrefaction is very much accelerated. That urea is an available source of nitrogen to plants seems to be conclusively proved, as we shall see later on.

Amides.—A very important class of bodies are the amides. In chemical language they may be described as ammonia derivatives, and are formed by displacing the one, two, or three atoms of hydrogen in the ammonia group. They can thus be divided into primary, secondary, and tertiary amides, or mon-, di-, or tri-amides.

Urea, the compound which we have just been describing, is the mon-amide of carbonic acid. A varying proportion of the nitrogen present in vegetable matter

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tracting with alcohol, from which it may be crystallised out in prisms by evaporation.

[1] The nature of the change is as follows: $CON_2H_4+2H_2O=(NH_4)_2CO_3$.

has been recently shown to be present in the form of these amides. Thus potatoes contain a considerable amount of them. The percentage, however, of amide nitrogen in most plants has yet to be determined.

Uric and Hippuric Acids.—Nitrogen also occurs in urine as uric ($C_5H_4N_4O_3$) and hippuric ($C_9H_9NO_3$) acids. The percentage of the former is very variable, however. Uric acid is a white crystalline powder (prismatic), very slightly soluble in water. It occurs in the urine of man and many other animals only in very minute quantities, but is abundant in the urine of birds and reptiles.[1] In healthy human urine it is present to the extent of not more than one part per thousand of the urine, but in the case of certain diseases it occurs in greater quantity. Uric acid and its salts the urates are common constituents of urinary *calculi*, and they are also found in the blood and other animal fluids. Uric acid is a less concentrated compound of nitrogen than urea, only about $\frac{1}{3}$ of its weight being nitrogen. Hippuric acid is a much more abundant constituent of urine than uric acid, its percentage, according to Von Bibra, ranging from .55 to 1.2 per cent; but its quantity varies very much, and depends on the food. While uric acid occurs more in the urine of carnivorous animals, hippuric acid is found chiefly in the urine of herbivorous animals. In experiments with oxen, a fodder consisting of wheat or oat straw was found to give the largest percentage of hippuric acid in the urine, from which it has been inferred that fodder rich in lignin causes the production of this substance in the urine (Henneberg and Stohmann). It would seem that the extent to which a food is digestible has an important bearing on the relative proportions of uric and hippuric acids in urine; the more digestible food giving rise to the formation of a larger amount of

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[1] It is prepared in this country from the urine of the boa-constrictor.

uric acid, the less digestible foods to a larger amount of hippuric acid. Peruvian guano contains uric acid in large quantity, as urate of ammonia; the older and richer Peruvian guano containing as much as 10 per cent of this substance. Hippuric acid is a white crystalline powder, sparingly soluble in water, and, unlike urea, is not speedily decomposed.

In addition to the above-mentioned compounds (ammonia, nitric acid, urea, uric and hippuric acids), nitrogen occurs in a number of other forms. Many of these compounds are of rare occurrence, however, and need not here be enumerated.

The nature of the albuminoid compounds (bodies resembling in their composition albumen), in which form nitrogen chiefly occurs in animal and vegetable tissue, will be discussed in a subsequent chapter.

CHAPTER IV. 4

COMPOSITION OF THE ATMOSPHERE.

The relation of the atmosphere to plant and animal life is so important, that it is essential to have a clear comprehension of its chemical composition if we are to grasp the elementary principles of agricultural chemistry.

The air is usually described as the gaseous envelope surrounding the earth. That it has a definite weight is easily proved; and that it exerts a certain pressure on the earth's surface is a fact known to every schoolboy. To what height the air extends is an unsolved problem. By some this has been estimated at 25 to 50 miles.

It is more probable, however, that no actual limit exists. Some idea of the enormous extent of the atmosphere may be obtained when it is stated that its total weight has been estimated at 5100 billion tons.

For long the belief was entertained that the air was an elementary body. Thanks, however, to the investigations of Priestley and others towards the close of last century, this old belief was shown to be false, and we now know it to be chiefly made up of the two gases, oxygen and nitrogen, the properties of which we have already discussed in the preceding chapter.

Discarding for a moment the other constituent gases of the air, we find the relative amounts of these two gases are as follows :—

	By Volume.	*By Weight.*
Nitrogen . .	79.19	76.99
Oxygen	20.81	23.01
	100.00	100.00

A point of importance to notice is that the air contains these gases in a free state and not chemically combined. The air, therefore, is a *mechanical mixture* and not a *chemical compound.* Despite this fact, a very large number of laborious researches show that its composition is wonderfully uniform.

In addition to these two chief constituents, the air contains a number of other gaseous bodies, the most abundant being water (in a gaseous form) and carbonic acid gas.

Amount of Water in the Air.—The amount of moisture present in the air varies very considerably, and depends on a variety of conditions. Among these the most important is temperature. Experiments have shown that a cubic metre (or 35.316 cubic feet) of air is only able to hold the following quantities of water in a state of vapour at the following temperatures under ordinary atmospheric pressure:—

	Grammes of Water.		*Grammes of Water.*
0° C	4.871	30° C	30.095
10° C	9.962	35° C	39.252
20° C	17.175	40° C	50.700
25° C	22.843		

When the air absorbs as much water as it can hold in a gaseous state, it is said to be *saturated.* Ordinary air, however, it may be mentioned, is rarely saturated with watery vapour. As a rule, it may be said only to contain about 60 per cent of the moisture it is capable of absorbing. When the percentage is 40 per cent or under, such air may be described as dry, while that containing 80 per cent or over, may be described as damp. When air is suddenly cooled the moisture it contains in the invisible vapour state is at once condensed, and is deposited in the form of rain, snow, hail, dew, or fog. On an average the percentage of moisture in the air may be stated at 1.4 per cent., but it varies from .6 to 3.8. The month during which the air is driest in this country, it may be mentioned, is May; while the most humid month is January.

The amount of air which water is able to dissolve depends on two conditions—viz., temperature and pressure. The lower the temperature, and the greater the pressure the water is subjected to, the greater the proportion of air it dissolves. The fact that all natural waters contain air dissolved in them is easily shown by boiling them, when the atmospheric gases are expelled, and rise through the water in minute bubbles. The quantity varies in the different natural waters, and depends on their source. In some experiments it was found that in 100 parts (by volume) of rain water at 11.4° C. and ordinary barometric pressure, 2.5 parts of air were present. The different gases are not dissolved in the same proportion as they are present in the air; and this, we may mention in passing, forms a strong argument in support of the belief that the air is not a chemical compound, but a mechanical mixture, for were it a chemical compound the gases would be dissolved by water in the *same* proportions. This fact is illustrated by the analysis of the air found dissolved in rain-water, and which has been shown to consist of—

	Per cent.
Nitrogen	64.67
Oxygen	33.76
Carbonic anhydride	1.77

Oxygen is more soluble than nitrogen, while carbonic acid is much more soluble than either. The more water is brought into contact with air, the greater is the proportion of oxygen it contains. Stirring up water, therefore, increases its percentage of oxygen. Water, also, in which plants are growing, generally contains a fair amount of oxygen. The gases present in the air find their way into the soil, both dissolved in water and absorbed directly by the soil itself. The air enclosed in the pores of the soil is distinctly poorer in oxygen than ordinary air, but very much richer in carbonic acid. Thus, soil which has not been disturbed by tillage for a year or so has been found to be 22 to 23 times richer in carbonic acid than the air, while a soil eight days after manuring has been shown to contain 245 times as much. This is due, of course, to the rapid evolution of carbonic acid going on in the presence of decaying vegetable matter. The rate at which the decay of the organic matter goes on in the soil will determine the composition of the air enclosed in its pores, and also the depth of the soil. The more carbonic acid in the soil the less the quantity of nitrogen. This is shown by the following experiments by Boussingault and Levy:—

PROPORTIONS OF AIR AND CARBONIC ACID IN SOILS UNDER DIFFERENT CONDITIONS OF CULTURE.

Kind of Soil.	Culture.	Contained in air of soil in per cent by volume.		
		Carbonic Acid.	Oxygen.	Sum.
Sand, unmanured . .	...	9.74	10.35	20.09
Sand	Vineyard	1.06	19.72	20.78
Sand, very stony . .	Forest	0.87	19.61	20.48
Sand, unmanured . .	Asparagus	1.54	18.80	20.34
Pits, with rotten wood .	...	3.64	16.45	20.09
Chalky . . .	Red beets	0.87	19.71	20.58
Heavy clay . . .	Artichokes	0.66	19.99	20.65
Fertile, moist . .	Meadow	1.79	19.41	21.20

Air is also to be found in all the juices and air spaces of the plant. Sometimes its composition in those cases is the same as the atmosphere, and sometimes it differs considerably. Its composition depends, indeed, on the part of the plant it is present in, the stage of the plant's development, and the season of the year. Similarly, air is found in all the juices and air spaces of the animal body. There, again, it differs in composition.

We have already mentioned that the composition of the air is wonderfully uniform, and this despite the fact that very large quantities of oxygen are being constantly withdrawn to support animal life and for other purposes, while, at the same time, very large quantities of carbonic acid are being poured into the air every day from a variety of sources. It may be well to draw the student's attention, therefore, to a consideration of the way in which these two gases are respectively removed from and added to the air—how, in short, the uniformity in the composition of the air is maintained.

The Amount and Sources of Oxygen in the Air.—That oxygen is constantly being withdrawn from the air the most superficial observation of the nature of animal life will at once discover; but this withdrawal of oxygen from the air is compensated for by the action of plant life, which splits up the carbonic acid gas into oxygen and carbon, the former being set free, and the latter being assimilated.

That the uniformity of the composition of the air is a fact of enormous importance for animal life may be illustrated by the statement that air containing 20.6 per cent of oxygen instead of 20.84 becomes noticeably heavy and unfit for respiration, and that it is difficult to remain in air containing 17.2 per cent.

Air expired from the lungs has lost 4 to 6 per cent of its oxygen, the loss in oxygen being in proportion to the increase of carbonic acid gas.

A full-grown man requires in twenty-four hours about 750 grammes of oxygen, and gives out about 870 grammes of carbonic acid gas.

Amount of Carbonic Acid Gas in the Air.—Some reference has already been made to the properties of this compound gas. Its percentage in the air is wonderfully uniform, and may be stated at .035. In the air of the large cities it is slightly more. Certain conditions of the atmosphere also tend to increase its percentage. Thus during fogs it has been found to be present to 1 per cent. At night the air is probably slightly richer in carbonic acid than during daytime, especially in the country, this being due to the action of plant life. The quantity may also be said to vary with the season of the year, being greatest in winter; the altitude above sea-level (less at high altitudes), and the proximity to forests. It is occasionally found in certain parts on the earth's surface in great abundance, due to some subterranean source. A well-known example of this is the poison valley of Java; while there is also a grotto in the vicinity of Naples which contains it in large quantities. In both cases the proportion of carbonic acid gas is so great that all animal life is unable to exist. The density of the gas is considerably greater than that of either nitrogen or oxygen, so that its tendency is to remain on the surface of the earth immediately after its formation. Owing, however, to the law of the diffusion of gases, it becomes speedily mixed with the other constituent gases of the air. This law of the diffusion of gases, according to which all gases, no matter how they may differ in density, readily mix with one another, is the reason of the uniformity in the composition of the air, and facilitates the purification of a vitiated atmosphere in houses or in any confined air space.

Sources of Carbonic Acid.—The rate at which air becomes vitiated by the presence of animal life may be inferred from the fact, already pointed out, that an adult exhales in the course of twenty-four hours about 870 grammes of carbonic acid gas. In order to maintain a healthy atmosphere it is necessary to introduce 60 cubic metres of fresh air per hour per person (Pettenkofer). One of the chief sources of carbonic acid is that produced in the decay of vegetable matter constantly going on in all soils. As illustrating this, and as we have already pointed out (see p. 37), it has been calculated that one acre of good garden land in summer evolves, through the decay of its vegetable matter, more than 6 tons of carbonic acid (Mendeleeff). Faraday long ago calculated that the daily production of carbonic acid gas amounted to about 3½ million tons, and that this was derived from the following sources. The total quantity of carbonic acid has been estimated at 6300 billion pounds:—

	Lb.
Respiration of man . . .	1,000,000,000
" animals . . .	2,000,000,000
Combustion and fermentation . .	1,000,000,000
Decay and other processes . .	4,000,000,000
Total	8,000,000,000

The chief way in which this gas is removed from the air is by the action of growing plants. The exact method in which plants effect this assimilation, and the conditions which determine its rate, will be discussed further on. Suffice it to say here, that wherever vegetable growth is taking place this purifying process is going on. The extent to which this goes on will be best illustrated by one or two calculations. Thus, it has been calculated that the vegetation growing on one square metre of soil may decompose from 200 to 250 grammes of carbonic acid annually. Similarly, it has been estimated that an acre of forest producing 5755 lb. of dry matter would consume the carbonic acid produced by the respiration of 15.4 men. An ingenious calculator has estimated that the total woods of Great Britain give out in the course of their growth during one year as much oxygen as would be required by the respiration of 8,000,000 people during a similar period.

Owing to these and similar causes the quantity of carbonic acid gas given forth into the atmosphere is found to equal pretty nearly the amount withdrawn by the action of plant life, and the percentage in the air is thus kept pretty constant.

Minor Constituents of the Air.—In addition to nitrogen, oxygen, carbonic acid gas, and watery vapour, the air contains other bodies in very minute traces. Of these, *ozone*, *nitric* and *nitrous acid*, and *ammonia* may be mentioned. The presence of ozone in greater or less quantity in the air has been supposed to be connected with the prevalence of certain epidemic diseases. It has also been held to account, to a certain extent at any rate, for the bleaching properties of air. In the air above marshes, or in the vicinity of manure-heaps containing putrefying organic matter, ozone does not exist; nor has it been detected in the air of large towns or inhabited houses. Its amount seems to vary with the seasons, being greatest in spring and least in winter. It is also supposed to be present in the air in greater abundance during stormy and wet weather than during fine weather. It is questionable, however, whether ozone is actually present in the air to anything like the extent formerly believed. We have no accurate method for its quantitative estimation.

Ammonia, although it is the most abundant of the combined forms of nitrogen present in the air, only amounts to, at most, a few parts per million of air. Air at a great altitude is supposed to be poorer in ammonia than air near the earth's surface (Müntz and Aubin). It finds its way into the air from putrefying nitrogenous organic matter. According to Schlœsing, the chief source of the ammonia present in the air is the tropical ocean, which yields gradually to the atmosphere, under the action of the powerful evaporation constantly going on, a large amount of nitrogen in this form. The sources of the nitrogen of the ocean are the nitrates which it receives from the drainage of land, animal and vegetable matter, sewage, &c.[1] It must be borne in mind that ammonia does not exist in the air in the free state. It is either combined with the nitric and nitrous acids, as nitrates and nitrites of ammonia, or along with carbonic acid, as ammonium carbonate. Lawes and Gilbert have found the amount of ammonia per million of rain-water collected in the country to be from .927 to 1.142. Ac-

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[1] See Aikman's 'Manures and the Principles of Manuring,' p. 109.

cording to Angus Smith, rain in some parts of Scotland only contained about half this amount. In rain collected in towns it has been found to amount to over 9 parts per million.

We have already seen under what conditions nitric and nitrous acids are formed in the air. Their actual amount is even less, as has been pointed out, than ammonia. The reason why these combined forms of nitrogen cannot exist in the air, except in very minute traces, is owing to their extreme solubility, which causes them to be washed out of the air by every shower of rain. As illustrating this fact, it may be mentioned that Bunsen found in rain collected at the beginning of a shower 3.7 grammes of ammonia per cubic metre, while that collected at the end of the same shower only contained .64 grammes per cubic metre. According to Angus Smith, in a million parts of rain-water collected from different parts of Scotland, Ireland, and England, the amount of nitrous and nitric acids varied from .305 to .749. This was in the country. In towns the amount was higher—.863 to 1.164.

Organic Matter in the Air.—Recent researches by Aitken and others have furnished some interesting details with regard to the solid matter in the air, which is made up both of organic and inorganic matter. Of these solid particles there are millions in a cubic inch of air. Among the organic matter there are a large number of micro-organisms. Dr P. F. Frankland has estimated their number in the air of different places. Thus he found in 10 litres of air taken from the roof of the South Kensington Museum there were 35, whilst 279 was the average number which fell on 1 square foot in one minute. Tissandier has analysed the atmospheric dust of Paris, and finds it to consist of 27 to 34 per cent volatile matter, and from 66 to 75 per cent mineral matter; the latter consisting of sulphates and chlorides of the alkalies and alkaline earths, oxides of iron, &c.

CHAPTER V. 5

THE CONSTITUENTS OF THE ASHES OF PLANTS.

That portion of animal or vegetable substance which remains after combustion is termed *ash*. Its proportion varies from a mere trace to 10 or 12 per cent. The following substances are found in the ashes of plants, either as such or in combination:—

Sulphuric Acid (H_2SO_4)—commonly known as oil of vitriol—is a very heavy, oily-looking, sour, and corrosive liquid, which becomes hot when mixed with water, chars and blackens straw or wood when these are immersed in it, and is capable of dissolving many organic and inorganic substances. It is manufactured by burning sulphur or iron pyrites, which is a sulphide of iron, and leading the sulphurous vapours into leaden chambers, in which they are mixed with nitrous fumes, steam, and air. It consists of sulphur and oxygen only—combined with water.

Sulphuric acid was first manufactured about 400 years ago, the substance from which it was obtained being green vitriol, or ferrous sulphate ($FeSO_4, 7H_2O$). A very strong acid, known as Nordhausen sulphuric acid, is still manufactured by this process at Nordhausen in Saxony.

Sulphuric acid is manufactured in this country in enormous quantities, the annual consumption at present in Great Britain being over 100,000 tons. It was first manufactured on a large scale by Dr Roebuck in Birmingham in 1770, where lead chambers were first used. Sulphuric acid is characterised by its great weight, the strong acid being, bulk for bulk, nearly twice the weight of water. Nordhausen acid differs from the ordinary acid in being strongly fuming, due to the presence in it of sulphuric anhydride (SO_3).[1] The most expensive part in the manufacture of sulphuric acid consists in concentrating the weak acid. When the acid attains a certain strength it acts upon lead. The use of leaden vessels is no longer, therefore, permissible, and glass retorts are used. The breakage of these, however, is very great, due to the difficulty of boiling the strong acid. Platinum stills have of recent years been used, but the price of this metal is very great. The specific gravity of the strongest H_2SO_4 is 1.84, that of Nordhausen acid being 1.9. The specific gravity of the acid when it leaves the leaden chambers is 1.6, and this acid is sufficiently concentrated for its use in certain chemical manufactures. When its specific gravity reaches 1.72 it acts upon lead, so that the difference in the expense of acid of this strength and the stronger acid is considerable.

Sulphuric acid combines with potash, soda, lime, magnesia, and ammonia, and forms *sulphates*. These sulphates exist in the soil, and when dissolved by water are conveyed into the sap of plants, and supply the sulphur which is necessary for the formation of their albuminoids and other portions which require sulphur. Sulphates occur in most of the juices of the animal body. The strong acid is now employed largely for dissolving bones and the numerous mineral phosphates from which the artificial manure known as superphosphate of lime is manufactured.

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[1] Nordhausen sulphuric acid contains SO_3, as well as H_2SO_4, and may be represented by the formula $H_2S_2O_7$.

Phosphoric Acid (H_3PO_4).—If a piece of phosphorus be kindled in the air, it burns with a brilliant flame, and gives off dense white fumes. These white fumes are phosphorus pentoxide, or phosphoric anhydride (P_2O_5). They are produced by the union of the burning phosphorus with the oxygen of the atmosphere. 100 lb. of phosphorus, when burned, form 229½ lb. of phosphorus pentoxide. If the experiment be performed under a glass (fig. 10), the white fumes will condense on the cool inside of the vessel in the form of a white powder, which speedily absorbs moisture from the air, and runs to a liquid. When phosphorus burns freely in air it forms P_2O_5. This, when combined with water (H_2O), forms phosphoric acid, thus—

Fig. 10.

$$P_2O_5 + 3\ H_2O = 2\ (H_3PO_4).$$

This acid is very sour and corrosive. It combines with potash, lime, &c., and forms *phosphates*, and in these states of combination it exists in soils and manures, and enters into plants. The bones of animals contain a large proportion of this acid, in combination with lime and magnesia.

The composition on the ends of lucifer-matches consists chiefly of phosphorus mixed with potassium chlorate and sulphur. In the patent safety-matches the phosphorus is on the box, the other ingredients on the matches. to here

Silicic Anhydride (SiO_2).—This compound (commonly termed silica) is the oxide of the non-metal *silicon*. It is the most abundant constituent of the crust of the globe, forming about one-half of its total crust. It is found in the form of six-sided crystals in the mineral termed rock-crystal, and in several forms of quartz. We have it, when coloured brown, forming Cairngorm stones, or Scotch pebbles. Opal is silica in the uncrystallised form, and calcedony and agate are mixtures of crystallised and uncrystallised silica. The common flint is a variety of calcedony, and carnelian and amethyst are silica coloured with oxide of iron. The different kinds of clay are composed of silica and alumina combined as aluminium silicate; and felspar, which is one of the most abundant minerals from which soils are formed, consists of silicates of aluminium along with various proportions of potassium, sodium, calcium, and traces of other substances. Melted with potash, soda, alumina, oxide of iron, &c., silica forms the various kinds of glasses, some of which, containing large proportions of soda or potash, are soluble in water. Compounds of silica are termed *silicates*, and a large number exist in rocks, soils, porcelain, cements, bricks, &c. When a solution of a soluble silicate is decomposed by an acid, the silica separates in the form of a white jelly-like substance, soluble in about 7000 parts of water, but rendered insoluble by a temperature of 212° Fahr. The ashes of the grasses usually contain a large amount of silica, generally combined with lime and potash.

Potassium Monoxide (K_2O) is not met with in commerce, and when prepared in the scientific laboratory is preserved with great difficulty, owing to its tendency to absorb moisture from the air, with which it unites with the evolution of great heat. It is formed by exposing potassium to dry air or oxygen, or by igniting potassium hydrate with potassium—

$$KHO + K = K_2O + H.$$

It is a greyish-white brittle substance. It unites with water to form potassium hydrate or potash, according to the following reaction:—

$$K_2O + H_2O = 2\ KOH.$$

Potassium Hydrate, or Caustic Potash, is prepared by boiling milk of lime (calcium hydrate, CaH_2O_2) with pearl-ash (potassium carbonate, K_2CO_3). By double decomposition calcium carbonate (which is insoluble) and the soluble potassium hydrate are formed—

$$K_2CO_3 + Ca(OH)_2 = CaCO_3 + 2\ KOH.$$

The solution of the latter is evaporated to dryness, the resulting solid compound fused in an iron or silver vessel, and cast into cylinders in a metallic mould, or poured on a slab to be broken into lumps. Caustic potash is a white, hard, opaque substance, soluble in half its weight of water, and soluble in alcohol. It has a somewhat nauseous odour, and a very acrid flavour. It soon destroys animal and vegetable substances. It acts as a powerful cautery, destroying the skin. It is largely used for making soft-soap.

Potash, in some form, is present in the soil, and in nearly every kind of rock. In the ashes of tobacco and other plants it is often the most abundant constituent. In the wool of the sheep potash is found in large quantity.

Potassium Carbonate (K_2CO_3).—This compound is also termed carbonate of potash and pearl-ash. It is prepared by lixiviating (*i.e.*, washing) the ashes of wood and boiling down the solution in large iron pots. Hence the name—Pot-ash.

Potash exists in plants; it is more abundant in the leaves and small twigs than in the stems and larger branches, chiefly in combination with organic acids—*tartaric*, *oxalic*, &c.,—but during the combustion of the vegetable matter the acids are destroyed, and one of the products of their decomposition is carbonic acid, which forms, with the potash, potassium carbonate; 1000 parts of timber yielding from 2 to 4 parts of pearl-ash. Potassium carbonate is crystalline and deliquescent (*i.e.*, takes up moisture from the air). In its odour and flavour it resembles, but in a milder degree, caustic potash. It dissolves in a little more than its weight of cold, and in less than half its weight of boiling water, but it is not soluble in alcohol. It fuses at a red heat, and is partly volatilised at very high temperatures.

Potassium Chloride (KCl) is obtained from kelp, or the ashes of sea-weeds, and in the mineral carnallite. It is also obtained from the refuse of the manufacture of sugar from sugar-beet. It crystallises in small cubes, and is soluble in three parts of cold water. The residue of sea-water from which salt, &c., has been obtained, is termed *bittern*, and is rich in potassium chloride.

Sodium Oxide (Na_2O) resembles the corresponding potassium compound. Mixed with water, it forms caustic soda (sodium hydrate, $NaOH$), a body very like caustic potash, but not so energetic in its reactions. It is prepared in the same way as potassium hydrate, and is largely used in the manufacture of soap and other industrial products.

Sodium Chloride ($NaCl$).—The metal sodium and the gaseous, non-metallic element chlorine unite readily, and produce salt, or sodium chloride. Sea-water contains 27 per cent of sodium chloride, or at the rate of rather more than ¼ lb. per imperial gallon. Immense beds of common salt have been discovered in India, the United States, Hungary, Poland, Spain, in the north of England, and in the north of Ireland. Rock-salt is crystallised sodium chloride. Common salt has an agreeable flavour if used in moderate quantity. It forms cubes soluble in three parts of cold water and nearly the same proportion of hot water—a rather curious fact.

Strong alcohol does not dissolve it. At a bright red heat it fuses, and at a white heat, sufficiently prolonged, it volatilises.

Lithia (Li_2O) and lithium hydrate resemble potassium oxide and hydrate. Only minute quantities of lithium have as yet been detected in plants.

Rubidia and Cæsia are two compounds which have a remarkable resemblance to potash. They have been found,[1] but only in minute quantities, in various plants.

Calcium Oxide or Lime (CaO).—Pure lime is a white infusible powder. When mixed with water it evolves heat, and forms calcium hydrate or slaked lime ($CaO + H_2O = CaH_2O_2$). Lime is soluble in 760 parts of cold water (*i.e.*, at 0° C), but it requires a much larger proportion of hot water to dissolve it—viz., 1650, and alcohol has no effect upon it. When lime in masses is exposed to the air, it absorbs water. It gradually slakes and crumbles into a fine powder. Fifty-six parts of lime combine with eighteen parts of water, and yet the resulting compound is quite dry. Lime is called an alkaline earth because, like the alkalies potash and soda, it restores reddened litmus to its blue colour. It possesses considerable causticity, and acts upon organic matter in the same way that potash does, but not with anything like the same energy.

Calcium Carbonate, or Carbonate of Lime ($CaCO_3$), occurs in a very pure form in the minerals *Iceland spar* (rhombohedras), *aragonite* (six-sided prisms), and white marble (in small granular crystals). It is found abundantly in many plants, in the bones of animals, and in the shells of crustaceans, &c. When slaked lime is exposed to the action of the air for any length of time, it absorbs the carbonic acid in the air, with which it

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[1] "Occurrence of Rubidia, Cæsia, and Lithia in Plants."—C. A. Cameron in 'Journal of Royal Dublin Society,' 1867.

combines and forms calcium carbonate. In close vessels, under very great pressure, it may be fused; but heated in the open air it gives off carbonic dioxide, and leaves lime ($CaCO_3 = CaO + CO_2$).

Magnesium Oxide or Magnesia (MgO) is formed by heating magnesium carbonate to redness ($MgCO_3 = MgO + CO_2$). Magnesia is a bulky white powder, which forms a hydrate (MgH_2O_2), but requires many thousand times its weight of water to dissolve it. It is tasteless, odourless, and infusible. Moistened and placed on turmeric paper, it changes the colour of the latter from yellow to brown; hence it is said to be alkaline. Magnesium carbonate is found as a white hard mineral, termed magnesite. It occurs associated with calcium carbonate in many minerals, rocks, and all soils. Lime and magnesia are always found in the ashes of plants, combined with phosphoric, carbonic, and silicic acids. In the plants they may exist combined with sulphuric acid and organic acids. It is not often that the earths are found uncombined in the ashes of plants.

Oxides of Iron.—Ferric oxide (Fe_2O_3) is always found in small quantity in the ash of plants. It is a reddish-brown substance, well known as rust of iron. It is generally found combined with water ($Fe_2O_3 + 3\ H_2O$).

Oxides of Manganese.—There are several oxides of the metal manganese, and one of them, manganoso-manganic oxide (Mn_3O_4), is found in the ashes of plants, though in the living vegetable manganese probably exists in some other form. Manganoso-manganic oxide is a red substance. It is formed by highly heating with access of air any of the other oxides of manganese.

CHAPTER VI.

STRUCTURE AND MODES OF GROWTH OF THE PLANT.

The Structure of Plants.—From the compound substances described in the preceding chapters, plants derive the various elements found in their ashes, and the carbon, hydrogen, oxygen, nitrogen, the sulphur and phosphorus of which their organic part consists. The living plant possesses the power of absorbing these compound bodies, of *decomposing* them in the interior of its several vessels, and of *re-compounding* their elements in a different way, so as to produce new substances—the ordinary products of vegetable life. Let us consider the wonderful mechanism in which these operations are conducted.

A perfect plant consists of three several parts: a root, which throws out arms and fibres in all directions into the soil; a trunk, which branches into the atmosphere on every side; and leaves, which, from the ends of the branches and twigs, spread out a more or less extended surface into the surrounding air. Each of these parts has a peculiar structure, and special functions are assigned to it.

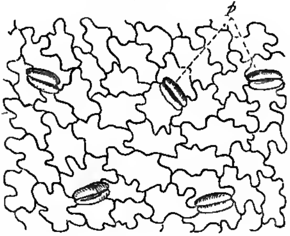
THE STEM of any of our common trees consists of three parts—the pith in the centre, the wood surrounding the pith, and the bark which covers the whole. The pith consists of a collection of minute cells, supposed to communicate horizontally with the external air through the medullary rays and the outer bark; while the wood and inner bark are composed of long tubes bound together in a *vertical* position, so as to be capable of carrying liquids up and down between the roots and the leaves. When a piece of wood is sawn across, the ends of these tubes may be distinctly seen. The branch is only a prolongation of the stem, and has a similar structure.

THE ROOT, immediately on leaving the trunk or stem, has also a similar structure. But as the root tapers away, the pith disappears,—in some, as in the walnut and horse-chestnut, gradually,—in others immediately. The bark also thins out, and the wood softens, till the white tendrils, of which its extremities are composed, consist only of a colourless spongy mass, full of pores, and in which no distinction of parts can be perceived. In this spongy mass the vessels or tubes which descend through the stem and root lose themselves, and by these tubes the spongy extremities in the soil are connected with the leaves in the air. Hellreigel estimates the length of the entire root-system of a vigorous barley-plant to be 136 feet, and that of an oat-plant to be 155 feet.

THE LEAF is an expansion of the twig. The fibres, which are seen to branch out from the base through the interior of the leaf, are prolongations of the vessels of the wood, and are connected with similar prolongations of the inner bark, which usually lie beneath them. The green exterior portion of the leaf is, in like manner, a continuation of the outer or cellular tissue of the bark, in a very thin and porous form. The pores, or mouths (*stomata*), contained in the green part, are an essential feature in the structure of the leaves, and are very numerous. The leaf of the common lilac contains as many as 120,000 of them on a square inch of surface. They are generally most numerous on the under part of the leaf; but in the case of leaves which float upon water, they are chiefly confined to the upper part.

Fig. 11 shows the appearance of the oval pores (*p*) on the leaf of the garden balsam. Connected with these pores, the green part of the leaf consists of, or contains, a collection of tubes or vessels which stretch along the surface of the leaf, and communicate, as we have said, with those of the inner bark.

Fig. 11.



Each of these principal parts of the plant performs peculiar functions.

FUNCTIONS OF THE ROOT.—The root serves to fix the plant firmly in the soil, and to keep it in an erect position. It is also the organ by which a large proportion of the food of the plant is collected and absorbed. In the case of many plants, the root is a storehouse or magazine, filled with nourishment either for the use of the plant or for that of its offspring. In autumn the farmer removes the roots of the crops—turnips, mangels, &c.—which by cultivation had attained to a large size. Allowed to remain in the soil for a second year they would become exhausted by supplying nourishment to the flowers and seeds of the second year's growth. The root sends out fibres in every direction through the soil in search, as it were, of water and of *liquid* food, which its extremities suck in and send forward with the sap to the upper parts of the tree. The part of the roots where absorption chiefly takes place is near the extremities, but it has been shown that the tops of the roots or spongioles take no part in the process. It is to aid the roots in procuring the food more rapidly that in the art of culture such substances are mixed with the soil as experience has shown to be favourable to the growth of the plants we wish to raise.

The chemical changes which the food is made to undergo in entering or passing along the roots are not yet well understood.

Nearly all the plants cultivated by the farmer have roots which are adapted to existence in the soil. Many plants, however (some of which are cultivated by the gardener), have air-roots—that is, roots which are altogether out of the soil, and are capable of directly absorbing nutriment from the atmosphere. Indian corn frequently throws out roots from the lower portion of its stem, and although they usually descend into the soil, yet that portion which is above ground acts like a true air-root. The roots of aquatic plants have no outer skin or integument such as land plants have when they are removed from the soil. There are, however, plants, such as rice, which can grow in either soil or water.

The development of the root depends on a variety of conditions. Roots that grow in water are more elongated than those growing in soil. The percentage of moisture in the soil has also an important influence on root-development.

FUNCTIONS OF THE LEAF.—It is not so obvious to the common observer that the leaves spread out their broad surfaces into the air for the same purpose precisely as that for which the roots diffuse their fibres through the soil; the only difference is, that while the roots suck in *liquid*, the leaves inhale *gaseous* food. In the daytime, whether in the sunshine or in the shade, the green leaves are continually absorbing carbonic acid from the air, and giving off oxygen gas—that is to say, they are continually appropriating carbon from the air.

We see, then, why in arctic climates, where the sun, once risen, never sets again during the entire summer, vegetation should almost rush up from the frozen soil; the green leaf is ever gaining from the air and never losing, ever taking in and never giving off carbonic acid, since no darkness ever interrupts or suspends its labours.

How beautiful, too, does not the contrivance of the expanded leaf appear! The air contains only one gallon of carbonic acid in 2500, and this proportion has been adjusted to the health and comfort of animals to whom this gas is hurtful. But to catch this minute quantity, the tree hangs out thousands of square feet of leaf—in perpetual motion, through an ever-moving air; and thus, by the conjoined labours of millions of pores, the substance of whole forests of solid wood is slowly extracted from the fleeting winds. On a single oak-tree seven millions of leaves have been counted. The multitude of absorbing mouths in a forest—like those of the coralline animals in a reef—will appear equal to the most gigantic effects.

Another great function of the leaves is the exhalation of watery vapour; and to such an extent does this take place, that it has been calculated that from a single acre in crop, from three to five million pounds of water are exhaled during the growth of the crop.

FUNCTIONS OF THE STEM.—From the root the sap ascends through the vessels of the woody stem till it is diffused over the interior of the leaf by the woody fibres which the leaf contains. During this passage the substances which the sap contains undergo certain chemical changes which are as yet not well understood. From the woody fibre of the leaf—along the vessels which lie beneath these fibres, and are covered by the green part of the leaf, and after it has absorbed or given off the gases which the pores transmit—the sap is returned towards the outer part of the stem, and through the vessels of the *inner* bark descends again to the root.

In the plant, till it has passed maturity, most of the vessels are full of sap, and this sap is in continual motion upwards within the stem, and downwards along its surface within the inner bark. In spring and autumn the motion is more rapid. In winter it is sometimes scarcely perceptible; yet the sap, except when frozen, is supposed to be rarely quite stationary in any part of the tree.

The Vegetable Cell.—All the structures of a plant are found to be composed of minute bags, or vesicles termed cells, lying closely together. To the organised bodies cells are what molecules are to mineral compounds. The smallest portion of water which can exist is a molecule—the most minute structure in the composition of a plant is its cell. As the molecule is formed out of the indivisible atoms, so the cell is produced from the most elementary principle found in living beings—namely, *protoplasm*, or *formative matter*. This substance is mucilaginous, and sometimes granular. It fills up the interior of the cells, and there is no doubt but that it furnishes the materials from which new cells are formed. It exhibits no trace of organised structure, and it is believed to be the most simple principle in animals and plants—that from which all the other structures are developed.

The primary cell of the vegetable is globular, but various circumstances contribute to modify its shape, which varies in different plants and in different parts of the same vegetable. In the pith of rushes it is star-shaped, and in loose tissue it is generally an irregular spheroid. In cotton and flax the cells are long and slender. The size of the cell is very variable: in the spores of fungi they are only the 1-5000th part of an inch in diameter; whilst the marine plant, *Caulerpa prolifera*, consists of a single cell often a foot in length. In general, however, cells are very small.

The wall of the vegetable cell is elastic and permeable to liquids and gases, but in old cells these properties exist in a diminished degree. The wall consists chiefly of the substance termed cellulose (which will be described in the next chapter). The more important contents of the cell comprise protoplasm, coloured particles (chlorophyll corpuscles), and starch. There are also present sugar, saline compounds, oily matters, &c. By the aid of the microscope we can detect in cells one or more round or lenticular-shaped bodies, transparent, colourless, or yellowish: these are termed nuclei (singular, nucleus). They are filled with a yellowish mucilaginous fluid, in which are contained excessively minute rounded bodies, termed *nucleoli* (singular, *nucleolus*). The nucleus is not an immature cell, and there is some reason to suppose that it is mainly composed of fat. Although the nucleus never becomes a new cell, it is concerned in the production of one. For this purpose the nucleus sometimes divides itself into two parts, and the protoplasm forms a cell-wall round each moiety. Cells multiply by division. In some plants the growth of cells proceeds with a wonderful degree of rapidity—as, for example, in the case of a species of puff-ball, which is stated to produce three or four hundred millions per hour.

Cellular Tissue.—The *parenchyma*, or *cellular tissue* of vegetables, consists altogether of ordinary cells, and contains no vessels. Some of the lower kinds of plants (*cellulares*), such as sea-weeds, are composed exclusively of parenchyma.

Woody Tissue is composed of long and slender cells, tapering at each extremity. These cells overlap each other, forming what is termed woody *fibre*. *Bast* tissue is a modification of woody tissue, but the cells are longer and more elastic. This tissue is abundant in flax, and is also present in the *bast* or inner bark of trees. Hemp, &c. (but not cotton), consists chiefly of bast tissue.

Vascular Tissue consists of tubes produced by the complete coalition of several simple cells and of wood-cells. It is usually found in bundles. These tubes assume a great variety of shapes. *Spiral* vessels are very long tubes clustered together, and having each a spiral fibre or fibres in its interior.

Pitted Vessels, or dotted ducts, are common in plants. They contain numerous pores, which are conspicuous in the wood of the cane or rattan when cut across.

Lactiferous Vessels consist of branched tubes filled with a milk-like liquid. They are abundant on the under side of leaves, and within the inner bark, but are not found in other parts of the plant. The sap ascends through the pitted vessels. Some vegetable physiologists class dotted ducts with cellular tissue.

CHAPTER VII.

THE PROXIMATE CONSTITUENTS OF PLANTS.

In the plant various chemical compounds exist, but they may all be included in three main groups or classes — nitrogenous, non-nitrogenous (including the saccharine and pectose groups), and fatty.

When the grain of wheat, barley, oats, rye, Indian corn, &c., is sent to the mill to be ground, two products are obtained—the bran or husk, and the flour. When washed free from flour, the bran or husk is tasteless, insoluble in water, and woody. It is the same thing, indeed, for the most part, as the cellular and fibrous part of wood or straw.

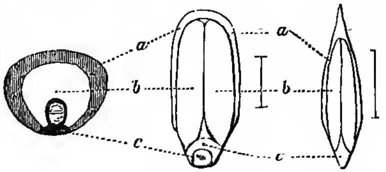
Again, when a portion of the flour is made into dough, and this dough is kneaded with the hand under a stream of water upon a piece of muslin, or on a fine sieve (see fig. 12), as long as the water passes through milky, there will remain on the sieve a glutinous sticky substance resembling bird-lime, while the milky water will gradually deposit a pure white powder. This white powder is starch, the adhesive substance which remains on the sieve is gluten. Both of these substances exist, therefore, in the flour; they both also exist in the grain.

Fig. 12.

Further, when bruised wheat, oats, Indian corn, linseed, or even chopped hay and straw, are boiled in alcohol or ether, a portion of oil or fat, of wax and of resin, is extracted, and is obtained separately by allowing the solution to evaporate to dryness in the air.

Thus, from the seed or grain we have obtained four different substances—the woody part which covers it, starch, gluten, and fat. Fig. 13 shows the position and relative quantities of the last three substances in the seeds of wheat, barley, and Indian corn. Thus *a* shows the position of the oil in the outer part of the seed—it exists in minute drops, enclosed in six-sided cells, which consist chiefly

Fig. 13.



Indian Corn. Wheat. Barley.

of gluten; *b*, the position and comparative quantity of the starch, which in the heart of the seed is mixed with only a small proportion of gluten; *c*, the germ or chit, which contains much gluten.

These substances represent the three great classes of organic bodies of which the bulk of all plants is made up.

The woody matter and the starch represent what is called the *carbohydrate* group. The oil or resin represents the *fatty* group. The gluten represents the *gluten*, or albumin group.

We shall briefly describe these several groups or classes of substances.

Carbohydrates comprehend a great number of different substances, possessing different properties, but all characterised by this similarity in composition, that they contain either six atoms, or its multiples, of carbon, combined with hydrogen and oxygen in the proportions in which the latter elements exist in water. They are consequently termed carbohydrates, or hydrates of carbon, though their hydrogen and oxygen do not actually exist as water. If oil of vitriol be poured upon a saturated solution of sugar contained in a long narrow glass vessel or tube, the mixture will blacken, solidify, and swell up to five or six times its original volume. The acid takes away the hydrogen and oxygen (which become water), and the residue is carbon or charcoal.* The carbohydrates are all non-volatile solids, the non-saccharine bodies being all convertible into sugar by treatment with dilute acid. Of the carbohydrates, cellulose is insoluble in water, the gums dissolve, or at any rate they swell up, and the sugars are all soluble. The closeness of relationship between the different members of the carbohydrate group is worthy of notice. This is seen in the similarity of their composition, their ready conversion the one into the other, and the similarity of their reactions with reagents. Starch seems to be first[1] formed in the plant, and from it the other carbohydrates;[2] while these may again be converted into starch later on. Heat or treatment with alkalies or acids converts the different members of the group into dextrine and sugar.

The *saccharine* or sugar group comprises about a dozen substances more or less closely allied to common or cane sugar.

Cane-sugar, or *Sucrose* ($C_{12}H_{22}O_{11}$), the ordinary sugar of commerce, occurs abundantly in the sugar-cane, beetroot, carrots, maize, barley, almonds, walnuts, and a great variety of vegetables. It is also found in the sap of a number of different trees such as the maple, lime, birch, and sycamore, and in the juices of many fruits. Cane-sugar is more abundant in mature plants than in young plants. In the young plant during the early stages of vegetation, both grape and fruit sugars are chiefly formed. These, as the plant matures during ripening, are converted into sucrose or cane-sugar. In the form of sugar-candy, it occurs in large four-sided

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[1] It would seem that although starch is the first *visible* product of assimilation between the inorganic substances entering into the first chemical process of assimilation, there is a whole series of substances of the sugar class, and it is from the last members of this series that starch is elaborated. There seems to be reason to believe that cane-sugar is the starting-point of all the metabolic changes taking place in the leaf (see an important paper on "The Chemistry and Physiology of Foliage Leaves," by Brown and Morris, 'Jour. Chem. Soc.,' May 1893, p. 604).

[2] This has been till now the commonly accepted view. According to Brown and Morris, the view that all the assimilated products pass through the form of starch is not tenable. They think "it is far more probable that starch is only elaborated within the cell when the supply of nutriment is in excess of the cell requirements, and that most of the assimilated products never pass through the stage of starch at all."

oblique rhomboidal prisms; but loaf-sugar is made up of very minute transparent crystals. Sucrose is insoluble in absolute alcohol, but easily so in water. It fuses at 160° C. (320° Fahr.), and does not crystallise on cooling. When kept melted for some time, it becomes converted into a mixture of *dextrose* or grape-sugar, and *lævulosan*. When further heated, but below 190° C. (374° Fahr.), it becomes brown, and is converted into *caramelan*, the commercial form of which is caramel, the well-known brown substance used for colouring liquids. Sucrose is converted into *glucose* by heating it with dilute hydrochloric or sulphuric acid solutions.

Glucose, *Dextrose*, or *Grape-sugar* ($C_6H_{12}O_6$), is the crystallised sugar found in grapes, raisins, honey, and many fruits, and is a term which includes several kinds of sugar, closely resembling each other, but differing a little in their constitution, as shown by their action upon polarised light. Along with it is found another kind of sugar called *lævulose*, or fruit-sugar, which is isomeric with it—*i.e.*, possessing the same crystalline properties. Grape-sugar is also found in certain fluids of the animal body, and in the urine in certain diseases (diabetes). It is most conveniently obtained from honey. It is comparatively insoluble in cold alcohol, but soluble in boiling alcohol. It is considerably less soluble in water than sucrose. In the presence of alkalies it acts as a strong reducing agent. The commercial article is prepared by heating starch with dilute sulphuric acid. The dextrose is by this treatment converted into *dextrin*, which, combining with the elements of water, forms dextrose. It possesses less sweetening properties than cane-sugar.

It may be here mentioned that sugars can be divided into two classes, according as they divert a ray of polarised light to the right or the left; those diverting it to the right being known as *dextrorotatory*, while those diverting it to the left are known as *lævorotatory*.

Fruit-sugar, or *Lævulose* ($C_6H_{12}O_6$), is found associated with other kinds of sugar in treacle, honey, and fruits (cherries, plums, strawberries, &c.) when ripe and acidulous. It is prepared from cane-sugar by treatment with dilute sulphuric acid. The acid is removed by precipitation with barium carbonate, and the filtrate evaporated to a syrup, which contains a mixture of dextrose and lævulose. The lævulose is then separated from the dextrose. It is sweeter than dextrose, and nearly as sweet as cane-sugar. It also does not ferment so readily as dextrose. It derives its name from the fact that it is lævorotatory. It is soluble in alcohol.

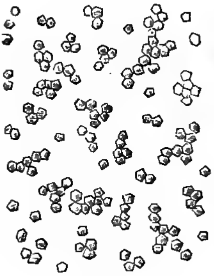
Lactose, or *Milk-sugar* ($C_{12}H_{22}O_{11}$), is the saccharine substance found in milk. Human milk contains from 5 to 8 per cent, cows' and ewes' milk from 4½ to 5 per cent, and mares' and asses' milk from 6 to 7 per cent. It is a body peculiar to milk, as it has not been met with anywhere else in the organism. When milk is evaporated down, lactose may be obtained in rhombic crystals, which contain one molecule of water of crystallisation, which is given off at 130° C. (266° Fahr.) It is soluble in 2½ parts of boiling water, and 6 parts of cold water. Dilute acids, as well as certain ferments, are able to convert it into another kind of sugar known as *galactose*, which is capable of undergoing alcoholic fermentation. The lactic acid present in sour milk is formed by the fermentation of the galactose derived from the lactose. It is distinguished from other sugars by its ready crystallisation, and by the formation of mucic acid when oxidised by nitric acid. It is less sweet than sucrose, resembling in this respect grape-sugar.

Inosite, or *Flesh-sugar* ($C_6H_{12}O_6 2H_2O$), is obtained from beef. It forms prismatic crystals, and is insoluble in absolute alcohol and ether. It is soluble in six parts of cold water, and possesses strong sweetening properties. It is not fermented by yeast. When treated with nitric acid it is converted into *oxalic acid* ($H_2C_2O_4$). Its occurrence is not limited to flesh, as it is also found in many vegetables and fruits. In unripe French beans it has been found to amount to .75 per cent. In unripe peas, in walnut-leaves, dandelion, and asparagus, it has been found in considerable traces. It also occurs in the urine in cases of Bright's disease.

Starch, *Fecula*, or *Amylose* ($C_6H_{10}O_5$), is widely distributed throughout the vegetable kingdom, being, next to cellulose, the most abundant substance in the vegetable world. It is the most abundant constituent of vegetable food. It is formed in the green portion of plants as the indirect product of the reduction of the carbonic acid of the air under the sunlight, and is deposited in certain parts of the plant in great quantity as the period of maturity approaches. Hence the stems of various palms, such as the sago, contain large quantities of it. It is absent in fungi. It is especially abundant in potatoes, and in the seeds of cereals; and, unlike the sugars, is insoluble in cold water. It is an odourless and tasteless white powder. There are several varieties of it. It occurs in oval or rounded granules formed of layers. The different starches vary in size and appearance when viewed under the microscope, according to the different plants producing them. The granules of rice-starch (fig. 14) do not exceed 1-3000th of an inch in diameter, whilst those of the *Canna*, or *tous les mois*, are about the 1-200th of an inch in diameter. Potato-starch (fig. 15) is the 1-300th of an inch in diameter, and wheat-starch (fig. 16) 1-1000th of an inch in diameter. When heated in water from 50° to 70° C. (122° to 150°

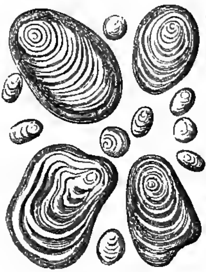
Fahr.), the granules burst. Starch-granules are made up of two substances—an external portion consisting of *starch cellulose* (*farinose*), and an internal portion consisting of *granulose.* When the starch, therefore, is heated, the external portion is ruptured, and the granulose is dissolved. The result is the viscous fluid known as paste. It must be noted that in reality granulose is comparatively insoluble in water, either cold or hot. Starch is obtained commercially from rice, which contains about 80 per cent; potato, which contains about 20 per cent; and wheat, which contains about 60 per cent. It may be converted into cane-sugar by digestion with dilute sulphuric acid at 100° C. (212° Fahr.) When heated to 205° C. (401° Fahr.), it is converted into dextrin, or "British gum." The starch undergoes a similar change when bread is toasted. When toast is soaked in water, the starch, thus converted into dextrin, is dissolved. Starch is insoluble in alcohol. The characteristic reaction of starch is that with iodine. When iodine is added to a solution containing it, a rich violet or blue colour is the result.

Fig. 14.



Rice-starch.

Fig. 15.



Potato-starch.

Fig. 16.

Wheat-starch.

Starch is also converted by the action of a peculiar ferment called *diastase,* a process which goes on in malting in the manufacture of beer or spirits. *Saliva* and the *pancreatic juice* have also the power of converting starch into sugar.

Dextrin ($C_6H_{10}O_5$), or something very like it, is supposed to exist in the sap of plants, but has seldom been found in any considerable quantity. It is prepared commercially by the action of dry heat on starch. In the baking of bread it is formed in a similar way, and occurs in a greater or less quantity in starchy foods prepared by cooking. It is entirely digestible.

Cellulose ($C_6H_{10}O_5$) is a white flavourless substance insoluble in water, alcohol, and ether. In appearance it has a silky or horny lustre. Cotton, white paper, linen, and the pith of the elder, are nearly pure cellulose. It forms the skeleton of the plant, and is so called from the fact that it constitutes the wall portion of a plant-cell. In certain portions of the plant the cellulose is thicker and harder than in other parts, it being impregnated with a harder kind of cellulose called *lignin.* This is the case in the stems and husks of plants. It may be conveniently identified by its reaction (after treatment with a dehydrating agent such as sulphuric acid) with iodine solution, when a blue colour is given. It is distinguished from the other carbohydrates by its slight solubility. Neither dilute alkalies nor acids dissolve it to any very great extent. Sulphuric acid and dilute acids and alkalies convert it on boiling, first into dextrine, and then into grape-sugar. Recent researches on the nature of celluloses seem to show that cellulose, instead of being one substance, is made up of a number of different substances, and that its nature varies with its source.

Gums are found in almost every kind of plant, but are more abundant in some than in others.

Arabin is well known under the name of *gum arabic,* a substance which exudes from several species of acacia, and occurs probably in most gums. It can be formed by the action of sulphuric acid on mucilage. It is a transparent, colourless, brittle body, being soluble in water. Its solutions exhibit an acid reaction to litmus paper, and possess a sharp, acid, mucilaginous, insipid taste.

Cerasin is found in the gum of the cherry-tree, chiefly in combination with calcium. It is also found in the residue from crushed beetroot.

Bassorin (*Mucilage*) is insoluble in water, in which, however, it swells up to a gelatinous mass. It is abundant in linseed, quince-seed, and in many roots. Gum-tragacanth contains it in large quantity. It is highly probable that the gums are digestible.

Glycogen, or *Animal Starch* ($C_6H_{10}O_5$), is a sugar-producing substance found in the liver. Nearly 10 per cent of the (dry) weight of the oyster consists of this substance. It is an amorphous powder, somewhat resembling starch in appearance, hence its name. It is also present in the muscles, blood, and in the yolk of egg. It is not found in the liver after death, being rapidly converted by fermentation into dextrose.

Inulin ($C_6H_{10}O_5$) is a variety of starch found in the dandelion, chicory, tubers of potatoes, Jerusalem artichoke, and some other plants. In appearance it resembles starch. It occurs, however, in another modification, where it resembles gum. In cold water it is slightly soluble; but in hot water it is readily so. It is insoluble in alcohol. It is a very hygroscopic substance. Unlike starch, its aqueous solution does not form a jelly, and with iodine it strikes a *yellow* colour. *Sinistrin*, a body found in the sea-onion, is supposed to be identical with inulin.

The Fats.—The fatty substances which occur in plants have the same composition essentially as animal fats, their average composition being:—

Carbon	76.5
Hydrogen	12.0
Oxygen	11.5
	100.00

They all agree in containing less oxygen than would be required to convert their hydrogen into water—less than 8 to 1 by weight. They are thus richer in carbon and hydrogen than the carbohydrates. For their complete combustion they require more oxygen than the carbohydrates, and give approximately, when burnt, 2½ times as much heat as the latter. This is a point of considerable importance when estimating the heat-giving powers of different food-constituents. Fat is found in all plants, at least in small quantities. Roots contain from .1 to .3 per cent; hay and straw, 1 to 3 per cent; cereal grains, 1.5 to 3 per cent; oats, however, contain as much as 6 per cent; and maize, 4 to 9 per cent. The seeds, it may be noted, are the richest part of the plant in fat. In some seeds especially—viz., those of flax, hemp, colza, cotton, &c.—the oil may amount to from 10 to 40 per cent. In the extraction of the oil from such seeds, a by-product of valuable feeding qualities is obtained in the shape of the so-called oil-cakes, reference to which will be made further on.

Most fats are mixtures of *olein* ($C_3H_5(C_{18}H_{33}O_3)_3$), *stearin* ($C_3H_5(C_{18}H_{35}O_2)_3$), and *palmitin* ($C_3H_5(C_{16}H_{31}O_2)_3$). These bodies are compounds of *glycerin* ($C_3H_8O_3$), with the different fatty acids *oleic*, *stearic*, and *palmitic*. When potash or soda is added to a fat, the process known as saponification takes place—that is, the potash or soda displaces the glycerin and unites with the fatty acid, a soap being the result. The proportion in which palmitin, stearin, and olein are present in the different fats or oils varies; beef-suet being almost entirely made up of stearin; olive-oil, on the other hand, consisting almost entirely of palmitin and olein.

The waxes are bodies found in animals and vegetables, resembling in appearance beeswax. They are not single chemical substances, but mixtures.

Resins, which are generally solid transparent bodies, are also largely mixtures. The chemistry of these bodies is not very well understood as yet.

Albuminoids (*Proteids*, *Albuminous*, or *Nitrogenous substances*[1]).—In all plants and animals there is present a group of substances containing, in addition to the elements found in the starchy and fatty bodies, nitrogen and small proportions of sulphur and phosphorus. They never occur in a crystalline condition; and, especially when soft or when in solution, they are apt to decompose very soon. They are found in all the organs and fluids of the animal body, with the exception of the urine. They only occur in plants and animals, and have never been prepared artificially. It is a characteristic difference between plants and animals that only plants can synthesise (*i.e.*, build up from their constituent elements) albuminoids. Animals are therefore dependent on plants for their albuminoids. As the vegetable albuminoids resemble very closely the animal, it will be more convenient to treat both together. Although there are a number of different albuminoids,

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[1] Albuminoids—*i.e.*, albumin-like bodies; name derived from albumin, which may be taken as type of the class. Protein (from proteids or protein-like bodies) was the name given by Mulder to designate a supposed substance which he believed formed the basis of all the albuminoids. It is now used as synonymous with albuminoids.

they do not vary much in their composition, which may be stated as follows :—

	Per cent.
Carbon	50 to 55
Hydrogen	6.9 " 7.5
Oxygen	20 " 24
Nitrogen	15 " 18[1]
Sulphur	.3 " 2

Most of them exist in two modifications—a soluble and an insoluble form. When heated, the soluble albuminoids are generally coagulated (or converted into the insoluble). In the case of some of them, coagulation begins at as low a temperature as 60° C. (or 140° Fahr.) They are also precipitated by a number of different reagents, among which may be mentioned carbolic acid, alcohol, nitric acid, acetic acid, potassium ferrocyanide, basic lead acetate, and corrosive sublimate. An excellent test for them is Millon's reagent (nitrate of mercury), which, when added to a solution containing albumen, gives a characteristic red colour. The chemistry of the albuminoids may be said to be scarcely known as yet. The most valuable researches on the subject are those by Béchamp, Ritthausen, Kreusler, and Martin.

Of these bodies the white of egg (albumen), animal fibrin, and casein, may be regarded as types. That these bodies contain unoxidised sulphur there is no doubt, but there is reason to doubt the statement that their phosphorus is other than in the form of phosphoric acid. Heated with nitric acid they become yellow, which colour is changed into deep orange on the addition of ammonia.

Albuminoids are divisible into the following seven groups :—

1. *Albumins.*

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[1] The average percentage of nitrogen in the albuminoids is generally taken as 16, and their amount in any substance is estimated by multiplying the percentage of nitrogen found by $6\frac{1}{4}$ ($6\frac{1}{4} \times 16 = 100$).

a. Egg albumin.—A neutral, transparent, slightly yellowish fluid, soluble in water. Heated to 155° Fahr. (68° C.), it is thrown down as a flocculent substance. Strong alcohol, mineral acids (especially nitric), and various metallic salts, precipitate egg albumin.

b. Serum albumin, or *blood albumin.*—This is an important part of the blood, and occurs in the serum of blood (forming nearly 8%), in the muscles, chyle, lymph, milk, &c.; and, though it strongly resembles egg albumin, differs from the latter in not being coagulated (clotted) by ether. Besides, hydrochloric acid readily coagulates egg albumin, and dissolves the clot with difficulty; whilst serum albumin is not readily coagulated by hydrochloric acid, and a slight excess of the acid dissolves the clot.

2. *Globulins.*—These do not dissolve in water, but they are soluble in dilute acids, alkalies, and various salts (common salt, &c.)

a. Crystallin occurs in the crystalline lens. It is soluble in water, and is coagulated by heat.

b. Myosin occurs in the muscles of animals. The clotting of this body, which takes place after death, is supposed to be the cause of the *rigor mortis.* It is dissolved out from the muscles by a salt solution, and is consequently in the brine used for pickling meat. In appearance it is a white mass, which on drying assumes a yellowish colour, and presents a horny appearance. It is insoluble in water, alcohol, and ether, but soluble in alkalies.

c. Serum globulin precipitates as a granular matter when fresh serum of blood is diluted with water, and carbonic acid passed into it. It is insoluble in water, alcohol, and ether, but is easily soluble in dilute acids and alkalies. On heating to a temperature of 70° C. (or 158° Fahr.), it is coagulated.

d. Fibrinogin resembles the preceding, and is found in the blood plasma. It is insoluble in water, but is soluble in dilute alkalies, and in a solution of common salt. The temperature at which it becomes coagulated is lower than serum globulin.

e. Vitellin is a granular substance found in the yolk of eggs. It is insoluble in water, alcohol, and ether, but soluble in dilute acids, alkalies, and solution of common salt.

3. *Derived albumins.*—These dissolve in diluted solutions of acids, alkalies, and in solution of common salt, but not in water. They comprise *casein* or *alkali-albumin* and *syntonin* or *acid-albumin.* The former is got from egg albumin, by acting on it with caustic alkalies; while the action of dilute hydrochloric acid on myosin furnishes the latter.

4. *Fibrin.*—This proteid is insoluble in water and saline solutions. It is elastic. It is the substance which chiefly constitutes the clot of blood, and it is largely present in muscle. According to Liebig, it is found in the gluten of plants. Fibrin varies in its properties according to the sources from which it is derived. It is insoluble in alcohol. On being dried, it becomes hard and friable.

5. *Coagulated albumin.*—This is the substance thrown down from soluble albumin by heat or strong alcohol. It is insoluble in water, saline solutions, and dilute acids and alkalies.

6. *Amyloid,* or *Lardacein,* a product of diseased action in the liver and elsewhere. Though its name implies that it is "like starch," it is a true proteid. It is insoluble in water and dilute acids, but is soluble in dilute ammonia. It is coloured blue or violet by iodine and sulphuric acid.

7. All proteids, except amyloid, are converted by the

action of the gastric or pancreatic juices into *peptones.* These are very soluble in water, and are not coagulated by acids and alkalies.

A few notes on some of the more important members of the albuminoid group may now be given.

1. *Gluten.*—If we wash the dough of wheat, a portion remains on the sieve of muslin, as we have already seen, to which the name of gluten is given. From wheat gluten different albuminoids have been extracted. These are gluten-fibrin, gliadin, and mucedin (Ritthausen). The elastic nature of the gluten is due to the gliadin. Its value in bread-making is considerable, as it helps to retain the carbonic acid produced by the action. It is most abundant in wheat; whereas rye, oats, and barley are deficient in it, and are on that account not so well suited for bread-making. Its percentage in plants varies according to the nature of the soil, grain grown on rich land being richer in it than grain grown on poor land. The grain of wheat contains from 11 to 13 per cent of gluten. The composition of gluten, according to Béchamp, is as follows:—

Carbon	52.6
Hydrogen	7.0
Nitrogen	16.0
Oxygen	24.4
	100.00

It is insoluble in water, ether, and alcohol (boiling alcohol partly dissolves it). It is soluble in alkalies, and slightly so in weak acids. Acetic acid, however, dissolves it easily. When moist, gluten is slightly yellow; but when perfectly dry, it is hard, brittle, and of a grey or brownish colour. When heated, it coagulates; and when it is kept for some time it liquefies. It does not dissolve in ammonia.

2. *Albumin.*—The white part of eggs is called albumin by chemists. In the natural state it is a glairy, thick liquid, which can be dissolved in water, but which coagulates, or becomes solid and opaque, when heated to about 165° Fahr. (or 74° C.) In this coagulated state it is insoluble in water, ether, or alcohol, but dissolves in vinegar, or in solutions of caustic potash or soda, or an alkaline salt. It is precipitated by alcohol and nitric acid. The last-named reagent is a good test for albumin when in the soluble condition, warming aiding precipitation. Dilute sulphuric acid produces a precipitate after some time, but dilute hydrochloric acid does not. When dried, it becomes hard, brittle, semi-transparent, and of a brownish colour. Béchamp has isolated three kinds of albumin from the white of an egg—viz., *primo-albumin*, *secondo-albumin*, and *leucozymase.*

When the expressed juice or sap of plants is heated, a solid substance coagulates, and separates from it in opaque white flocks. This substance possesses nearly all the properties of the albumin of the egg, and is therefore called vegetable albumin.

Albumin occurs in the young and growing parts of plants; and as the plant develops, is converted into other albuminoids. In the husks and envelopes of many seeds—the bran of corn, for example—and in the solid parts of woody and herbaceous plants, it is found in this state in greater or less proportion.

3. *Casein.*—When rennet, vinegar, or dilute muriatic acid is added to milk, it coagulates or curdles, and a white curd separates from the whey. Alcohol or ether extracts the fat or butter from the coagulated mass, and leaves pure curd behind. To this curd chemists give the name of casein. Casein may be conveniently extracted by heating fresh milk to 50° C. (122° Fahr.), and adding enough acetic acid to make the liquid dis-

tinctly acid. The curd may be then separated on a cloth, and washed with water containing a little acetic acid. The fat may be extracted by alcohol and ether, and the mass thereafter dissolved in dilute ammonia. The casein is again precipitated with acetic acid, washed with water, alcohol, and ether, and dried *in vacuo* over sulphuric acid. Casein is the characteristic constituent of cheese. It is a light white substance, which reddens litmus, and behaves like an acid. It is soluble in ammonia and the other alkalies, and *dilute* hydrochloric acid. It is insoluble in water. It does not coagulate on heating.

When cold water is shaken up with oatmeal for half an hour, and is then allowed to subside, the clear liquid becomes turbid on the addition of a little acid, and a white powder falls, possessing nearly all the properties of the casein of milk.

The sap of nearly all plants—the expressed juice of the potato, the turnip, and other roots after being heated to coagulate the albumin, and the solution obtained when the meal of the bean, the pea, and other legumes is treated with warm water—yield, on the addition of an acid, precipitates of this substance differing but little from one another. Vegetable casein, therefore, is a constant constituent of our best-known and cultivated plants.

The proteid richest in nitrogen is *gliadin* or vegetable glue. It has recently been found in gluten, and contains 18.01 per cent of nitrogen. *Mucedin* is another albuminoid found in wheat gluten.

Gelatinous and **Horny Substances.**—In the animal body, in addition to the albuminoids, there are other nitrogenous bodies, which, although they differ in many respects, have a composition very similar to the albuminoids. Of these *gelatin* ($C_{42}H_{66}N_{13}O_{16}$) is one of the most abundant. It forms the organic nitrogenous substance of the bone and cartilage, and is also present in the muscles, skin, ligaments, tendons, hoofs, and connective tissue. It may be obtained from these substances by prolonged boiling with water. It is a brittle, transparent body, insoluble in alcohol or ether, but soluble in acetic or mineral acids. When precipitated by tannic acid it forms tannate of gelatin, a body resembling in composition leather. Its value as a food has formed the subject of experiments, and it was actually tried as such during the first French Revolution. It is not, however, a flesh-forming food, and its heat-giving powers are probably low. The following is the percentage composition of gelatin :—

Carbon	50.00
Hydrogen	6.60
Nitrogen	18.30
Oxygen	25.10
	100.00

Chondrin is probably always present in gelatin, and resembles it. It is the chief ingredient of cartilage. Both contain more nitrogen and less carbon and sulphur than are found in albuminoids. Isinglass, glue, and size are forms of gelatin. When treated with cold water gelatin swells up.

Many active principles (quinine, strychnine, &c.), various acids, such as tartaric, oxalic, &c., and different saline substances, exist in plants; but the study of these compounds is beyond the scope of this work.

CHAPTER VIII. 8

THE COMPOSITION OF SOILS.

The term SOIL is given to the upper stratum of the crust of the earth, which is specially adapted for the maintenance of plants. Geologically, soil is a species of "rock," though usually it is a loosely coherent substance very unlike the dense masses popularly termed rocks.

Soils consist of two parts; of an *organic* part, which can readily be burned away when the soil is heated to redness; and of an *inorganic* part, which is fixed in the fire, and which consists entirely of earthy and saline substances.

The Organic Part of Soils is derived from the remains of vegetables and animals which have lived and died in or upon the soil, which have been spread over it by winds, rivers, and rains, or which have been added by the hands of man for the purpose of increasing its natural fertility.

This organic part varies very much in quantity in different soils. In some, as in peaty soils, it forms from 50 to 70 per cent of their whole weight; and even in rich long-cultivated soils it has been found, in a few rare cases, to amount to as much as 25 per cent. In general, however, it is present in much smaller proportion, even in our best arable lands. Oats and rye will grow upon a soil containing only 1½ per cent, barley when 2 to 3 per cent are present, while good wheat soils generally contain from 4 to 8 per cent. The rich alluvial soil of the valley of the Nile contains only 5 per cent of dry organic matter. In stiff and very clayey soils, 10 to 12 per cent is sometimes found. In very old pasture-lands, and in gardens, vegetable matter occasionally accumulates so as to overload the upper soil. The comparative value of peaty or boggy soils may be judged of from the fact, that of the 5000 flowering-plants of Central Europe, only 300 grow on peaty or boggy soils, and these mostly belong to the *rush* and *sedge* families, useless to the farmer.

The organic matter in the soil is chiefly composed of a brown or black substance, to which the name of *humus* has been given. Mulder considered it to be a mixture of three substances—namely, compounds of water, or of water and ammonia, with *geic acid*,[1] *humic acid*,[2] and *ulmic acid*.[3] In addition to these bodies, *crenic acid* (from the Greek *krene*, a spring) and *apocrenic acid* have been identified by Berzelius. There is some doubt as to their composition. Detmer assigns to humic acid the formula $C_{60}H_{54}O_{27}$, while according to Thenard its formula is $C_{24}H_{10}O_{10}$. Ulmic acid is probably identical with humic acid. Crenic and apocrenic acids seem to be products of oxidation of humic acid. All these compounds retain ammonia with great tenacity—a property of great utility in connection with the supply of nitrogen to plants, as we shall see further on. Humus when acted upon by acids and alkalies yields ammonia and soluble nitrogen compounds. The percentage of nitrogen in a soil is, as a rule, in proportion to its organic matter; the more organic matter a soil contains the more nitrogen will be present. Of course there are exceptions to this rule.

Another influence of the organic portion of the soil, whether naturally formed in it or added to it as manure,

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[1] From the Greek *ge*, the earth.

[2] From the Latin *humus*, the ground.

[3] From the Latin *ulmus*, an elm.

is not to be neglected. It contains—as all vegetable substances do—a considerable quantity of inorganic, that is, of saline and earthy matter, which is liberated as the organic part decays. Thus living plants derive from the remains of former races, buried beneath the surface, a portion of that inorganic food which can only be obtained from the soil, and which, if not thus directly supplied, must be sought for by the slow extension of their roots through a greater depth and breadth of the earth in which they grow. The addition of manure to the soil, therefore, places within the easy reach of the roots not only organic but also inorganic food. It must be remembered, however, that the absolute amount of nitrogen in a soil no more determines its fertility than does the amount of mineral food it contains. In both cases a great deal depends on the condition of the nitrogen and mineral matter—*i.e.*, as to whether it is in a condition available as plant food.

The Inorganic Part of Soils is that which remains when everything combustible is burned away by combustion in the open air. It consists of two portions, one of which is *soluble* in water, the other *insoluble.*

1. *The saline or soluble portion.*—In this country, the surface-soil of our fields, in general, contains very little soluble matter. If a quantity of soil be dried in an oven, a pound weight of it taken, and a pint and a half of pure boiling rain-water poured over it, and the whole well stirred and allowed to settle, the clear liquid, when poured off and boiled to dryness, may leave from 30 to 100 grains of mineral mixed with a variable quantity of organic matter. This matter will consist of common salt, gypsum, sodium sulphate (Glauber's salts), magnesium sulphate (Epsom salts), with traces of the chlorides, nitrates, phosphates, humates, and other organic compounds of calcium, magnesium, and potas-

sium. It is from these soluble substances that the plants derive the greater portion of the saline ingredients contained in the ash which they leave when burned.

Nor must the quantity thus obtained from the soil be considered too small to yield the whole supply which a crop requires. A single grain of saline matter in every pound of a soil a foot deep, is equal to 500 lb. in an acre. This is more than is carried off from the soil in ten rotations (forty years), where only the wheat and barley are sent to market, and the straw and green crops are regularly, and without loss, returned to the land in the manure.

In some countries—indeed, in some districts of our own country—the quantity of saline matter in the soil is so great as in hot seasons to form a white incrustation on the surface. This may often be seen in the neighbourhood of Durham; and is more especially to be looked for in districts where the subsoil is sandy and porous, and more or less full of water. In hot weather, the evaporation on the surface causes the water to ascend from the porous subsoil; and as this water always brings with it a quantity of saline matter, which it leaves behind when it rises in vapour, it is evident that, the longer the dry weather and consequent evaporation from the surface continue, the thicker the incrustations will be, or the greater the accumulation of saline matter on the surface. Hence, where such a moist and porous subsoil exists in countries rarely visited by rain, as in the plains of Peru, of Egypt, or of India, the country is whitened over in the dry season with an unbroken snowy covering of the different saline substances above mentioned.

When rain falls, the saline matter is dissolved, and descends again to the subsoil. In dry weather it reascends. Hence the *surface-soil* of any field will contain a larger proportion of soluble inorganic matter in the middle of a hot dry season than in one of even ordinary rain. Hence, also, the fine dry weather which, in early summer, hastens the growth of corn, and later in the season favours its ripening, does so probably, among its other modes of action, by bringing up to the roots from beneath a more ready supply of those saline compounds which the crop requires for its healthful growth. In some countries, however, this saline matter ascends in such quantity as to render the soil unfit to grow the more tender crops. Thus, on the plains of Attica, when the rainy season ends, saline substances begin to rise to the surface in such abundance as by degrees entirely to burn up or prevent the growth of grass, though abundant wheat crops are yearly ripened.

2. *The insoluble portion* (usually about 95 per cent) of the soil is composed of silica, aluminium silicates, calcium and magnesium carbonates, and phosphates, oxides of iron, and traces of a few other compounds. *Clays* are composed of water, silica, and alumina. The latter substance (Al_2O_3) is only found—probably as the result of accident—in the club-mosses, and we have not described it when treating of the ash ingredients of plants. It is the only oxide of the metal aluminium. It occurs nearly in a pure state in the mineral *corundum;* and, tinged with chromium oxide, in the *ruby* and *sapphire;* and, coloured with iron and manganese oxides, in *emery.* Chemically prepared, it occurs as a white powder, insoluble in water, but uniting greedily with that liquid to form $Al_2O_3 + 3H_2O$. White porcelain consists of aluminium silicate, free from potash, soda, and iron. Pipe-clay and blue clay are silicates of aluminium. The common *clay* of soils is a mixture of pure clay, which is a hydrated silicate of aluminium, and

of very minute sand which is similar in composition—the fertility of a clay soil is due to the presence of the substances other than the pure clay, as pure clay contains no plant food itself—aluminium silicate along with organic matter, alkalies, oxide of iron, &c.

Pure clay, when moist, forms a stiff, tenacious substance, insoluble in water, and capable of being moulded into any shape. It has a peculiar and well-known odour. Clay, like alumina, absorbs water, ammonia, and organic substances, and retains phosphoric acid, potash, lime, and other substances.

a. If an ounce of soil be intimately mixed with a pint of water till it is perfectly softened and diffused through it, and if, after shaking, the heavy parts be allowed to settle for a few minutes, the sand will subside, while the clay—which is in finer particles, and is less heavy—will still remain floating. If the water and fine floating clay be now poured into another vessel, and be allowed to stand till the water has become clear, the sandy part of the soil will for the most part be found on the bottom of the first vessel, and the clayey part mainly on that of the second, and they may be dried, and weighed separately.

b. If 100 grains of dry soil, not peaty or unusually rich in vegetable matter, leave no more than 10 of clay when treated in this manner, it is called a *sandy soil;* if from 10 to 40, a *sandy loam;* if from 40 to 70, a *loamy soil;* if from 70 to 85, a *clay loam;* from 85 to 95, a *strong clay soil;* and when no sand is separated at all by this process, it is a pure *agricultural clay.* There are a number of methods in use in agricultural laboratories on the Continent for making elaborate mechanical analyses of the soil. It is a question, however, to what extent such claborate analyses have a practical value.

c. This pure clay contains silica and alumina, in the proportion of about 60 of the former to 40 of the latter. Soils made up entirely of clay rarely occur—it being well known to all practical men that the strong clays (tile-clays), which contain from 5 to 15 per cent of sand, are brought into arable cultivation with the greatest possible difficulty. It will rarely, almost never, happen, therefore, that arable land will contain more than 30 to 35 per cent of alumina.

d. If a soil contain more than 5 per cent of carbonate of lime, it is called a *marl;* if more than 20 per cent, it is a *calcareous* soil. *Peaty soils*, of course, are those in which the vegetable matter predominates very much.

The Diversities of Soils and Subsoils.—*Varieties of Soil.*—Though the substances of which soils *chiefly* consist, are so few in number, yet every practical man knows how very diversified they are in character—how very different in agricultural value. Thus, in some of the southern counties of Scotland, we have a white soil, consisting apparently of nothing else but chalk; in the centre of England, a wide plain of dark-red land; in the border counties of Wales, and on many of our coal-fields, tracts of country almost perfectly black; while yellow, white, and brown sands and clays give the prevailing character to the soils of other districts. Such differences as these arise from the different proportions in which the sand, lime, clay, and the oxide of iron and organic matter which colour the soils, have been mixed together.

But how have they been so mixed—differently in different parts of the country? By what natural agency? For what end?

Subsoil.—Again, the surface-soil rests on what is usually denominated the *subsoil.* This also is very variable in its character and quality. Sometimes it is a porous sand or gravel, through which water readily ascends from beneath, or sinks in from above; sometimes it is light and loamy, like the soil that rests upon it; sometimes stiff, and more or less impervious to water.

The most ignorant farmer knows how much the value of a piece of land depends upon the character of the surface-soil,—the intelligent improver understands best the importance of a favourable subsoil. "When I came to look at this farm," said an excellent agriculturist, "it was spring, and damp, growing weather: the grass was beautifully green, the clover shooting up strong and healthy, and the whole farm had the appearance of being very good land. Had I come in June, when the heat had drunk up nearly all the moisture which the *sandy subsoil* had left in the surface, I should not have offered so much rent for it by ten shillings an acre." He might have said also, "Had I taken a spade, and dug down 18 inches in various parts of the farm, I should have known what to expect in seasons of drought."

But how come subsoils thus to differ—one from the other, and from the surface-soil that rests upon them? Are there any principles by which such differences can be accounted for—by which they can be foreseen—by the aid of which we can tell what kind of soil may be expected in this or that district, even without visiting the spot, and on what kind of subsoil it is likely to rest?

Geology explains the cause of many of these differences, and supplies us with principles by which we can predict the general quality of both soils and subsoils in the several parts of entire kingdoms; and where the soil is of inferior quality, and yet susceptible of improvement, the same principles indicate whether the means of improving it are likely to exist in any given locality, or to be attainable at a reasonable cost.

It will be proper shortly to illustrate these direct relations of geology to agriculture.

CHAPTER IX. 9

ORIGIN AND CLASSIFICATION OF SOILS.

Geology is that branch of knowledge which embodies all ascertained facts in regard to the nature and internal structure, both physical and chemical, of the solid parts of our globe. This science has many close relations with practical agriculture. It especially throws much light on the nature and origin of soils—on the causes of their diversity—on the agricultural capabilities, absolute and comparative, of different farming districts and countries—on the unlike effects produced by the same manure on different soils—on the kind of materials, by admixture with which they may be permanently improved—and on the sources from which these materials may be derived.

It tells beforehand, also, and by a mere inspection of a sufficiently detailed map, what is the general character of the land in this or that district of a country—where good land is to be expected—where improvements are likely to be effected—of what kind of improvements this or that district will be susceptible—and where the intending purchaser may hope to lay out his money to the greatest advantage.

Decay of Rocks.—If we dig down through the soil and subsoil to a sufficient depth, we always come sooner or later to the solid rock. In many places the rock actually reaches the surface, or rises in cliffs, hills, or ridges, far above it. The surface (or crust) of our globe, therefore, consists everywhere of a more or less solid mass of rock, overlaid by a covering, generally thin, of loose materials. The upper or outer part of these loose materials forms the soil.

The geologist has travelled over the greater part of the earth's surface, has examined the nature of the rocks which everywhere repose beneath the soil, and has found them to be very unlike in appearance, in hardness, and in composition—in different countries and districts. In some places he has met with a sandstone, in other places a limestone, in others a slate or hardened rock of clay. But a careful comparison of all the kinds of rock he has observed has led him to the general conclusion that they are all either sandstones, limestones, or clays of different degrees of hardness, or a mixture in different proportions of two or more of these kinds of matter.

When the loose covering of earth is removed from the surface of any of these rocks, and this surface is left exposed, summer and winter, to the action of the winds and rains and frosts, it may be seen gradually to crumble away. Such is the case even with many of those which, on account of their greater hardness, are employed as building-stones, and which, in the walls of houses, are kept generally dry; how much more with such as are less hard, or lie beneath a covering of moist earth, and are continually exposed to the action of water? The natural crumbling of a naked rock thus gradually covers it with loose materials, in which seeds fix themselves and vegetate, and which eventually form a soil. The soil thus produced partakes necessarily of the chemical character and composition of the rock on which it rests, and to the crumbling of which it owes its origin. If the rock be a sandstone, the soil is sandy—if a claystone, it is a more or less stiff clay—if a limestone, it is more or less calcareous—and if the rock consists of any peculiar mixture of those three substances, a similar mixture is observed in the earthy matter into which it has crumbled.

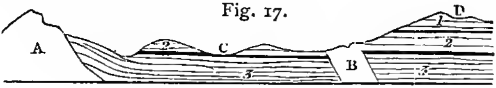
Led by this observation, the geologist, after comparing the rocks of different countries with one another, compared next the soils of various districts with the rocks on which they immediately rest. The *general* result of this comparison has been, that in almost every country the soils, as a whole, have a resemblance to the rocks beneath them, similar to that which the loose earth derived from the crumbling of a rock before our eyes bears to the rock of which it lately formed a part. The conclusion, therefore, is irresistible, that soils, generally speaking, have been formed by the crumbling or decay of the solid rocks—that there was a time when these rocks were naked and without any covering of loose materials—and that the accumulation of soil has been the slow result of the natural degradation or wearing away of the solid crust of the globe.

Causes of Diversity of Soils.—The cause of the diversity of soils in different districts, therefore, is no longer obscure. If the subjacent rocks in two localities differ, the soils met with there are likely to differ also, and in an equal degree.

But why, it may be asked, do we find the soil in some countries uniform in mineral character—that is, containing the same general proportions of sand, clay, lime, &c., or coloured red by similar quantities of oxide of iron—and general fertility over hundreds or thousands of square miles, while in others it varies from field to field—the same farm often presenting many well-marked differences both in mineral character and in agricultural value? A chief cause of this is to be found in the mode in which the different rocks are observed to lie—upon or by the side of each other.

1. Geologists distinguish rocks into two classes, the *stratified* and the *unstratified*. The former are found lying over each other in separate beds or *strata*, like the leaves of a book when laid on its side, or like the layers of stones in the wall of a building. The latter—the unstratified rocks—form hills, mountains, or sometimes ridges of mountains, consisting of one more or less solid mass of the same material, in which no layers or strata are usually anywhere or distinctly perceptible. Thus, in the following diagram (fig. 17), A and B represent *unstratified* masses, in connection with a series of *stratified* deposits, 1 2 3, lying over each other in a horizontal position. On A one kind of soil will be formed, on C another, on B a third, and on D a fourth—the rocks being all different from each other.

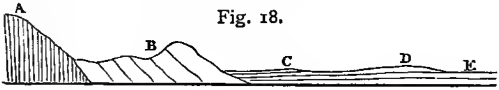
Fig. 17.



If from A to D be a wide valley of many miles in extent, the undulating plain at the bottom of the valley, resting in great part on the same rock (2), will be covered by a similar soil. On B the soil will be different for a short space; and again it will differ at the bottom of the valley C, and on the first ascent to A, at both of which places the rock (3), rises to the surface. In this case the stratified rocks lie horizontally; and it is the undulating nature of the country which, bringing different kinds of rock to the surface, causes a necessary diversity of soil.

2. But the degree of *inclination* which the beds possess is a more frequent cause of variation in the character of the soil in the same district, and even at very short distances. This is shown in the annexed diagram (fig. 18), where A B C D E represent the mode in which the stratified rocks of a district of country not unfrequently occur in connection with each other.

Fig. 18.



Proceeding from E in the plain, the soil would change when we came upon the rock D, but would continue pretty uniform in quality till we reached the layer C. Each of these layers may stretch over a comparatively level tract of perhaps hundreds of miles in extent. Again, on climbing the hillside, another soil would present itself, which would not change till we arrived at B. Then, however, we begin to walk over the edges of a series of beds, and the soil may vary with every new *stratum* or bed we pass over, till we gain the ascent to A, where the beds are much thinner, and where, therefore, still more frequent variations may present themselves.

Everywhere over the British Islands, valleys are hollowed out, as in the former of these diagrams (fig. 17), by which the different rocks beneath are in different places exposed and differences of soil produced; or the beds are more or less inclined, as in the latter diagram (fig. 18), causing still more frequent variations of the land to appear. By a reference to these facts, therefore, many of the *greater* diversities which the soils of the country present may be satisfactorily accounted for.

Uniformity in Composition and Arrangement of Stratified Rocks.—A fact, alike important to agriculture and to geology, is the natural order or mode of arrangement in which the stratified rocks are observed to occur in the crust of the globe. Thus, if 1 2 3 (fig. 17) represent three different kinds of rock,—a limestone, for example, a sandstone, and a hard clay rock (a shale or slate), lying over each other in the order here represented,—then, in whatever part of the country—nay, in whatever part of the world these same rocks are met with, they will always be found in the same position. *The bed* 2 *or* 3 *will never be observed to lie over the bed* 1.

This fact is important to geology, because it enables this science to arrange all the stratified rocks in a certain invariable order—which order indicates their relative age or antiquity—since that rock which is lowest, like the lowest layer of stones in the wall of a building, must generally have been the first deposited, or must be the oldest. It also enables the geologist, on observing the kind of rock which forms the surface in any country, to predict at once whether certain other rocks are likely to be met with in that country or not. Thus at C (fig. 17), where the rock 3 comes to the surface, he knows it would be in vain, either by sinking or otherwise, to seek for the rock 1, the natural place of which is far above it; while at D, he knows that by sinking he is likely to find either 2 or 3, if it be worth his while to seek for them.

To the agriculturist this fact is important, among other reasons,—

1. Because it enables him to predict whether certain kinds of rock, which may be used with advantage in improving his soil, are likely to be met with within a reasonable distance or at an accessible depth. Thus,

if the bed D (fig. 18) be a limestone, the instructed farmer at E knows that it is not to be found by sinking into his own land, and therefore brings it from D; while to the farmer upon C it may be less expensive to dig down to the bed D in one of his own fields, than to cart it from a distant spot, where it occurs on the surface. Or, if the farmer requires clay, or marl, or sand, to ameliorate his soil, this knowledge of the constant relative position of beds enables him to say where these materials are to be got, or where they are to be looked for, and whether the advantage to be derived is likely to repay the cost of procuring them.

2. It is observed that, when the soil on the surface of each of a series of rocks, such as C or D or E (fig. 18), is uniformly bad, *it is almost uniformly of better quality at the point where the two rocks meet.* Thus C may be dry, sandy, and barren—D may be a cold unproductive clay—and E a more or less unfruitful limestone soil; yet at either extremity of the tract D, where the soil is made up of an admixture of the decayed portions of the two adjacent rocks, the land may be of average fertility—the sand of C may adapt the adjacent clay to the growth of turnips, while the lime of E may cause it to yield large returns of wheat.[1] Thus, to the tenant in looking out for a farm, or to the capitalist in seeking an eligible investment, a knowledge of the mutual relations of geology and agriculture will often prove of the greatest assistance. But how little is such really useful knowledge diffused among either class of men—how little have either tenants or proprietors been hitherto guided by it in their choice of the localities in which they desire to live!

3. The further fact that the several stratified rocks are remarkably constant in their general mineral character, renders this knowledge of the order of relative superposi-

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[1] See pp. 110, 111.

tion still more valuable to the agriculturist. Thousands of different beds are known to geologists to occur on various parts of the earth's surface, each occupying its own unvarying place in the series. Most of these beds also, when they crumble or are worn down, produce soils possessed of some peculiarity by which their general agricultural capabilities are more or less affected,—and these peculiarities may *generally* be observed in soils formed from rocks of the same age—that is, occupying the same place in the series—in whatever part of the world we find them. Hence, if the agricultural geologist be informed that his friend has bought, or is in treaty for a farm or an estate, and that it is situated upon such and such a rock or geological formation, or is in the immediate neighbourhood of such another,—he can immediately give a very probable opinion in regard to the agricultural value of the soil, whether the property be in England, in Australia, or in New Zealand. If he knows the nature of the climate also, he will be able to estimate with tolerable correctness how far the soil is likely to repay the labours of the practical farmer—nay, even whether it is likely to suit better for arable land or for pasture; and if for arable, what species of grain and root crops it may be expected to produce most abundantly.

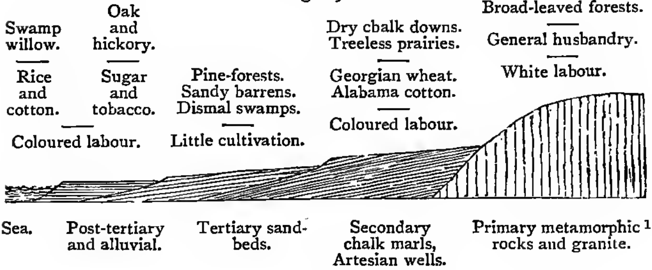
These facts are so very curious, and illustrate so beautifully the value of geological knowledge—if not to A and B, the holders and proprietors of this and that small farm, yet to enlightened agriculturists, to scientific agriculture in general—that I shall explain this part of the subject more fully in a separate section. To those who are in quest of new homes in our numerous colonies—who hope to find, if not a more willing, at least a more attainable, soil in new countries—no kind of agricultural knowledge can at the outset,—I may say, even through life,—be so valuable as that to which the rudiments of geology will lead them. Those who prepare themselves the best for becoming farmers or proprietors in Canada, in New Zealand, or in wide Australia, leave their native land in general without a particle of that preliminary practical knowledge which would qualify them to say, when they reach the land of their adoption, "on this spot rather than on that—in this district rather than that—will I purchase my allotment, because, though both appear equally inviting, yet I know, from the geological structure of the country, that here I shall have the more permanently productive soil; here I am more within reach of the means of agricultural improvement; here, in addition to the riches of the surface, my descendants may hope to derive the means of wealth from mineral riches beneath." And this oversight has arisen chiefly from the value of such knowledge not being understood—often from the very nature of it being unknown, even to otherwise well-instructed practical men. It is not to men well skilled merely in the details of local farming, and who are therefore deservedly considered as authorities, and good teachers in regard to local or district practice, that we are to look for an exposition, often not even for a correct appreciation, of those general principles on which a universal system of agriculture must be based—without which, indeed, it must ever remain a mere collection of empirical rules, to be studied and laboriously mastered in every new district we go to—as the traveller in foreign lands must acquire a new language every successive frontier he passes. England, the mistress of so many wide and unpeopled lands, over which the dwellings of her adventurous sons are hereafter to be scattered, on which their toil is to be expended, and the glory of their motherland by their exertions to be perpetuated—England should especially encourage all such learning, and the sons of English farmers should willingly avail themselves of every opportunity of acquiring it.

Subdivisions of Stratified Rocks.—The thousands of beds or strata lying one over the other in the crust of the globe, have—partly for convenience and partly in consequence of certain remarkably distinctive characters observed among them—been separated by geologists into three great divisions. The *primary* are oldest, and in general the lowest; the *secondary* lie over these; and the *tertiary* are the uppermost, and have been most recently formed. The sands, gravels, clays, and alluvial deposits, which frequently overlie the solid rocks and the beds of soft limestone, in many places formed by calcareous springs, are often spoken of as *post-tertiary*.

In some countries, on the surface of which these several divisions of the strata are seen to succeed each other very closely, the character of the surface-soil and its agricultural capability are also seen to vary as we pass from the rocks of the one epoch to those of the other. This is the case, for example, in the more southerly of the United States of America which lie along the Atlantic border. As we walk inland from the sea-shore, we pass over low and swampy, but rich muddy flats, which yield large returns of sea-island cotton and rice. As we proceed, the ground gradually rises above the sea-level—becomes firmer and drier—and instead of the swamp willow and cypress, bears the hickory and the oak. Tobacco and sugar are the marketable crops on this drier land, and Indian corn the staple food of the coloured population. After twenty miles or so, the edge of this drier alluvial plain is reached, and we ascend a low escarpment or terrace of yellow sand. Here we find ourselves amid thin forests of unmixed natural pine, growing upon a poor sandy soil; and till we cross this belt and reach a second terrace, few corn-fields, or attempts at clearing for the purposes of cultivation, meet the eye. The new terrace presents the remarkable contrast of an open prairie, void of trees, covered with a thin soil waving with grass, and resting, like our English downs, on chalk rocks beneath. This tract is dry and deficient in water; but the thin soil, when turned over, yields crops of corn, and bears, among others, a variety of hard wheat, known in the market by the name of Georgian wheat. Still farther on, this prairie is passed, and we ascend hilly slopes, upon which clays and loams of various qualities and capabilities occur at intervals intermingled, and broad-leaved trees of various kinds ornament the landscape. It is a country fitted for general husbandry, propitious to skill and industry, and, by its climate, adapted to the constitution of settlers of European blood.

These changes in agricultural character and capability are coincident with changes in the geological age of the beds which form its surface. These are shown in the preceding section (fig. 19) of the coast-line in question, from the sea to the mountains. The letterpress below the section indicates the geological formations; that

Fig. 19.



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[1] The word metamorphic here used means changed or altered—as clay, for example, is changed when it is baked into tiles or bricks.

placed above it indicates, first, the natural vegetation, and then the kind of husbandry and of labour which are best adapted to each.

In studying the foregoing paragraphs, the reader will have observed a close general relation between the changes in geological and agricultural character which appear on the several successive terraces or flats of land which intervene between the shores of the Atlantic and the slopes of the Alleghany Mountains. Where the most recent or alluvial loams and rich clay end, there the tobacco, Indian corn, and even wheat culture, for the time, end also. The tertiary sands belong to a more ancient epoch, and to them are limited, by a strictly defined boundary on each side, the dark pine-forests which are so striking a feature of the country. On the still older chalk, again, the treeless prairie and flinty wheat country is as distinctly limited by the formations on either hand; and beyond this, again, the changed forests and cultivation of the higher country are determined by the change in nature and in age which the rocks of this region exhibit.

CHAPTER X.

SUBDIVISION OF ROCKS.

The several great groups of strata of which we have spoken under the names of primary, secondary, &c., are themselves broken up or subdivided by geologists into a variety of subdivisions called systems and formations, each of which possesses its peculiar mineral characters and special agricultural relations. These, in so far as relates to the geology of our own country, it will be proper briefly to indicate.

The Tertiary Strata.—The tertiary strata, as they occur in England, consist chiefly of the crag, which lies above, and the London and plastic clays, which follow each other underneath.

1. The *Crag* consists of a mass of rolled pebbles mixed with marine shells and corals, and resting upon beds of sand and marl. It is in places as much as 50 feet in thickness, though generally of less depth, and forms a strip of flat land, a few miles in width, along the eastern shores of Norfolk and Suffolk. The soil is generally fertile, but varies in value from 5s. to 25s. an acre of rent.

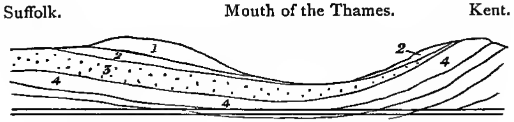
This crag is chiefly interesting to the agriculturist from its containing hard, rounded, flinty nodules—often spoken of as *coprolites*—in which as much as 60 per cent of calcium phosphate (bone-earth) is frequently found. These nodules are scattered through the body of the marls, and through the subsoils of the fields far inland, and are collected for sale to the manufacturers of superphosphate of lime, and other artificial manures.

2. The *London and Plastic Clays*, from 500 to 900 feet thick, consist of stiff, almost impervious, dark-coloured clays—the soils formed from which are still chiefly in pasture. The lower beds—the plastic clay—are mixed with sand, and produce an arable soil; but extensive heaths and wastes rest upon them in Berkshire, Hampshire, and Dorset. The crops of corn and roots yielded by the stiff clay soils of these strata have hitherto, in many districts, been found insufficient to pay the cost of raising them. The drain and the subsoil plough, with lime or chalk—in which these clays are very deficient, and for the addition of which they are very grateful—

would render them more productive and more profitable to the farmer.

The Secondary Strata.—3. The *Chalk*, about 600 feet in thickness, lies below the London and plastic clays above described. It consists—as shown in the section, fig. 20—in the upper part, of a purer chalk with layers of flint (3); in the lower, of a marly chalk without flints (4). The soil of the upper chalk is chiefly in sheep-walks; that of the lower chalk is very productive of corn. In some localities (Croydon) the arable soils of the upper chalk have lately been rendered much more productive in corn and beans by deep ploughing, and thus mixing with the upper soil as much as 6 or 8 inches of the inferior chalk. Excellent crops of carrots also have been obtained by deep-forking such land.

Fig. 20.



1. London clay.
2. Plastic clay.
3. Upper chalk, with flints.
4. Under chalk, without flints.

The general and comparative agricultural value of the soils upon the chalk may, to a certain extent, be judged of by the fact, that in the lowest-rented counties in England chalk is the prevailing rock.

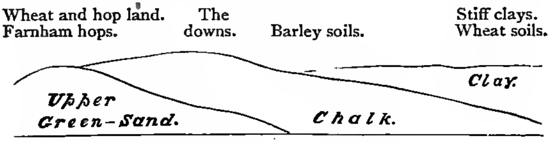
4. The *Greensand*, 500 feet thick, consists of 150 feet of clay, with about 100 feet of a greenish, more or less indurated, sand above, and 250 feet of sand or sandstone below it. The upper sand forms a very productive arable soil; but the clay forms impervious, wet, and cold lands, chiefly in pasture. The lower sand is generally unproductive.

In the greensand, both upper and lower, but especially in the upper, beds of marl occur, in which are found layers of so-called coprolites and other organic remains, rich in phosphate of lime. To the presence of these beds is ascribed the fertility of the soil of the upper greensand, which in some localities is very remarkable, and, as at Farnham in Surrey, is found to be especially favourable to the growth of hops. The organic remains are in some places so abundant that, as in the crag, they are sought for and dug up, as a natural source of the phosphate of lime, usually supplied to the soil directly in the form of bones.

It is an important agricultural remark, that where the plastic clay comes in contact with the top of the chalk, an improved soil is produced; and that where the chalk and the greensand mix, extremely fertile patches of country present themselves.

The following imaginary section (fig. 21) shows the relative positions of these two fertile strips of country, above and below the chalk. At the contact with the plastic clay it is particularly adapted for the growth of barley, which, for quality and malting properties, is not excelled by any in the kingdom. In Essex, barley grown on this soil is principally sold to maltsters at Stortford, &c.; and when malted, is sold again in London under the name of Ware malt. This name is derived from Ware in Hertfordshire, a market town standing on a similar soil.

Fig. 21.



The soils at the contact of the chalk and upper greensand are celebrated for their crops of wheat, in producing which the phosphates in the marls of the upper greensand are supposed to have some influence.

5. The *Wealden formation*, which succeeds the greensand, is nearly 1000 feet thick, and consists of 400 feet of sand, covered by 300 of clay, resting upon 250 of marls and limestones. The clay forms the poor, wet, but improvable pastures of Sussex and Kent. These clays, in many places, harden like a brick when dried in the air; and clods which have lain long in the sun, ring, when struck, like a piece of pottery. By draining alone, their produce has been raised from 16 to 40 bushels of wheat an acre. On the sands below the clay rest heaths and brushwood; but where the marls and limestones come to the surface, the land is of better quality, and is susceptible of profitable arable culture.

6. In the *Upper Oolite*, of 600 feet in thickness, we have a bed of clay (Kimmeridge clay) 500 feet thick, covered by 100 feet of sandy limestones. The clay lands of this formation are difficult and expensive to work, and are therefore chiefly in old pasture. The sandy limestone soils above the clay are also poor; but where they rest immediately upon, and are intermixed with, the clay, excellent arable land is produced.

7. The *Middle Oolite*, of 500 feet, consists also of a clay (Oxford clay), dark blue, adhesive, often rich in lime, and nearly 400 feet thick, covered by 100 feet of limestones and sandstones. These latter produce good arable land where the lime happens to abound; but the clays, especially while undrained, form close, heavy, compact soils, most difficult and expensive to work. In wet weather they are often adhesive like bird-lime, and in dry summers become hard like stone, so as to require a pick-axe to break them. They have therefore, hither-

to, been very partially brought into arable culture. The extensive pasture-lands of Bedford, Huntingdon, Northampton, Lincoln, Wilts, Oxford, and Gloucester, rest chiefly upon this clay; as do also the fenny tracts of Lincoln and Cambridge. The use of burned clay upon the arable land has, in some parts of this clay district, been of much advantage.

8. The *Lower* or *Bath Oolite*, of 500 feet in thickness, consists of many beds of limestone and sandstone, with about 200 feet of clay in the centre of the formation. The soils are very various in quality, according as the sandstone or limestone predominates in each locality. The clays are chiefly in pasture; the rest is more or less productive, easily worked, arable land. In Gloucester, Northampton, Oxford, the east of Leicester, and in Yorkshire, this formation is found to lie immediately beneath the surface, and a little patch of it occurs also on the south-eastern coast of Sutherland.

9. The *Lias* is an immense deposit of blue clay with limestones, from 500 to 1000 feet in thickness, which produces cold, blue, unproductive clay soils. It forms a long strip of land, of varying breadth, which extends in a south-western direction, from the mouth of the Tees in Yorkshire, to Lyme Regis in Dorset. It is chiefly in old, and often very valuable, pasture. An efficient system of drainage is converting much of this clay into most productive wheat land.

10. The *New Red Sandstone*, though only 500 feet in thickness, forms the surface of nearly the whole central plain of England, and stretches northwards through Cheshire to Carlisle and Dumfries. It consists of red sandstones and red marls, the soils produced from which are easily and cheaply worked, and form some of the richest and most productive arable lands in the island. This is in some degree indicated by the fact that the

three highest-rented counties in England rest chiefly upon this rock. In whatever part of the world the red soils of this formation have been met with, they have been found to possess in general the same valuable agricultural capabilities.

11. The *Magnesian Limestone*, from 100 to 500 feet in thickness, is covered by a strip of generally poor thin soil, extending from Durham to Nottingham, capable of improvement as arable land by high farming, but bearing naturally a poor pasture, intermingled sometimes with magnificent furze.

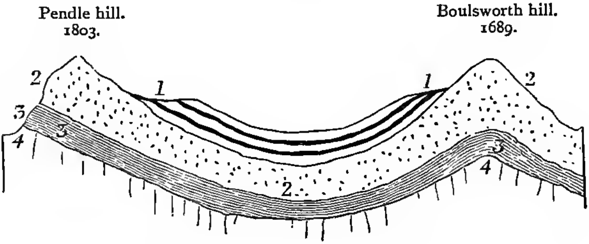
12. The *Coal-measures*, from 300 to 3000 feet thick, consist of beds of grey sandstone, and of dark-blue shale, or hardened clay, intermingled (*interstratified*) with beds of coal. Where the sandstones come to the surface, the soil is thin, poor, hungry, sometimes almost worthless. The shales, on the other hand, produce stiff, wet, almost unmanageable clays—not unworkable, yet expensive to work, and requiring draining, lime, skill, capital, and a zeal for improvement to be applied to them, before they can be made to yield the remunerating crops of corn they are capable of producing. The blaes or shales of this formation, when dug out of cliffs or brought from coal-mines, may be laid with advantage on loose sandy soils, and even, it is said, on the stiff whitish clays almost destitute of vegetable matter, which, as in Lanarkshire, occasionally occur on the surface of our coal-fields.

13. To the *Millstone-grit*, of 600 feet or upwards in thickness, the same remarks apply. It lies below the coal, but is often only a repetition of the sandstones and shales of the coal-measures, and forms in many cases soils still more worthless. Where the sandstones prevail, large tracts lie naked, or bear a thin and stunted heath. Where the shales abound, the naturally difficult

soils of the coal-shales again recur. The rocks of this formation generally approach the surface, around the outskirts of our coal-fields.

This arises from the circumstance that our coal-measures often lie in basin-shaped deposits, from beneath each edge of which the millstone-grit and mountain-limestone rocks rise up to the surface. This is illustrated by the annexed section (fig. 22) across a part of Lancashire, in which 1 represents the coal-measures; 2, the coarse sandstones, &c., of the millstone-grit; 3, a thick shale-bed, which often overlies the thick masses of mountain-limestone represented by 4.

Fig. 22.



The traveller passes off the poor, often cold and wet, clay soils of the coal-measures, on to the equally poor lands of the millstone-grit, and over its top, as at Pendle hill, descends upon the sweet herbage and rich dairy pastures of the mountain-limestone at 4.

The section shows also how in this country the millstone-grit often rises into high hills. These are then covered with poor heaths and worthless moors, while limestone hills of equal height bear green herbage to the very top.

14. The *Mountain-limestone*, 500 to 2000 feet thick, is a hard blue limestone rock, separated here and there

into distinct beds by layers of sandstones, of sandy slates, or of bluish-black shales like those of the coal-measures. The soil upon the limestone is generally thin, but produces a naturally sweet herbage, everywhere superior in value to that which grows on the sandier soils of the millstone-grit. When the limestone and clay (shale) adjoin each other, as where 3 and 4 in the section meet, arable land occurs, which is naturally productive of oats, and, where the climate is favourable, may, by skilful treatment, be converted into good wheat land. In the north of England—in Derbyshire, for example, and among the Yorkshire dales—a considerable tract of country is covered by these rocks; but in Ireland they form nearly the whole of the interior of the island.

15. The *Old Red Sandstone* varies in thickness from 500 to 10,000 feet. It possesses many of the valuable agricultural qualities of the *new red* (No. 10), consisting, like it, of red sandstones and red marls, which crumble down into rich red soils. Such are the soils of Brecknock, Hereford,[1] and part of Monmouth; of part of Berwick and Roxburgh; of Haddington and Lanark; of southern Perth; of either shore of the Moray Firth; and of part of Sutherland, Caithness, and the Orkney Islands. In Ireland, also, these rocks abound in Tyrone, Fermanagh, and Monaghan; in Waterford, in Mayo, and in Tipperary. In all these places the soils they form are generally the best in their several neighbourhoods. Here and there, however, where the sandstones are harder, more silicious and impervious to water, tracts, sometimes extensive, of heath and bog occur; while in others the rocks have crumbled into

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[1] On the concretionary limestones or cornstones which form subordinate beds in this formation, grow the finest orchards of Herefordshire and its best oaks.

hungry sands, which swallow up the manure, and are expensive to maintain in arable culture.

The Primary Strata.—The primary stratified rocks, which lie underneath all those already described, are separable into three natural divisions: the *Silurian*[1] above, which contain the remains of animals in a fossil state; the *Cambrian*[2] below, in which few animal remains have yet been discovered; and lowest of all, the *mica-slate* and *gneiss* rocks, which exhibit marks of change or alteration by the agency of heat. Hence these last are often spoken of as *metamorphic*, or changed rocks.

16. The *Upper Silurian system* is nearly 4000 feet in thickness, and forms the soils which cover the lower border counties of Wales. It consists of sandstones and shales, with occasional limestones; but the soils formed from these beds take their character from the general abundance of the clay. They are cold—usually unmanageable *muddy* clays; with the remarkably inferior agricultural value of which the traveller is immediately struck, as he passes westward from the red sandstones of Hereford to the Upper Silurian rocks of the county of Radnor.

17. The *Lower Silurian* rocks are many thousand feet in thickness, and in Wales lie to the west and north of the Upper Silurian rocks. They consist, on the upper part, of about 25,000 feet of sandstone, on which, when the surface is not naked, barren heaths alone rest.

Beneath these sandstones lie 1200 feet of sandy and earthy limestones, from the decay of which, as may be seen on the southern edge of Caermarthen, fertile arable lands are produced.

The high land, which stretches across the whole of

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[1] Or older *Palæozoic*, as containing evidences of most ancient life.

[2] Or *Azoic*, from containing few traces of life.

southern Scotland, from St Abb's Head to Portpatrick, including the Lammermoor Hills, so far as they have yet been examined, consists of strata belonging to the upper part of the Lower Silurian, and the lower part of the Upper Silurian. The soils in general are of inferior quality, the slaty rocks crumbling with difficulty, and being poor in lime. Cold and infertile farms cover the higher grounds, and wide heathy moors and bogs.

18. The *Cambrian system* is at present a subject of dispute among geologists, and its limits even in our own island are not well defined. It is probably many thousand feet in thickness—lies beneath the Lower Silurian—and in its agricultural relations has much resemblance to these rocks. It consists in great part of slaty rocks, more or less hard, which often crumble very slowly, and almost always produce either poor and thin soils—or cold, difficultly manageable clays, expensive to work, and requiring *high farming* to bring them into profitable arable cultivation. In Cornwall, western Wales, the mountains of Cumberland; in the mountains of Tipperary, in the extreme south of Ireland, on its east coast, and far inland from the bay of Dundalk, such slaty rocks occur, though the limits of the two formations have not been everywhere defined. Patches of rich, well-cultivated land occur here and there in these districts, with much also that is improvable; but the greater part is usurped by worthless heaths and extensive bogs. On the difficult soils of these formations—thinly peopled, inhabited by small farmers with little capital, and therefore hitherto neglected—much improvement is now here and there appearing; and the introduction of the drain promises to make much corn grow, where little food, either for man or beast, was previously produced. These rocks in general contain little lime, and therefore, after the drain, the addition

of lime is usually one of the most certain means of increasing the productiveness of the soils formed from them.

19. The *Mica-slate* and *Gneiss systems* are of unknown thickness, and consist chiefly of hard and slaty rocks, crumbling slowly, forming poor, thin soils, which rest on an impervious rock, and which, from the height to which this formation generally rises above the level of the sea, are rendered more unproductive by an unpropitious climate. They form extensive heathy tracts in Perth and Argyle, and on the north and west of Ireland. Here and there only—in the valleys or sheltered slopes, and by the margins of the lakes—spots of bright green meet the eye, and patches of a willing soil, fertile in corn.

Relations of Geology to Agriculture.—A careful perusal of the preceding sketch of the general agricultural capabilities of the soils formed from the several classes of stratified rocks, will have presented to the reader many illustrations of the facts stated in the previous chapter. He will have drawn for himself—to specify a few examples—the following among other conclusions:

1. That some formations, like the new red sandstone, yield a soil almost always productive; others, as the coal-measures and millstone-grits, a soil almost always *naturally* productive; and others, again, like the mountain-limestone, a short sweet herbage, grateful to cattle, and productive of butter and cheese.

2. That good land—or better, at least, than generally prevails in a district—may be expected where two formations, or two different kinds of rock, meet. As when a limestone and a clay mingle their mutual ruins for the formation of a common soil.[1]

3. That in almost every country extensive tracts of

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[1] See fig. 21, p. 115.

land, on certain formations, will be found laid down to natural grass, *in consequence of the original difficulty and expense of working.* Such are the Lias, the Oxford, the Weald, the Kimmeridge, and the London clays. In raising corn, it is natural that the lands which are easiest and cheapest worked should be first subjected to the plough. It is not till implements are improved, skill increased, capital accumulated, and population presses, that the heavier lands in a country are rescued from perennial grass, and made to produce that greatly increased amount of food for both man and beast, which they are easily capable of yielding.

4. That the rotations adopted in a district, though faulty, and, in the eyes of improved agriculture, deserving of condemnation, are often not only determined, but rendered necessary, by the natural structure of the country. When cold clays refuse to bear even average crops of any other kinds than wheat and bean, the old European rotation of wheat, beans, fallow—which in this country has prevailed, in many places, since the times of the ancient Britons—becomes almost a necessity to the farmer. It is unfair to blame his rotations, or accuse him of prejudice and ignorance in clinging to them, till the natural condition of the land has been altered by art, so as to fit it for the profitable growth of other crops.

5. That there are larger tracts of country still—such as rest on the slates of the Lower Silurian and Cambrian systems, for example—from which the efforts of the enlightened agriculturist have hitherto been withheld, in consequence of the apparent hopelessness of ever bringing them into profitable culture. Over these tracts, however, there are large portions which will pay well for skilful improvement. Make roads and drains, bring in lime, and manure well. You will thus improve the soil,

gradually ameliorate the climate, make modern skill and improvements available, obtain a remunerative return for labour economically expended and for capital judiciously invested, and you will at the same time increase the power and the resources of the country.

CHAPTER XI.

THE RELATION BETWEEN SOILS AND THE ROCKS FROM WHICH THEY WERE FORMED.

It was stated in a preceding chapter that rocks are divided by geologists into the stratified and the *unstratified*. The unstratified are often called *crystalline* rocks, because they frequently have a glassy appearance, or contain regular crystals of certain mineral substances; often also *igneous* rocks, because they appear all to have been originally in a melted state, or to have been produced by fire. The stratified rocks cover by far the largest portion of the globe, and form the great variety of soils, of which a general description has just been given. The unstratified rocks are of two kinds—the *granites* and the *trap* rocks; and as a considerable portion of the area of Great Britain and Ireland is covered by them, it will be proper shortly to consider the peculiar characters of each, and the differences of the soils produced from them.

1. The *Granites* consist of a mixture, in different proportions, of three minerals, known by the names of *quartz*, *felspar*, and *mica*. The last, however, is generally present in such small quantity, that in our general description it may be safely left out of view.

Granites, therefore, consist chiefly of quartz and felspar, in proportions which vary very much; but the former, on an average, constitutes perhaps from one-third to one-half of the whole.

Gneiss resembles granite in composition, but presents a somewhat stratified appearance. When hornblende replaces mica in granite, the rock is termed *syenite.*

Quartz has already been described as being the same substance as flint, or the silica of the chemist. When the granite decays, this portion of it forms a more or less coarse silicious sand.

Felspar is a white, greenish, or flesh-coloured mineral, often more or less earthy in its appearance, but generally hard and brittle, and sometimes glassy. It is scratched by quartz, and thus is readily distinguished from it. When felspar decays, it forms an exceedingly fine tenacious clay (pipe-clay). Felspar differs in composition, some kinds of felspar (orthoclase) being very much richer in potash than others (albite and oligoclase). The fertility of the soil due to the decay of felspar will depend on what class of felspar predominates.

Granite generally forms hills, and sometimes entire ridges of mountains. When it decays, the rains and streams wash out the fine felspar clay, and carry it down into the valleys, leaving the quartz sand on the sides of the hills. Hence the soil in the bottoms and flats of granite countries consists of a cold, stiff, wet, more or less impervious clay, which, though capable of much improvement by draining, often bears only heath, bog, or a poor and unnutritive pasture. The hillsides are either bare, or are covered with a thin, sandy, and ungrateful soil, of which little can be made without the application of much skill and industry. Yet the opposite sides of the same mountains often present a remarkable difference in this respect; those which are most beaten by the rains having the light clay most thoroughly washed from their surfaces, and being therefore the most sandy and barren.

2. The *Trap* rocks, comprising the greenstones and basalts—both sometimes called *whin*-stones—consist essentially of felspar and *hornblende*, or *augite*. In contrasting the trap rocks with the granites, it may be stated *generally*, that while the granites consist of felspar and *quartz*, the traps consist of felspar and *hornblende* (or augite). In the traps, both the felspar and the hornblende are reduced, by the action of the weather, to a more or less fine powder, affording materials for a soil; in the granites, the felspar is the principal source of the fine earthy matter they are capable of yielding. If we compare together, therefore, the chemical composition of the minerals (potash felspar, hornblende and felspar), we shall see in what respect these two varieties of soil ought principally to differ. Thus they consist respectively of—

	Felspar.	Hornblende.
Silica	65	52
Alumina	18	12
Potash and soda . .	17	trace.
Lime	trace.	10
Magnesia	do.	15
Oxides of iron . . .	do.	10½
Oxide of manganese . .	do.	½
	100	100

A remarkable difference appears thus to exist, in chemical composition, between these two minerals—a difference which must affect also the soils produced from them. A *granite* soil, in addition to the silicious sand, will consist chiefly of silica, alumina, and potash, derived from the felspar. A *trap* soil, in addition to the silica, alumina, and potash from its felspar, will generally contain also much lime, magnesia, and oxide of iron, derived from its hornblende. If the variety of trap consist chiefly of hornblende, as is sometimes the case, the soil formed from it will derive nearly 2½ cwt. each of lime, magnesia, and oxide of iron, from every ton of decayed rock. A hornblende soil, therefore, contains a greater number of those inorganic substances which plants require for their healthy sustenance, and therefore will prove more generally productive than a soil of decayed felspar. But when the two minerals, hornblende and felspar, are mixed together, as they are in the variety of trap called greenstone, the soil formed from them must be still more favourable to vegetable life. The potash and soda, of which the hornblende is nearly destitute, are abundantly supplied by the felspar; while the hornblende yields lime and magnesia, which are known to exercise a remarkable influence on the progress of vegetation.

This chemical knowledge of the nature and differences of the rocks from which the granite and trap soils are derived, explains several interesting practical observations. Thus it shows—

a. That while granite soils, in their natural state, may be eminently unfruitful, trap soils may be eminently fertile; and such is actually the result of observation and experience in every part of the globe. *Unproductive* granite soils cover nearly the whole of Scotland north of the Grampians, as well as large tracts of land in Devon and Cornwall, and on the east and west of Ireland. On the other hand, *fertile* trap soils extend over thousands of square miles in the Lowlands of Scotland, and in the north of Ireland; and where in Cornwall they occasionally mix with the granite soils, they are found to redeem the latter from their natural barrenness.

But while such is the *general* rule in regard to these two classes of soils, it happens on some spots that the presence of other minerals in the granites, or of hornblende or mica in larger quantity than usual, gives rise to a granitic soil of average fertility, as is the case in the Scilly Isles. In like manner the trap rocks are sometimes, as in parts of the Isle of Skye, so peculiar in their composition as to condemn the land to almost hopeless infertility.

b. While in some districts the decayed traps, under the local names of *rotten rock, marl,* &c., are dug up, and applied with advantage, as a top-dressing, to other kinds of land. They afford supplies of lime, magnesia, &c., of which the soils they are found to benefit may be naturally deficient. And as, by admixture with the decayed trap, the granitic soils of Cornwall are known to be improved in quality, so an admixture of decayed granite with many trap soils, were it readily accessible, might add to the fertility of the latter also.

c. Why the application of lime in certain trap districts adds nothing to the fertility of the land. The late Mr Oliver of Lochend stated that he had never known a case in which the application of lime within five miles of Edinburgh had done any good. This he attributed to the vast number of oyster-shells which are mixed with the town dung laid on by the Edinburgh farmers. Another important reason, however, is the abundance of lime contained in the trap rocks from which the soils are formed, and of which they contain so many fragments.

d. Why, as in many parts of the counties of Ayr and Fife, the application of lime is found to be useful when the trap soils are first broken up or reclaimed, but to produce little sensible benefit for twenty or thirty years afterwards, however frequently applied. In these cases the lime has been washed out of the surface-soil, and from the thoroughly decayed parts of the trap, so that, when first broken up, lime is necessary to supply the deficiency. But the constant turning up of the soil by the after-cultivation exposes fresh portions of trap to the air, the decay of which annually supplies a quantity of lime to the soil from the rocky fragments themselves, and renders further artificial applications less necessary. We have picked up a piece of decaying trap, of which the outer portion contained scarcely any lime, while the central kernel contained a large proportion. The plough and harrow break up such decaying masses, and expose the undecomposed kernels to the weathering action of the atmosphere, and to the roots of the growing crops.

3. The *Lavas*, which often cover large tracts of country where active or extinct volcanoes exist, are composed essentially of the same mineral substances as the trap rocks. These latter, indeed, are in general only lavas of a more ancient date. Like the traps, the lavas not unfrequently abound in hornblende or augite, and consequently in lime. They also crumble, with various degrees of rapidity, when exposed to the air, and in Italy and Sicily often form soils of the most fertile description. Like the traps also, when in a decayed state they may be advantageously employed for the improvement of less fruitful soils. In St Michael's, one of the Azores, the natives pound the volcanic matter and spread it on the ground, where it speedily becomes a rich mould, capable of bearing luxuriant crops. It may be here mentioned as bearing upon the fertility of soils formed out of rocks occurring in the different formations, that the older rocks, the so-called primitive rocks, and those of igneous origin, are as a general rule richer in potash than other rocks, while fossiliferous rocks are richer in phosphoric acid.

Transported Soils.—It is necessary to guard the reader against disappointment when he proceeds to examine the relations which exist between the soils and the rocks on which they lie, or to infer the quality of the soil from the known nature of the rock on which it rests—in conformity with what has been above laid down—by explaining another class of geological appearances, which present themselves not only in our own country, but in almost every other part of the globe.

Every one who has lived long on the more exposed shores of our islands, has seen that, when the weather is dry and the sea-winds blow strong, the sands of the beach are carried inland and spread over the soil, sometimes to a considerable distance from the coast. In some countries this sand-drift takes place to a very great extent, travels over a great stretch of country, and gradually swallows up large tracts of fertile land, and converts them into sandy deserts.

Again, most people are familiar with the fact, that during periods of long-continued rain, when the rivers are flooded and overflow their banks, they not unfrequently bear with them loads of sand and gravel, which they carry far and wide, and strew at intervals over the surface-soil.

So the annual overflowings of the Nile, the Ganges, the Mississippi, and the Amazon, gradually deposit accumulations of soil over surfaces of great extent;—and so also the bottoms of most lakes are covered with thick beds of sand, gravel, and clay, which have been conveyed from the higher grounds by the rivers which flow into them. Over the bottom of the sea, also, the ruins of the land are spread. Torn by the waves from the crumbling shore, or carried down from great distances by the rivers which lose themselves in the sea, they form beds of mud, or banks of sand and gravel of great extent, which cover and conceal the rocks on which they lie.

To these and similar agencies, a large portion of the existing dry land of the globe has been, and is still, exposed. Hence, in many places, the rocks and the soils naturally derived from them are buried beneath accumulated heaps or layers of sand, gravel, and clay, which have been brought from a greater or less distance, and which have not unfrequently been derived from rocks of a totally different kind from those of the districts in which they are now found. *On these accumulations of transported materials, a soil is produced which often has no relation in its characters to the rocks which cover the country; and the nature of which soils, therefore, a familiar acquaintance with the rocks on which they immediately rest would not enable us to predict.*

To this cause is due that discordance between the first indications of geology, as to the origin of soils from the rocks on which they rest, and the actually observed characters of those soils in certain districts—of which discordance mention has been made as likely to awaken doubt and mistrust in the mind of the less instructed student, in regard to the predictions of agricultural geology. There are several circumstances, however, by which the careful observer is materially aided in endeavouring to understand what the nature of the soils is likely to be in any given district, and how they ought to be treated even when the subjacent rocks are thus overlaid by masses of drifted materials. Thus—

1. It not unfrequently happens that the materials brought from a distance are more or less mixed up with the fragments and decayed matter of the rocks which are native to the spot,—so that, though modified in quality, the soil nevertheless retains the general char-

acters of that which is formed in other places from the decay of these rocks alone.

2. Where the formation is extensive, or covers a large area,—as the new red sandstones and coal-measures do in this country, the mountain-limestones in Ireland, and the granites in the north of Scotland,—the transported sand, gravel, or clay, strewed over one part of the formation, has not unfrequently been derived from the rocks of another part of the *same* formation; so that, after all, the soils may be said to be produced from the rocks on which they rest, and may be judged of from the known composition of these rocks.

3. Or if not from rocks of the same formation, they have most frequently been derived from those of a neighbouring formation—from rocks which are to be found at *no great distance geologically*, and generally on higher ground. Thus the ruins of the millstone-grit rocks are in this country often spread over the surface of the coal-measures—of these, again, over the magnesian limestone—of the latter over the new red sandstone, and so on. The effect of this kind of transport of the loose materials upon the character of the soils is merely to overlap, as it were, the edges of one formation with the proper soils of the formations that adjoin it, in the particular direction from which the drifted materials are known to have come.

It appears, therefore, that the occurrence on certain spots, or tracts of country, of soils that have no apparent relation to the rocks on which they immediately rest, tends in no way to throw doubt upon, to discredit or to disprove, the conclusions drawn from the more general facts and principles of geology. It is still generally true that soils *are* derived from the rocks on which they rest. The exceptions are local, and the difficulties which these local exceptions present require only from agricultural geologists a more careful study of the structure of each district,—of the direction of the high lands—the nature of the slopes—the course and width of the valleys—and the extent of the plains,—before they pronounce a decided opinion as to the degree of fertility which the soil either naturally possesses, or by skilful cultivation may be made to attain. For some time now the Geological Survey have had in preparation surface geological maps, which are designed to show the surface geology of different parts of the country in more detail than is shown in ordinary geological maps. These maps, we need scarcely say, will be of great value to agriculturists.

Uniformity in the character of Soils on Rocks of the same age.—There is a wonderful degree of general uniformity in the mineral character and agricultural capabilities of the same geological formation in different countries, even when they lie at great distances from each other. We have already alluded, for example, in a preceding chapter,[1] to the natural dryness of the belt of chalk which runs along the Atlantic border of the United States. The scarcity of water experienced by those who reside upon it is often great. Every one knows that the same is true of our own chalk region in England, and that this very materially affects its agricultural capabilities. It is familiar to every one also, that in very many places wells are sunk through it with the view of reaching water, and that in London great depths are gone to, and at a vast expense, through the London clay and the chalk, before water can be obtained. In the Paris basin the chalk is equally dry; and there are very few who have not read of the remarkably deep well at Grenelle in the neighbourhood of Paris, which, like the less profound London wells, has been sunk to the sands below the chalk, and with similar success. So, in the remote

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[1] See fig. 19, p. 111.

State of Alabama, on this formation, water is only to be obtained by sinking through the chalk; and there also this circumstance modifies in a wonderful degree the general dispositions of rural economy. In this State there is generally a well of from 400 to 600 feet deep in each plantation. And thus, while the climate there, as elsewhere, determines the general character of the vegetable produce, and what kind of plants under the meteorological conditions can arrive at perfection, yet the geological structure determines, and enables us to judge beforehand, to a certain extent, whether or not any crops shall be able to grow at all, and of the kind of plants suitable to the climate, which can be profitably cultivated, under the circumstances of soil and dryness which that geological structure implies.

CHAPTER XII. 12

THE PHYSICAL PROPERTIES OF SOILS—FERTILE AND BARREN SOILS.

Soils formed, as we have described, from the ruins of crumbled rocks, more or less sorted and drifted by water, possess three classes of properties, intimately related to each other, and to their special agricultural value. These are their *physical*, *chemical*, and *botanical* properties. A brief consideration of these may now be given.

The Physical Properties of Soils.—The chief physical properties of soil which are of interest to agriculturists are their density, or specific gravity; their capacity for absorbing and retaining moisture; their porosity;

and their temperature under varying conditions. Many of these properties depend on the character and arrangement of the soil particles. The force by which these are held together decides the compactness of the soil. The ease with which the soil can be tilled will depend on this property. It will also influence a very important property of a soil—viz., its *porosity.* This is of great importance as influencing plant growth. Plants can only develop successfully where the air is permitted free access to their roots.

1. *Density.*—Some soils are heavier than others, sands and marls weighing most, and dry peaty soils least. The specific gravity or relative weight of sands is about twice that of water. Strange as it may appear, it is a fact that a stiff clay is about one-fourth lighter than an equal volume of a sandy soil. This density is of so much practical importance, that treading with sheep and other stock is resorted to in many districts, with the view of rendering the land more solid ; or heavy rollers are passed over it, to prepare a firm seed-bed for the corn. Also, in reclaiming peaty soils, it is found highly beneficial to increase their density by a covering of clay or sand, or of limestone gravel, as is the practice in Ireland. A stiff clay has been found to retain 50 per cent of water, and yet to appear quite dry. On the other hand, pure sands will hardly retain 5 per cent of their weight of moisture.

2. *Absorption of water.*—The relation of the soil to moisture is a most important property. Water is the most necessary of all plant foods, and unless the water-absorbing and water-retaining properties of the soil are satisfactory, healthy growth of crops is impossible. Some soils absorb the rains that fall, and retain them in larger quantity and for a longer period than others. Strong

clays absorb and retain nearly three times as much water as sandy soils do, while peaty soils absorb a still larger proportion. Hence the more frequent necessity for draining clayey than sandy soils; and hence also the reason why, in peaty land, the drains must be kept carefully open, in order that the access of springs and of other water from beneath may be as much as possible prevented. Plants absorb their soil food dissolved in water. In order that plants may healthily develop, they have to transpire large quantities of water. The following table illustrates this, and shows that for every 1 lb. of dry plant-tissue formed, they have to consume from 233 *lb. to* 912 *lb. of water* :—

PROPORTIONS OF WATER TRANSPIRED THROUGH THE PLANT DURING THE PERIOD OF GROWTH.

EXPERIMENTS BY HELLRIEGEL.		EXPERIMENTS BY WOLLNY.	
Kind of plant.	Water consumed for each kilogram of dry substance in the plant.	Kind of plant.	Water consumed for each kilogram of dry substance in the plant.
	Kilos.		Kilos.
Horse-beans .	262	Maize . . .	233
Peas	292	Millet . . .	416
Barley . . .	310	Peas	447
Clover . . .	330	Sunflower . .	490
Spring wheat .	359	Buckwheat . .	646
Buckwheat . .	371	Oats	665
Lupine . . .	373	Barley . . .	774
Spring rye . .	377	Mustard . .	843
Oats	402	Rape	912

The amount of transpiration is directly affected by the amount of leaf-surface and the period of the plant's growth.

In seasons of prolonged drought cattle often find abundance of herbage in low-lying, undrained pastures.

It is only at such times that these pastures are of much value.

3. The *capillary action* of soils also differs. Some, when immersed in water, will become moist, or attract the water upwards for 10 or 12 inches, some as many as 16 or 18 inches, above the surface of the water. This property is of great importance in reference to the growth of plants, to the rising of water to the surface of land which rests upon a wet subsoil, to the necessity for thorough drainage, to the general warmth of the soil, and so on. It largely depends on the closeness of the soil-particles.

4. *Evaporative power.*—When dry weather comes, soils lose water by evaporation with different degrees of rapidity. In this way a silicious sand will give off the same weight of water, in the form of vapour, in one-third of the time necessary to evaporate it from a stiff clay, a peat, or a rich garden-mould, when all are equally exposed to the air. Hence the reason why plants are so soon burned up in a sandy soil. Not only do such soils *retain* less of the rain that falls, but that which is retained is also more speedily dissipated by evaporation. When rains abound, however, or in very moist seasons, these same properties of sandy soils enable them to dry quickly, and thus to sustain a luxuriant vegetation at a time when plants will perish on clay lands from excess of moisture. Every soil has a certain water absorbing and retaining power. Two different soils may contain exactly the same amount of water, and yet plants might flourish on the one and wilt on the other. According to Wollny, the most favourable amount of moisture in a soil is from 40 to 75 per cent of its water-holding capacity, the amount differing for different kinds of crops. The following experiments by Wollny illustrate this:—

EFFECTS OF DIFFERENT PROPORTIONS OF WATER IN THE SOIL UPON THE GROWTH OF SUMMER RAPE.

Water in soil in per cent of total water-holding capacity.	PRODUCE (Six Plants in each case).				
	Number of pods.	Weight of Plants (air dry).			
		Seeds.	Straw.	Chaff.	Total.
		Grams.	Grams.	Grams.	Grams.
10	43	1.4	2.8	1.4	5.6
20	61	2.4	4.4	2.6	9.7
40	142	6.9	10.4	6.7	24.0
60	97	4.3	8.1	4.4	16.8
80	95	3.9	7.3	3.9	15.1
100	19	0.3	2.0	0.6	2.9

It will be seen in these experiments that the most favourable amount of water was 40 per cent. When the amount was either less or more the results were less favourable. Up to a certain point the more water a soil contains the more favourable will it be for promoting plant-growth. When this amount is exceeded the reverse is the case. It is worthy of note that the development of the different parts and organs of the plant is affected. The influence of water in regulating the rate of growth is striking. In a dry soil development seems to take place more quickly than in a damp. The amount of moisture also seems to affect the chemical composition of the crop. The reasons for the above facts are not entirely understood. They are closely connected with the porosity and temperature of the soil, both of which properties are influenced by the amount of water present in a soil. Evaporation of the water in a soil is always greater on a soil covered with vegetation than on a bare soil. The rate at which it goes on will depend on the compactness of the soil-particles. Open soils lose water less quickly than more compact ones, their capillary power being less. The presence of a large number of stones on a field has been found to diminish the rate of evaporation.

5. *Shrinkage.*—In drying under the influence of the sun, soils shrink in, and thus diminish in bulk, in proportion to the quantity of clay or of peaty matter they contain. Sand scarcely diminishes at all in bulk by drying, but peat shrinks one-fifth in bulk, and strong agricultural clay nearly as much. The roots are thus compressed and the air excluded from them, especially in the hardened clays, in very dry weather, and the plant is thereby placed in a condition unfavourable to its growth. Hence the value of proper admixtures of sand and clay. By the latter (the clay) a sufficient quantity of moisture is retained, and for a sufficient length of time; while by the former the roots are preserved from compression, and a free access of the air is permitted.

6. *Absorption of moisture from the air.*—In the hottest and most drying weather, the soil has seasons of respite from the scorching influence of the sun. During the cooler season of the night, even when no perceptible dew falls, it has the power of again extracting from the air a portion of the moisture it had lost during the day. Perfectly pure sand possesses this power in the least degree; it absorbs little or no moisture from the air. A stiff clay, on the other hand, will, in a single night, absorb sometimes a 30th part of its own weight, and a dry peat as much as a 12th of its weight; and generally the quantity thus drunk in, by soils of various qualities, is dependent upon the proportions of clay and vegetable matter which they severally contain. Humus has the greatest power of absorbing moisture from the air. The addition, therefore, of a manure containing large quantities of organic matter, as farmyard manure, increases this power in a soil. A similar result follows the plough-

ing in of green crops. Sandy soils suffer most from drought, because their water-absorbing and water-retaining powers are very small. We cannot fail to perceive from these facts how much the productive capabilities of a soil are dependent upon the proportions in which its different earthy and vegetable constituents are mixed.

7. *The temperature of a soil*, or the degree of warmth it is capable of attaining under the influence of the sun's rays, materially affects the progress of vegetation. Every gardener knows how much *bottom*-heat forces the growth, especially of young plants; and wherever a natural warmth exists in the soil, independent of the sun, as in the neighbourhood of volcanoes, there it exhibits the most exuberant fertility. One main influence of the sun, in spring and summer, is dependent upon its power of thus warming the soil around the young roots, and rendering it propitious to their rapid growth. But the sun does not warm all soils alike—some become much hotter than others, though exposed to the same sunshine. When the temperature of the air in the shade is no higher than 60° or 70°, a *dry* soil may become so warm as to raise the thermometer to 90° or 100°. Among the Pyrenees the rocks actually smoke after rain, under the influence of the summer sun, and become so hot that one cannot sit down upon them. In Central Australia, where the thermometer is sometimes so high as 132° Fahr. in the shade, the ground becomes so hot that it kindles matches that fall on it, and burns the skin off the dogs' feet. In *wet* soils the temperature rises more slowly, and rarely attains the same height as in a dry soil by 10° or 15° Hence it is strictly correct to say that wet soils are *cold;* and it is easy to understand how this coldness is removed by perfect drainage. Dry sands and clays, and blackish garden-mould, become warmed to nearly an equal degree under

the same sun; brownish-red soils are heated somewhat more, and dark-coloured peaty soils the most of all. It is probable, therefore, that the presence of dark-coloured vegetable matter renders the soil more absorbent of heat from the sun, and that the colour of the dark-red marls of the new and old red sandstones may, in some degree, aid the other causes of fertility in the soils which they produce. Especially important at the time of seed germination is the temperature of the soil. This is discussed in a future chapter, and need not further be referred to here. Not merely, however, does the temperature affect germination; it has a most important influence on the plant's subsequent growth. Sachs found that in forty-eight hours a very considerable difference in the growth of the roots and of the aerial parts of a maize-plant was effected by difference in temperature. The following table shows this, in which the difference in length in centimetres is given :—

GROWTH OF ROOTS AND TOPS OF MAIZE-PLANTS IN FORTY-EIGHT HOURS AT DIFFERENT TEMPERATURES.

	TEMPERATURE OF SOIL.			
	17.1° C.	26.2° C.	33.2° C.	34.0° C.
	C.M.	C.M.	C.M.	C.M.
Roots . .	2.5	24.5	39.0	55.0
Aerial organs .	4.6	5.6	11.0	13.0

Just as with the amount of water, so with the temperature beyond a certain temperature—increase is accompanied with diminished growth.

The following table shows the results of some experiments by Bialablocki. The cereals were grown in pots, the soil of which was maintained at temperatures varying with the different pots, but constant for each pot during the period of growth :—

EFFECT OF DIFFERENT SOIL-TEMPERATURES UPON DEVELOPMENT OF CEREAL PLANTS.

Temperature of soil.	AVERAGE WEIGHT OF DRY SUBSTANCE PER PLANT.		
	Rye.	Barley.	Wheat.
Degrees C.	Milligrams.	Milligrams.	Milligrams.
10	22.8	18.0	20.8
15	32.4	34.4	29.5
20	49.5	36.7	30.8
25	42.4	42.0	43.9
30	35.0	35.0	46.9

In reading the above observations, the practical reader can hardly fail to have been struck with the remarkable similarity in physical properties between stiff clay and peaty soils. Both retain much of the water that falls in rain, and both part with it slowly by evaporation. Both contract much in drying, and both absorb moisture readily from the air, in the absence of the sun. In this similarity of properties we see not only why the first step in improving both kinds of soil must be very nearly the same, but why, also, a mixture either of clay or of vegetable matter will equally impart to a sandy soil many of those elements of fertility—of which they are alike possessed. The influence which the physical properties of a soil exert upon its fertility will be seen, from what has been already said, to be very considerable. Their full importance can only be appreciated in the light of their influence on the chemical properties of the soil, which we shall now consider.

Chemical Composition of Soils.—Soils perform at least three functions in reference to vegetation. They serve as a basis in which plants may fix their roots and sustain themselves in their erect position—they supply food to vegetables at every period of their growth—and they are the medium in which many chemical changes take place, that are essential to a right preparation of the various kinds of food which the soil is destined to yield to the growing plant.

We have spoken of soils as consisting chiefly of sand, lime, and clay, with certain saline and organic substances in smaller and variable proportions. But the study of the ash of plants (see chap. v.) shows us that a fertile soil, besides its organic matter, must of necessity contain an appreciable quantity of different mineral substances, which, in most cases, exist in greater or less relative abundance in the ash both of wild and of cultivated plants.

The following analyses of wheat soils are given on the authority of the late Professor Anderson ('Transactions of the Highland and Agricultural Society,' July 1860):—

ANALYSES OF SOILS.

100 parts contain—

	1.		2.	
	Soil.	Subsoil.	Soil.	Subsoil.
Silica	74.5529	82.5874	61.1954	61.6358
Peroxide of iron	5.1730	3.4820	4.8700	6.2303
Alumina	6.9350	5.3250	14.0400	14.2470
Lime	1.2290	0.9392	0.8300	1.2756
Magnesia	1.0827	0.8366	1.0200	1.3938
Potash	0.3544	0.1687	2.8001	2.1761
Soda	0.4335	0.0649	1.4392	1.0450
Sulphuric acid	0.0443	0.0970	0.0911	0.0396
Phosphoric acid	0.4300	0.1970	0.2400	0.2680
Chlorine	traces	traces	0.0098	0.0200
Organic matter	10.1981	4.8358	8.5508	6.8270
Water	2.6840	1.7670	2.7000	4.5750

No. 1 analysis refers to a soil immediately under the brow of Corstorphine Hill, Mid-Lothian, on the sandstone of the coal formation. The crops had been rather poor for some years previous to the time at which the soil was analysed. No. 2 refers to a soil in the Carse of Gowrie, Perthshire, and which produced excellent crops. The quantity of potash in this soil is quite remarkable. Here the application of kainit or other potash salts would indeed be a waste of material.

Two well-known geological facts lead to precisely the same conclusion. We have seen that the soils formed from the unstratified rocks—the granites and the traps—while they each contain certain earthy substances in proportions peculiar to themselves, yet contain also in general, especially the trap soils, a *trace* of most of the other kinds of matter which are found in the ash of plants. Again, it is equally certain that the stratified rocks are only the more or less slowly accumulated fragments and ruins of more ancient stratified or unstratified masses, which, under various agencies, have gradually crumbled to dust, been strewed over the surface in alternate layers, and have afterwards again consolidated. The reader will readily grant, therefore, that in all rocks, and consequently in all soils, *traces* of every one of these substances may generally be presumed to exist.

Actual chemical analysis confirms these deductions in regard to the composition of soils. It shows that, in most soils, the presence of all the constituents of the ash of plants may be detected, though in very variable, and sometimes in very minute, proportions; and following up its investigations in regard to the effect of this difference in their proportions, it establishes certain other points of the greatest possible importance to agricultural practice. Thus it has found, for example—

1. That as a proper adjustment of the proportions of clay, sand, and vegetable matter is necessary in order that a soil may possess the most favourable *physical* properties, so the mere presence of the various kinds of food, organic and inorganic, in a soil, is not sufficient to make it productive of a given crop, but that they must be present in such quantity that the plant shall be able readily—at the proper season, and within the time usually allotted to its growth—to obtain an adequate supply of each.

Thus a soil may contain, on the whole, far more of a given ingredient, such as potash, soda, and lime, than the crop we have sown may require; and yet, being diffused through a large quantity of earth, the roots may be unable to collect this substance fast enough to supply the wants of a rapidly growing plant. To such a soil it will be necessary to add a further portion of what the crop requires.

Again, a crop of winter wheat, which remains nine or ten months in the field, has much more leisure to collect from the soil those substances which are necessary to its growth than a crop of barley, which in cold climates like that of Sweden is only from 6 to 7½ weeks in the ground, and which in warm countries like Sicily may be reaped twice in the year. Thus a soil which refuses to yield a good crop of the quick-growing barley may readily nourish a crop of slow-growing wheat.

2. That when a soil is particularly poor in certain of these substances, the valuable cultivated corn crops, grasses, and trees, refuse to grow upon them in a healthy manner, and to yield remunerative returns. And—

3. That when certain other substances are present in too great abundance, the soil is rendered equally unpropitious to the most important crops.

In these facts the intelligent reader will perceive the foundation of the varied applications to the soil which are everywhere made under the direction of a skilful practice, and of the difficulties which, in many localities, lie in the way of bringing the land into such a state as shall fit it readily to supply all the wants of those kinds of vegetables which it is the special object of artificial culture easily and abundantly to raise.

Chemical analysis of a soil, as ordinarily conducted, valuable though it is in some respects, is not of much service in indicating the actual fertilising matters at the moment available in the soil. The agencies at work, whereby the elements of fertility are rendered available for the plants' uses, are so complicated and numerous that the best test of a soil's fertility is to carry out experiments with the plant itself. The true value of a chemical analysis is becoming more recognised every day. What a chemical analysis indicates is more the *potential* fertility of a soil than its actual fertility. It is not desirable, therefore, to occupy much space by detailing various analyses of soils. Instead of doing so, it may be more useful to dwell on some of the more important constituents in the soil and their amount.

Amount of Phosphoric Acid and Potash in the Soil.—The two most important mineral ingredients in a soil are phosphoric acid and potash. The amount of these two ingredients, along with the amount of nitrogen, may be said to practically determine a soil's fertility, so far as that is purely a chemical consideration. The amount of phosphoric acid in a soil is rarely over two-tenths of a per cent; while half that amount may be taken as the average. In exceptional cases it has been found to be as high as .3 per cent, while in the Russian black earth it amounts to .6 per cent. The amount of potash is very much more variable, and may vary from a trace to several per cent. The condition in which these ingredients is present is of importance.

The phosphoric acid is almost entirely in a *condition insoluble in water*. This is necessarily the case, since soluble phosphoric acid, when added to a soil, is at once converted into an insoluble condition by the iron and lime salts present in the soil. The potash present in a soil, on the other hand, is slightly more soluble—from .001 to .009 per cent being soluble. The former ingredient is much more apt to be lacking than the latter. Indeed, with potash many soils are abundantly supplied. An important point for the student to clearly understand is that, while most soils contain, as is shown by chemical analysis, an abundance of fertilising matter, only a very trifling amount of this is in an available form. This accounts for the striking results obtained in increased growth of crops by the addition of, comparatively speaking, small quantities of artificial manures. The fertilising ingredients in these manures are in a quickly available condition, and suitable for the immediate wants of the plant.

Way in which Fertilising is rendered available.—The rate at which the inert fertility of a soil is set free depends on a variety of conditions. Food is prepared for the plant by a variety of agencies, some of these of a purely physical or chemical nature; while others are of a biological nature. A class of agents which have only of recent years been discovered are micro-organisms, which are the cause of the different fermentative actions going on in the soil. The *rôle* of these minute works in the economy of nature is a most important one. Every soil is teeming with them. Their chief function is to prepare plant food for the plants' uses. The putrefactive changes which organic matter undergoes in the soil are caused by them, and so numerous are they that their number in an ounce of soil amounts to millions. The "ripening" of various fertilisers and the "rotting" of farmyard manure are due to their agency.

Their action is varied. Some decompose the organic matter by oxidising it, by either giving off oxygen or by assimilating the organic compounds and reducing them into such simple substances as carbon dioxide and water. Others act as reducing agents—*i.e.*, they take away oxygen from bodies—while a third class actually enrich the soil in fertilising matters. Among these the most important are those active in the process known as *nitrification*, whereby the nitrogen in the soil is elaborated into nitric acid; and those still more recently discovered, which are active in fixing the free nitrogen of the air. As the rate of development of these organisms is chiefly determined by the physical properties of the soil, this fact furnishes another reason for regarding these properties as of very great importance in influencing the question of soil-fertility.

Organic Matter of Soils.—There is no ingredient of soils of greater importance than that portion which is termed organic matter, and from which a large proportion of the nitrogen of plants is derived. The nitrogen in this organic matter is not available for plant food. In order to become so, it must be converted into nitrates.

In some wheat soils of Scotland Anderson found the amount of nitrogen to vary from .15 to .97 per cent in the subsoil, and from .074 to .22 per cent in the supersoil. In sandy soils of Saxony, Ritthausen found the nitrogen to vary from .089 to .126 per cent. According to Petzoldt, Russian black earth from the government of Tambow contained, when arable and manured, .17 per cent, unmanured .30 per cent, and unmanured subsoil .3 per cent of nitrogen. Rothamsted pasture soils have been found to contain from .247 to .151 per cent. Ordinary arable land contains about .1 per cent. The surface-soil is, as a rule, richer in nitrogen than the subsoil. In fact, the amount may be said to decrease with the depth of the soil. Nitrogen, however, as is too commonly stated, is not wholly limited to the upper layer of the soil, as a sample of calcareous clay, taken from a depth of 500 feet at Rothamsted, was found on analysis to contain .04 per cent. The following table will illustrate the amount of nitrogen in two Rothamsted soils —(*a*) on an arable soil; (*b*) an old pasture soil taken to a depth of 54 inches:—

NITROGEN IN SOILS AT VARIOUS DEPTHS.
ROTHAMSTED SOILS.

DEPTH.	ARABLE SOIL.		OLD PASTURE SOIL.	
	Per cent.	Lb. per acre.	Per cent.	Lb. per acre.
First 9 inches . . .	0.120	3015	0.245	5351
Second 9 inches . .	0.068	1629	0.082	2313
Third 9 inches.	0.059	1461	0.053	1580
Fourth 9 inches . .	0.051	1228	0.046	1412
Fifth 9 inches . . .	0.045	1090	0.042	1301
Sixth 9 inches . .	0.044	1131	0.039	1186
Total, 54 inches .	...	9554	...	13,143

Further analyses of soil taken from greater depths have shown that the amount grows fairly constant below a depth of 3 feet from the surface. The soils richest in nitrogen are peat soils. S. W. Johnson found in fifty different samples he analysed, that it varied from about .5 per cent to 3 per cent, the average being about 1.5 per cent. Sandy soils and soils generally destitute of organic matter contain least nitrogen.

Form in which Nitrogen is present in the Soil.—Nitrogen is present in the soil chiefly as organic nitrogen, but also, in lesser quantities, as ammonia and nitric acid. The amount present as ammonia was formerly very much overrated. It is now known to be very trifling, and may be stated at from .0002 to .0008 per cent in ordinary soils. In exceptional cases it may amount to something more. Thus in rich garden-soils it has been found to amount to .002 (Boussingault), while samples of peat and leaf-mould have shown .018 and .05 per cent respectively. The amount present as nitric acid is more abundant, but still very slight when compared with the organic nitrogen. On an average, not more than 5 per cent of the total nitrogen of a soil is present as nitric acid; indeed it is impossible that either ammonia or nitrates should be abundant in the soil. In the case of the ammonia, a process of conversion into nitrates is constantly taking place; while the nitrates present in the soil are either being constantly washed out of the soil in the drainage water, or absorbed by the plants' roots. It is a striking fact that while the organic form of nitrogen as well as ammonia salts are not liable to be washed out of the soil, nitrates are. Nitrates are constantly being formed from the organic nitrogen and the ammonia salts in the soil by the process of nitrification.

Nitrification.—The process of nitrification is one which is of the highest importance; and although the discovery that the conversion of nitrogen in the organic form and as ammonia into nitrates is due to micro-organisms in the soil is only some fifteen years old, thanks to numerous researches we are in possession of a good deal of information regarding the process and the conditions under which it takes place. The discovery was due to two French chemists, Schlœsing and Müntz, and much light has been thrown on the subject by the work of Warington, Munro, P. F. Frankland, Winogradsky, and others. The work is due, so far as is at present known, to at least two organisms, both of which have been isolated. The one effects the conversion of ammonia into nitrites, and the other effects the conversion of nitrites into nitrates. We know most regarding the former organism, which was the first to be isolated; indeed the second organism has only recently been isolated. The nitrous organisms are described as spherical corpuscles varying extremely in size, the largest being not more than the $\frac{1}{1000}$th of a millimetre, while the smaller ones are so minute as to be hardly discernible under the microscope.

Conditions under which they develop.—A point of very great practical importance is with regard to the conditions under which they develop. They require the presence of certain food constituents, among which phosphoric acid is especially important. They also require for their development the presence of a base with which the nitric acid may combine as it is formed. The substance that serves in this way is carbonate of lime. Possibly magnesia and potash salts are also necessary. There must also be a plentiful supply of oxygen present. It is for this reason that nitrification cannot freely take place in waterlogged or badly drained soils. Another condition which influences the rate of development of nitrification is the temperature. Numerous experiments have shown that it ceases at a temperature near the freezing-point. It also does not take place at a temperature above 55° C. (131° F.) The temperature most favourable seems to be about 37° C. (99° F.), at which temperature the process is ten times as active as at 14° C. (57° F.) The activity of the process is thus very much greater in summer than at any other time of the year. In fact it is to be doubted if it takes place to any extent during the winter-time. A further condition is the presence of a sufficient quantity of moisture. A complete absence of moisture at once arrests the process; on the other hand, too much moisture is equally unfavourable, since such a condition prevents the increase of oxygen, which, as we have pointed out, is a necessary condition. Lastly, it may be mentioned that it goes on best in darkness; indeed the presence of strong sunlight seems to check it. The action of plant poisons also at once arrests the process. From these facts it will be seen that the soils most suited for promoting nitrification are well-drained, properly tilled soils, not poor in lime or other necessary plant mineral ingredients; while soils least suited for its development are badly drained soils destitute of lime salts. Tillage operations have thus a distinct influence in promoting this most important process.

Denitrification. — Indeed it would seem that in waterlogged soils a process the reverse of nitrification is apt to go on whereby the nitrates present in the soil become deoxidised or denitrified, with the result that the nitrogen is set free and escapes. This process is also due to organisms.

The nitrification organisms seem to be of very wide occurrence. In the soil they are chiefly found in the surface portion, although it has been found that nitrification may take place at a depth of six feet (Warington). Nitrification chiefly takes place within the first 12 inches of soil, where the conditions, as a rule, are most favourable for its development.

The depth down to which it occurs in a soil will depend largely on the nature of the soil. The action of plant-roots in permitting access of air to the lower layers of the soil, and in this way promoting nitrification at depths at which it would otherwise not take place, is worthy of being pointed out. The rate at which nitrification may take place in various nitrogenous manures has unfortunately not been made the subject of much investigation. That it goes on, however, with considerable rapidity in most of the commonly used nitrogenous manures, is abundantly proved. Ammonia salts are of all manures most easily nitrified, while next to these come guanos, dried blood, &c. It has been found that of the nitrogenous matter present in the soil there is always a certain quantity more easily nitrifiable than the rest.[1]

Rate at which Nitrification takes place.—A very important consideration is the rate at which nitrification takes place. As the temperature of the soil during most months of the year is very much below the most favourable temperature for the development of nitrification, the amount formed during a few of the summer months is probably more than that formed during the rest of the year. The rate at which it takes place in the field can be estimated from the amount of nitrates found in the drainage-water added to that found in the soil. In calculating it in this way on a fallow soil at Rothamsted, it has been found that the quantity of nitrogen converted into nitrates in fourteen months' time was between 80 and 90 lb. per acre, an amount equal to 5 cwt. of nitrate of soda.

The Black Earth of Russia.—The *Tchornoi Zem*, or black earth of Central Russia, illustrates, in a very striking manner, the fact that the *kind* and *quantity* of the organic matter which a soil contains are scarcely less influential upon its fertility than the mineral constituents to which, in the last section, we principally adverted. This remarkable black soil, "the finest in Russia, whether for the production of wheat or grass," covers an area of upwards of 60,000 square geographical miles, and is said

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[1] For a fuller account of the process of nitrification, see Aikman's 'Manures and the Principles of Manuring,' pp. 161-198.

to be everywhere of extreme and of nearly uniform fertility. It nourishes a population of more than twenty millions of souls, and yet annually exports upwards of fifty millions of bushels of corn. This black earth stretches into Hungary, and forms the largest extent of fertile soil possessing common and uniform qualities which is anywhere known to exist. Its origin and chemical composition, therefore, have naturally engaged the attention both of scientific and of practical observers.

Its depth varies from 1 or 2 to 20 feet: when moist, it is jet black; and when dry, of a dark brown. This dark colour, from which it derives its name, is due to the presence of organic, chiefly vegetable, matter, in a peculiar decomposed state, minutely divided and intimately mixed with mineral matter. Of the weight of the dry soil, it forms, in different samples, from 16 to 18 per cent. This vegetable matter is distinguished by two circumstances—

1. That it is in an exceedingly minute state of division, and is intimately mixed with finely divided mineral matter. The black earth, therefore, forms a comparatively free and open soil, into which the air penetrates, and the roots of plants descend freely.

2. It contains in a state of combination a considerable proportion of nitrogen. In different samples this constituent has been found to vary from 2½ (Payne) to 8 per cent (Schmidt) of the weight of the organic matter. Through the action of the air, this nitrogen will favour the production in the soil of nitric acid, ammonia, and other soluble compounds containing nitrogen, which I have already described as propitious to the growth of plants.

But in this black earth the composition of the mineral or inorganic part is also such as to promote fertility. In one of the richest varieties, in which the organic matter amounted to 18 per cent, the mineral matter was found to consist of—

	Per cent.
Potash	5.81
Soda	2.31
Lime	2.60
Magnesia	0.95
Alumina and oxide of iron, with traces of phosphoric acid	17.32
Silica, of which 7 or 8 per cent was soluble	70.94
	99.93

We see in this analysis an abundant supply of those mineral substances which appear to be so necessary to the healthy growth of plants.

The general results of our analytical examination of soils, therefore, are chiefly these :—

a. That a due admixture of organic matter is favourable to the fertility of a soil.

b. That this organic matter will prove the more valuable in proportion to the quantity of nitrogen it holds in combination.

c. That the mineral part of the soil must contain all those substances which are met with in the ash of the plant, and in such a state of chemical combination that the roots of plants can readily take them up in the requisite proportion.

It is to the long accumulation of the remains of forests, or other abundant ancient vegetation, that the colour of the black earth, and its richness in organic matter, is, with the greatest probability, ascribed. The chief source of nitrogen in a soil, as will be pointed out hereafter, is the vegetable matter which slowly accumulates by successive generations of plants. In agriculture this accumulation is not allowed to take place to the same extent as in nature, owing to the removal of crops, &c.,

and hence arises the necessity for the application of artificial manures. But it may be well to point out here that when soils are under permanent pasture or leguminous crops, a very marked accumulation of nitrogen takes place.

CHAPTER XIII.

THE RELATION BETWEEN PLANTS AND THE SOILS IN WHICH THEY GROW, AND THE MANURES APPLIED TO THEM.

The importance of a minute study of the chemical composition of soils will, perhaps, be most readily appreciated by a glance at the very different kinds of vegetables which, under the same circumstances, different soils naturally produce; in other words, by a glance at their botanical relations.

There are none so little skilled in regard to the capabilities of the soil, as not to be aware that some lands naturally produce abundant herbage or rich crops, while others refuse to yield a nourishing pasture, and are deaf to the often-repeated solicitations of the diligent husbandman. There exists, therefore, a universally understood connection between the kind of soil and the kind of plants that naturally grow upon it. It is interesting to observe how close this relation in many cases is.

The sands of the sea-shore, the margins of salt lakes, and the surfaces of salt plains, like the Russian steppes, are distinguished by their peculiar tribes of salt-loving plants — by varieties of salsola, salicornia, &c. The *Triticum junceum* (sea-wheat) grows on the seaward slopes of the downs at no great distance from the sea.

The drifted sands more removed from the beach produce their own long, waving, coarser grass—the *Arundo arenaria* (sea-bent), the *Elymus arenarius* (sea lime-grass), and the *Carex arenarius* (sand-sedge), the roots of which plants bind the shifting sands together. The beautiful sea-pink spreads itself over the loose downs of the sea-shore, and upon inland sandy plains; while as we leave the downs, or as the soil changes, new vegetable races appear.

The peaty hills and flats of our island naturally clothe themselves with the common ling (*Calluna vulgaris*), the fine-leaved heath (*Erica cinerea*), and the cross-leaved heath (*Erica tetralix*). When drained and laid down to grass, or when they exist as natural meadows, they produce one soft woolly grass almost exclusively—the *Holcus lanatus*. After they are limed, these same soils become propitious to green crops and produce much straw, but refuse to fill the ear. The grain is thick-skinned, and therefore light in flour. There is a greater tendency to produce cellular fibre, and the insoluble matter associated with it, than the more useful substances starch and gluten.

On the margins of water-courses in which silica abounds, the mare's-tail (*Equisetum*) springs up in abundance; while, if the stream contain much carbonate of lime, the water-cress appears and lines the sides and bottom of its shallow bed, sometimes for many miles from its source.

The Cornish heath (*Erica vagans*) shows itself rarely above any other than the serpentine rocks in which magnesia abounds; the red broom-rape (*Orobanche rubra*), only on trap or basaltic rocks; the *Anemone pulsatilla*, on the dry banks of chalky mounds, as in the neighbourhood of Newmarket; the *Medicago lupulina*, on soils which abound in marl; while the red clover and the vetch delight in the presence of gypsum, and the white clover in that of alkaline matter in the soil.

So the red and white fire-weeds, *Epilobium coloratum* and *Erichtites hieracifolius*, cover with their bright blossoms every open space in the North American woods, over which the fires, so frequent there, have run during the previous year. The ashes of the burned trees and underwood are specially grateful to the seeds of these plants, which in vast quantities lie dormant in the soil.

The clays, too, have their likings. The rest-harrow (*Ononis arvensis*) delights in the weald, the gault, and the plastic clays, but passes by the greensand and chalk soils, by which these clays are separated from each other. The oak, in like manner, characterises the clays of the weald; while the elm flourishes, in preference, on the neighbouring soils of the greensand formation.

Thus also :—

Wheat thrives in clay soils;

Oats and *Clover*, in heavy and compact loams;

Barley and *Turnips*, in open and free loams;

Maize, in an open, free, and even sandy soil;

Rye, in a sandy soil;

Rice, in a stiff, wet, impervious clay;

Beans and *Peas*, in stiff, well-drained clays;

Cocoa-tree, in sandy soils of the coast;

Cotton, in dry, open alluvial (sea islands); dry and porous uplands (chalk-marls of Alabama); hot, dry, and somewhat droughty climate.

Tea-plant, in warm sloping banks, on light dry loams free from clay;

Earth-nut, or *bean*, in light sandy soil;

Cactus tribe, fleshy and water-bearing, in light dry sands, exposed three-fourths of the year to a burning sun;

Oil-palms, in the moist sea-sands of the West African coast.

Cinnamon-tree, in an almost pure sand;

The *Hop* "joyeth in a fat and fruitful ground," open, rich, calcareous loam.

The *Date* loves sandy but well-watered places; *e.g.*, near springs in the Great Desert.

Coffee flourishes in rich dry soil and warm situation.

Then, again, plants seem to alternate with each other on the same soil. Burn down a forest of pines in Sweden, and one of birch takes its place *for a while.* The pines after a time again spring up, and ultimately supersede the birch. These changes take place naturally. On the shores of the Rhine are seen ancient forests of oak from two to four centuries old, gradually giving place at present to a natural growth of beech, and others where the pine is succeeding to both. In the Palatinate, the ancient oak-woods are followed by natural pines; and in the Jura, the Tyrol, and Bohemia, the pine alternates with the beech.

These and other similar differences are believed to depend in great part upon the chemical composition of the soil. The slug may live well upon, and therefore infest, a field almost deficient in lime; the common land-snail will abound at the roots of the hedges only where lime is plentiful, and can easily be obtained for the construction of its shell. So it is with plants. Each grows spontaneously where its wants can be most fully and most easily supplied. If they cannot move from place to place like the living animal, yet their seeds can lie dormant, until either the hand of man or the operation of natural causes produces such a change in their position, in reference to light, heat, &c., as to give them an opportunity of growing—or in the composition and physical qualities of the soil itself, as to fit it for ministering to their most important wants. Change the chemical character of the soil, and the plants change. White clover is a natural plant in all good pasture in Ireland, especially on the great limestone formations. It is a lime-loving, acid-hating plant. Hence lime heavily a sour Irish or Scottish bog or a heathy hillside, and white clover springs up forthwith, as if the seed had been sown. In like manner drainage brings it up by removing the acidity of the soil.

And such changes do naturally come over the soil. The oak, after thriving for long generations on a particular spot, gradually sickens; its entire race dies out, and other races succeed it. Has the operation of natural causes gradually removed from the soil that which favoured the oak, and introduced or given the predominance to those substances which favour the beech or the pine? On the light soils of the State of New Jersey the peach-tree used to thrive better than anything else, and large sums of money were made from the peach-grounds in that State. But of late years they have almost entirely failed. In Scotland, the Scotch fir has been known at once to die out over an area of 500 or 600 acres—and the forests of larch are now in many localities exhibiting a similar decay. This decay is often, no doubt, owing to the presence of noxious matters in the subsoil, but it is due in some cases also to a natural change in the composition and character of the several soils, which has taken place since the peach, the fir, and the larch trees were first planted upon them.

In the hands of the farmer, the land grows sick of this crop—it becomes tired of that. These facts may be regarded as indications of a change in the chemical composition of the soil, and also, as we have now reason to believe, for biological reasons connected with the micro-organic life of the soil. This alteration may proceed slowly and for many years; and the same crops may still grow upon it for a succession of rotations. But at length the change is too great for the plant to bear; it sickens, yields an unhealthy crop, and ultimately refuses altogether to grow.

The plants we raise for food have similar likes and dislikes with those that are naturally produced. On some kinds of food they thrive; fed with others they sicken or die. The soil must therefore be prepared for their special growth.

In an artificial rotation of crops we only follow nature. One kind of crop extracts from the soil a certain quantity of all the inorganic constituents of plants, but some of these in much larger proportions than others. A second kind of crop carries off, in preference, a large quantity of those substances of which the former had taken little: and thus it is clearly seen, both why an abundant manuring may so alter the composition of the soil as to enable it to grow almost any crop; and why, at the same time, this soil may, in succession, yield more abundant crops, and in greater number, if the kind of plants sown and reaped be so varied as to extract from the soil, one after the other, the several different substances which the manure we have originally added is known to contain.

So with regard to the organic matter which soils contain. That form of organic food which suits one, may not equally favour another species of plant, and thus, at different times, different species may be most suited to the chemical condition of the same field.

It may be that one reason why certain plants are always found in particular soils and situations (as, for example, the Fuci), is, not that they like their surroundings, but because, under other and more favourable conditions, they would be overpowered by other plants. "I saw," says Dean Herbert, "a crocus, a sternbergia, and an ornithogalum growing in contact with each other aloft on the meagre soil of Mount Œnos, but not a seed-pod of the sternbergia could be discovered, and very few of the crocus. In a more fertile soil they would have been choked by some stronger plant, but they would rejoice in a better soil if protected against the oppressor."

Influence of Soils on Cereals.—The varying quality of barley raised in different localities is familiar to every farmer. On stiff clays, barley may yield a greater produce, but it is of a coarser quality. On light chalky soils it is thin-skinned, rich in colour, and, though light in weight, well adapted for *malting;* while on loamy lands and on sandy marls it assumes a greater plumpness, yet still retains its malting quality.

Similar differences affect the same variety of wheat when grown upon different soils. In a previous chapter it was stated that the quantity of gluten contained in wheat is believed to vary with the climate, and in some degree also with the manure applied to the land; but a similar variation occurs on unlike soils, when manured or otherwise treated in every respect alike. The miller knows by experience the relative qualities of the wheat grown on the several farms in the neighbourhood of his mill, so that even when his eye can detect no difference of quality between two samples, a knowledge of the places where they were grown enables him to decide which of the two it will be most for his interest to buy.

The oat varies in quality likewise with the soil on which it is grown. The meal made from oats grown upon clay land is the best in quality, is the *thriftiest,* keeps the longest, and generally brings the highest price.

Rye also flourishes upon light and sandy soils in general, but when grown upon sandy marls it is found (in Germany) to yield much bran.

The question of the influence of soil on the quality of cereals is a most interesting one. In composition cereals exhibit considerable range. Some cereals have a thick husk, such as oats, and as the proportion of husk to kernels differs considerably, the composition of such cereals varies to a corresponding extent. A soil rich in nitrogen and poor in phosphates and potash is apt to produce cereals rich in nitrogen. A soil in which premature ripening is apt to take place produces a higher percentage of nitrogenous matter in the crop and lessens the percentage of starch, &c.

Influence of Soils upon Leguminous Plants.—The *pea* and the *bean* are distinguished by similar peculiarities when grown in light and in heavy soils. There are certain spots in the neighbourhood of all large towns, which are known to produce the best boiling peas—such as boil soft and mealy. Lime and gypsum are said by some to impart the boiling quality, while by others exactly the reverse is stated. No doubt the different results are owing to differences in the soils upon which the several experiments were made.

Influence of Soils upon the Potato.—It is familiarly known to the potato-grower, that clay soils produce waxy, and sandy soils mealy potatoes. But the condition of the land also exercises a material influence both upon their growth and quality. When, for example, potatoes are planted in rich newly-broken-up land, they run up greatly to *shaws* or tops, produce generally few or small tubers, and of bad eating quality, because they seldom ripen before the frost sets in. It has been observed that the quantity of starch is larger in potatoes which are grown upon land long in arable culture than upon such as is newly brought into cultivation or broken up from grass.

Influence of Soils on the Turnip.—That the soil has an influence on the composition of the turnip crop, has long been believed by the practical man, because of the difference in the taste and feeding properties of the same kind of turnip grown on different fields and farms.

The chemical nature of this difference has been fully investigated by Dr Anderson. His analysis of turnips, grown in the same season and circumstances, upon

a. The heavy alluvial clay of the Carse of Gowrie;

b. The black land which separates the clay from the hill, and there, as in Lincolnshire, skirts the slopes;

c. The hill-land, which is a light loam—

showed that the proportion of proteids was almost always greater on the hill-land than on either of the other soils —sometimes *twice as great.* The turnips of the black land were also slightly superior in this respect to those of the clay. This result of analyses fully supports that of practical experience in the feeding of stock.

Influence of Soils on Fruit.—Fruits of all kinds, like our corn and root crops, are affected in flavour and quality by the soil on which they grow. In the Norman orchard, the *goût de terrain* is a recognised quality both in the apple and in the cider. The extended apple and peach culture of North America has led to similar observations; and the peculiar qualities possessed by the wines of neighbouring vineyards are familiar everywhere. There are only three farms situated on the side of a hill which produce the famous Constantia wine. The same grape has been tried in various parts of the Cape colony without success. Even a mile from the hill the wine is of a very inferior description. In Europe, on the banks of the Rhine, the Johannisberg is equally well known for the unique qualities of its celebrated wine.

CHAPTER XIV.

THE IMPROVEMENT OF SOILS.

The soil, in its natural condition, is possessed of certain existing and obvious qualities, and of certain other dormant capabilities. How are the existing qualities to be improved,—the dormant capabilities to be awakened?

The General Improvement of Soils.—There are few soils to which something may not still be done in the way of improvement, while by far the greatest breadth of the land, in almost every country, is still susceptible of extensive amelioration.

All soils may be arranged into one or other of two classes.

1. Those which contain in themselves an abundant supply of all those things which plants require, and are therefore fitted chemically to grow any crop.

2. Those which are deficient in some of those substances on which plants live, and are therefore not fitted to grow, perhaps, any one crop with luxuriance.

Both of these classes of soils, as they are naturally met with, are susceptible of improvement, the former by mechanical methods chiefly, the latter by mechanical partly, but chiefly by chemical methods. In the present chapter we shall consider the mechanical methods of improving the soil.

Draining Soils, and the benefits produced by it.—The first step to be taken in order to increase the fertility of nearly all the improvable lands of Great Britain, is to drain them. The advantages that result from draining are manifold.

1. The presence of too much water in the soil keeps it constantly cold. The heat of the sun's rays, which is intended by nature to warm the land, is expended in evaporating the water from its surface; and thus the plants never experience that genial warmth about their roots which so much favours their rapid growth.

The temperature which a dry soil will attain in the summer-time is often very great. Sir John Herschel observed, that at the Cape of Good Hope the soil attained a temperature of 150° Fahr., when that of the air was only 120°; and Humboldt says that the heat of the soil between the tropics often rises to from 124° to 136°.

When the land is full of water, it is only after long droughts, and when it has been thoroughly baked by the sun, that it begins to attain the temperature which dry land under the same sun may have reached, day after day, probably for weeks before.

2. Where too much water is present in the soil, also, that portion of the food of the plant which the soil supplies is so much diluted, that either a much greater quantity of fluid must be taken in by the roots—much more work done by them, that is—or the plant will be scantily nourished. The presence of so much water in the stem and leaves keeps down *their* temperature also—when the sunshine appears, an increased evaporation takes place from their surfaces—a lower natural heat, in consequence, prevails in the interior of the plant, and the chemical changes, on which its growth depends, proceed with less rapidity.

3. By the removal of the water, the physical properties of the soil, also, are in a remarkable degree improved. Dry pipe-clay can be easily reduced to a fine powder, but it naturally, and of its own accord, runs together when water is poured upon it. So it is with clays in the

field. When wet, they are close, compact, and adhesive, and exclude the air from the roots of the growing plant. But remove the water and they gradually contract, crack in every direction, become thus open, friable, and mellow, more easily and cheaply worked, and pervious to the air in every direction.

4. The access of this air is essential to the fertility of the soil, and to the healthy growth of most of our cultivated crops. The insertion of drains not only makes room for the air to enter by removing the water, but actually compels the air to penetrate into the under parts of the soil, and renews it at every successive fall of rain. Open such outlets for the water below, and as this water sinks and trickles away, it will *suck* the air after it, and draw it into the pores of the soil wherever itself has been. It thus permits of the process of disintegration of the mineral matter in the lower portion of the soil going on under the influence of oxygen.

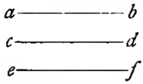
Vegetable matter becomes of double value in a soil thus dried and filled with atmospheric air. When drenched with water, this vegetable matter either decomposes very slowly, or produces acid compounds more or less unwholesome to the plant, and even exerts injurious chemical reactions upon the earthy and saline constituents of the soil. In the presence of air, on the contrary, this vegetable matter decomposes rapidly, produces carbonic acid in large quantity, as well as other compounds on which the plant can live, and even renders the inorganic constituents of the soil more fitted to enter the roots, and thus to supply more rapidly what the several parts of the plant require. Hence, on dry land, manures containing organic matter (farmyard manure, &c.) go farther, or are more profitable to the farmer. Draining also exerts a very important influence on the changes going on in the soil, whereby the nitrogen is prepared for the plant's use. In a water-logged soil not only is the process of nitrification checked, but a reverse process goes on, whereby the nitrates already present are deoxidised and a portion of the nitrogen is set free, and escapes in the form of gas.

5. Nor is it only stiff and clayey soils to which draining can with advantage be applied. It will be obvious to every one, that when springs rise to the surface in sandy soils, a drain must be made to carry off the water; it will also readily occur, that where a sandy soil rests upon a hard or clayey bottom, drains may likewise be necessary; but it is not unfrequently supposed, that where the subsoil is sand or gravel, thorough draining can seldom be required.

Every one, however, is familiar with the fact that when water is applied to the bottom of a flower-pot full of soil, it will gradually find its way towards the surface, however light the soil may be. So it is in sandy soils or subsoils in the open field—all possess a certain power of sucking up water from beneath. If water abound at the depth of a few feet, or if it so abound at certain seasons of the year, *that* water will rise towards the surface; and as the sun's heat dries it off by evaporation, more water will follow to supply its place. This attraction from beneath will always go on when the air is dry and warm, and thus a double evil will ensue—the soil will be kept moist and cold, and instead of a constant circulation *of air downwards*, there will be a constant current *of water upwards.* Thus will the root, the under soil, and the organic matter it contains, be all deprived of the benefits which the access of the air is fitted to confer, and both the crops and the farmer will suffer in consequence. The remedy for these evils is to be found in an efficient system of drainage.

6. It is a curious, and apparently a paradoxical obser-

vation, that draining often improves soils on which the crops are liable to be *burned up* in seasons of drought. Yet, upon a little consideration, the fact becomes very intelligible. Let *a b* be the surface of the soil, and *c d* the level at which the water stagnates, or below which there is no outlet by drains or natural openings. The roots will readily penetrate to *c d;* but they will in general refuse to descend farther, because of the unwholesome substances which usually collect in water that is stagnant. Let a dry season come, and their roots, having little depth, the plants will be more or less speedily burnt up. And if water ascend from beneath the line *c d*, to moisten the upper soil, it will bring with it those noxious substances into which the roots have already refused to penetrate, and will cause the crop to droop and wither. But put in a drain, and lower the level of the water to *e f*, and the rains will wash out the noxious water from the subsoil, and the roots will descend deep into it; so that if a drought again come, it may parch the soil above *c d*, as before, without injuring the plants, since now they are watered and fed by the soil beneath, into which the roots have descended.



7. In many parts of the country, and especially in the red-sandstone districts, the oxide or rust of iron abounds so much in the soil, or in the springs which ascend into it, as gradually to collect in the subsoil, and form a more or less impervious layer or pan, into which the roots cannot penetrate, and through which the surface-water refuses to pass. Such soils are beneficial for a time by breaking up the pan where the plough can reach it; but the pan gradually forms again at a greater depth, and the evils again recur. In such cases, the insertion of drains below the level of the pan is the most certain mode of permanently improving the

soil. If the pan be now broken up, the rains sink through into the drains, and gradually wash out of the soil the iron which would otherwise have only sunk to a lower level, and have again formed itself into a solid cake.

8. It is not less common, even in rich and fertile districts, to see crops of beans, or oats, or barley, come up strong and healthy, and shoot up even to the time of flowering, and then begin to droop and wither, till at last they more or less completely die away. So it is rare in many places to see a second year's clover crop come up strong and healthy. These facts indicate, in general, the presence of noxious matters in the subsoil, which are reached by the roots at an advanced stage of their growth, but into which they cannot penetrate without injury to the plant. The drain calls in the aid of the rains of heaven to wash away these noxious substances from the soil, and of the air to change their nature; and this is the most likely, as well as the cheapest, means by which these evils can be prevented.

9. Another evil in some countries presents itself to the practical farmer. Saline substances are in certain quantity beneficial, nay, even necessary to the growth of plants. In excess, however, they are injurious, and kill many valuable crops. We have already adverted to the existence of such saline substances in the soil, and to the fact of their rising in incrustations to the surface when droughts prevail.

In some countries, as, for example, in the plains of Athens, and near the city of Mexico, they come to the surface in such quantity as actually to kill the more tender herbage, and to permit only the stronger plants to grow. In the plains of Athens, when the rainy season ends, a rapid evaporation of water from the surface begins. The water, as it rises from beneath, brings much saline matter with it. This it leaves behind as it ascends in vapour, and thus at length so overloads the surface-soil that tender grass refuses to grow, though the stronger wheat plant thrives well and comes to maturity.

This result could scarcely happen if an outlet beneath were provided for the waters which fall during the rainy season. These would wash out and carry away the excess of saline matter which exists in the under soil, and would thus, when the dry weather comes, prevent it from ascending in such quantities as to injure the more tender herbage.

It may be objected to this suggestion, that drains in such countries would render more dry a soil already too much parched by the hot suns of summer. It is doubtful, however, if this would really be the case. Deep drains, as in the case above explained (6), would enable the roots to penetrate deeper, and would thus render them more independent of the moisture of the surface-soil.

10. On this subject we shall add one important practical remark, which will readily suggest itself to the geologist who has studied the action of air and water on the various clay-beds that occur here and there, as members of the series of stratified rocks. There are no clays which do not gradually soften under the united influence of air, of frost, and of running water. It is false economy, therefore, to lay down tiles of the common horse-shoe form without soles, however hard and stiff the clay subsoil may appear to be. In the course of ten or fifteen years, the stiffest clays will *generally* soften so much as to allow the tile to sink to some extent—and many very much sooner. The passage for the water is thus gradually narrowed; and when the tile has sunk a couple of inches, the whole may have to be taken up.

The *economical* advantages of draining in such soils as we possess are chiefly these:—

(1.) Stiff soils are more easily and more cheaply worked.

(2.) Lime and manures have more effect, and go farther.

(3.) Seed-time and harvest are earlier and more sure.

(4.) Larger crops are reaped, and of better quality.

(5.) Nutritive grasses spring up where inferior grasses formerly grew.

(6.) Valuable crops of wheat and turnips are made to grow where scanty crops of oats were formerly the chief return.

(7.) Naked fallows are rendered less necessary, and more profitable rotations can be introduced.

(8.) The climate is improved, and rendered not only more suited to the growth of crops, but more favourable to the health of man and other animals.

(9.) The soil is actually enriched by what the rains bring down.

(10.) Air is sucked down into the subsoil.

(11.) Certain processes whereby plant food is being prepared in the soil are promoted, such as nitrification.

Proper Depth to which Drains ought to be dug.—Much has lately been written in regard to the depth to which drains ought to be dug in a system of thorough drainage. It is difficult, perhaps impossible, to establish any empirical or general rule upon this subject; but there are certain indisputable points which will serve to guide the intelligent farmer in most cases which are likely to occur.

1. It is acknowledged, as a general rule, to be of great importance that the soil should be deepened—that it should be opened up, for the descent of the roots, to the greatest depth to which it can be economically done. Now, by the use of the subsoil-plough or the fork, the

soil can be stirred to a depth of from 22 to 24 inches. The tile—or the top of the drain, if made of stones—should be at least three inches clear of this disturbance of the upper soil; and as most tiles will occupy at least 3 inches, we reach 30 inches as the minimum depth of a tile drain, and about 3 feet as the minimum depth of a stone drain, in which the layer of stones has a depth of not more than 9 inches.

2. Where the outfall is bad, and a depth of 30 or 36 inches cannot be obtained, the drains should be as deep as they can be made to run and deliver water.

3. The roots of our corn and other crops will, in favourable circumstances, descend to a depth of 4 or 5 feet. They do so in quest of food, and the crop above ground is usually the more luxuriant the deeper the roots are enabled to penetrate. It is therefore theoretically desirable to dry the soil to a greater depth even than 3 feet, where it can be done without too great an outlay of money.

4. The question of economy, therefore, is one of great importance in this inquiry. In some places it costs as much to dig out the fourth or lowest foot as is paid for the upper three; and this additional cost is, in many localities, a valid reason for limiting the depth to 30 inches or 3 feet.

5. But the question of economy ought to be disregarded, and deeper drains dug where springs occur beneath, or where, by going a foot deeper, a bed or layer is reached in which much water is present. The reason of this is, that though water may not rise from this wet layer in such quantity as actually to run along the drains, yet it may do so in sufficient abundance to keep the subsoil moist and cold, and thus to retard the development of the crops that grow on its surface.

The above circumstances appear sufficient to guide the practical man in most cases that will present themselves to him. No uniform depth can be fixed upon; it must be modified by local circumstances, and may vary from 2½ to 4 feet.

In regard to the distance apart at which drains should be placed, experience appears to be the only satisfactory guide. This says, as yet, that 18 to 21 feet are safe distances, and that drains placed at greater distances are doubtful, and may fail to dry the land.

Passage of Rain through the Soil.—The most important immediate effect of thorough drainage is, that it enables the rain or other surface-water to descend more deeply and escape more rapidly from the soil. It may be interesting to specify briefly the benefits which are known to follow from this descent of the rain through the soil.

1. *It causes the air to be renewed.*—The admission of frequently renewed supplies of air into the soil is favourable to its fertility. This the descent of the rain promotes. When it falls upon the soil it makes its way into the pores and fissures, expelling, of course, the air which previously filled them. When the rain ceases, the water runs off by the drains; and as it leaves the pores of the soil empty above it, the air follows, and fills with a renewed supply the numerous cavities from which the descent of the rain had driven it. Where land remains full of water, no such renewal of air can take place.

2. *It warms the under soil.*—As the rain falls through the air it acquires the temperature of the atmosphere. If this be higher than that of the surface-soil, the latter is warmed by it; and if the rains be copious, and sink easily into the subsoil, they will carry this warmth with them to the depth of the drains. Thus the under soil in well-drained land is not only warmer, because the

evaporation is less, but because the rains in the summer season actually bring down warmth from the atmosphere to add to its natural heat.

3. *It equalises the temperature of the soil during the season of growth.*—The sun beats upon the surface of the soil, and gradually warms it. Yet, even in summer, this direct heat does not descend much beneath the surface. But when rain falls upon the warm surface, and finds an easy descent, as it does in open soils, it becomes itself warmer, and carries its heat down to the under soil. Then the roots of plants are warmed, and general growth is stimulated.

It has been proved, by experiments with the thermometer, that the under as well as the upper soil is warmer in drained than in undrained land; and the above are some of the ways by which heat seems to be actually added to soils that have been thoroughly drained.

4. *It carries down soluble substances to the roots of plants.*—When rain falls upon heavy undrained land, or upon any land into which it does not readily sink, it runs over the surface, dissolves any soluble matter it may meet with, and carries it into the nearest ditch or brook. Rain thus robs and impoverishes such land.

But let it sink where it falls, then whatever it dissolves it will carry downwards to the roots—it will distribute uniformly the saline matters which have a natural tendency to rise to the surface, and it will thus promote growth by bringing food everywhere within the reach of plants.

5. *It washes noxious matters from the under soil.*—In the subsoil, beyond the reach of the air, substances are apt to collect, especially in red-coloured soils, which are injurious to the roots of plants. These the descent of the rains alters in part and makes wholesome, and in

part washes out. The plough may then safely be trusted deeper, and the roots of plants may descend in search of food where they would previously have been destroyed.

It is true that, when heavy rains fall, they will also wash out of the soil and carry into the drains substances which it would be useful to retain. Upon this fact some have laid unnecessary stress, and have adduced it as an argument against thorough drainage. But if we balance the constant benefit against the occasional evil, experience has shown that the former will greatly preponderate.

6. *It brings down fertilising substances from the air.*—Besides, the rains never descend empty-handed. They constantly bear with them gifts, not only of moisture to the parched herbage, but of organic and saline food, by which its growth is promoted. Ammonia and nitric acid, together with the many exhalations which are daily rising from the earth's surface, come down in the rains; common salt, gypsum, and other saline substances derived from the sea, are rarely wanting.

7. *Much of the rain is evaporated.*—And lastly, in answer to this objection, it is of importance to state, that in our climate a very large proportion of the rain that falls does not sink through the soil, even where there are drains beneath, but rises again into the air in the form of watery vapour. Experiments in Manchester have shown, that of 31 inches of rain which fall there in a year, 24 are evaporated; while in Yorkshire, of 24½ inches of rain which fall, only 5 inches run off through pipes laid at a depth of 2 feet 9 inches, the rest being evaporated. There is little cause, therefore, for the fear expressed by some, that the draining of the land will cause the fertility in any perceptible degree to diminish in consequence of the washing of the descending rains. They may, as we have said, improve the subsoil by

washing hurtful substances out of it; but, in general, the soil will have extracted from the water which filters through it much of the valuable matter it holds in solution before it has reached the depth of a 3-feet drain.

8. *Conservation of heat of soil.*—But perhaps one of the greatest advantages conferred by draining is the great saving of heat to the soil which it effects. In undrained soils, the water, by collecting on the surface of the soil, keeps down the temperature. A large amount of heat is thus expended in effecting its evaporation, which is a direct loss to the soil.

The greater the number of trees in a country, the greater, other conditions being equal, is its rainfall. In France the extent of forests and woods in 1750 was estimated to cover 40,000,000 of English acres; the area under timber is now reduced by one-half. This has led to a decrease in the annual rainfall, which, according to some authorities, is injurious to the agriculture of the country. Egypt was once a rainless country, but now, by the planting of millions of trees in it, rain descends regularly every winter.

CHAPTER XV.

IMPROVEMENT OF SOILS BY TILLAGE AND MIXING.

After the land has been laid dry by drains, other mechanical modes of improvement can be employed with advantage. Even the ordinary methods of mechanical culture become more useful, and the benefits which in favourable circumstances are derived from turning up the soil are greater and more manifest.

This is effected in a variety of ways. For one thing, by opening up a soil the action of the frost is rendered more powerful, and the disintegration of the soil goes on more rapidly. The soil is thus rendered more porous, and the roots of the plant are permitted to develop more quickly under such conditions. We have already pointed out that the soil can absorb from the air the minute quantities of ammonia present in it. The more the soil is tilled, the more freely will its particles be brought into contact with the air, and the more abundant will the absorption of the ammonia become. These facts will appear by a brief consideration of the effects produced by ploughing to various depths, and the causes from which they arise.

Use of the Subsoil-Plough.—The subsoil-plough is an auxiliary to the drain—it stirs and opens the under soil without mixing it with the upper or immediately active soil. Though there are few subsoils through which the water will not at length make its way, yet there are some so stiff, either naturally or from long consolidation, that the good effect of a well-arranged line of drains is lessened by the slowness with which they allow the superfluous water to pass through them. In such cases, the use of the subsoil-plough is most advantageous in loosening the under layers of soil, and in allowing the water to find a ready escape downwards to either side, until it reaches the drains.

It is well known that if a piece of stiff clay be cut into the shape of a brick, and then allowed to dry, it will contract and harden—it will form an air-dried brick, almost impervious to any kind of air. Wet it again, it will swell and become still more impervious. Cut up *while wet*, it will only be divided into so many pieces, each of which will harden when dry, or the whole of which will again attach themselves and stick together if exposed to pressure while they are still wet. But tear it asunder *when dry*, and it will fall into many pieces, will more or less crumble, and will readily admit the air into its inner parts. So it is with a clay subsoil.

After the land is provided with drains, the subsoil being very retentive, the subsoil-plough is used to open it up—to let out the water and let in the air. If this is not done, the stiff under-clay will contract and bake as it dries, but it will neither sufficiently admit the air, nor open so free a passage for the roots. Let this operation, however, be performed when the clay is still too wet, a good effect will follow in the first instance; but after a while the cut clay will again cohere, and the farmer will pronounce subsoiling to be a useless expense *on his land.* Defer the use of the subsoil-plough till the clay is dry—it will then *tear* and *break* instead of *cutting* it, and its openness will remain. Once give the air free access, and, after a time, it so modifies the drained clay that it no longer has an equal tendency to cohere.

Mr Smith of Deanston very judiciously recommended that the subsoil-plough should never be used till at least a year after the land has been thoroughly drained. This in many cases will be a sufficient safeguard—will allow a sufficient time for the clay to dry; in other cases, two years may not be too much. But this precaution has by some been neglected; and, subsoiling being with them a failure, they have sought, in some supposed chemical or other quality of their soil, for the cause of a want of success which is to be found in their own neglect of a most necessary precaution. Let not the practical man be too *hasty* in desiring to attain those benefits which attend the adoption of improved modes of culture; let him give every method a fair trial; and above all, let him make his trial in the way and with the precautions recommended by the author of the method, before he pronounce its condemnation.

The Profit of Subsoiling.—The benefits of subsoil-ploughing are well illustrated by the following numerical results observed on two farms in the neighbourhood of Penicuik, a few miles from Edinburgh.

1. Mr Wilson of Eastfield, Penicuik, made an experiment, after thorough drainage, upon two portions of land under each of three crops, and found the effects in the first year after subsoil-ploughing, compared with ordinary ploughing, to be as follows:—

	TURNIPS.	BARLEY.		POTATOES.
		Grain.	Straw.	
	tons cwt.	qrs.	cwt.	tons cwt.
Ploughed to 8 inches .	20 7	7½	28	6 14¼
Subsoiled to 15 inches .	26 17	8⅜	36½	7 9½
Difference .	6 10	⅞	8½	15¼

From this table, the effect of subsoiling to a depth of 15, above that of ploughing to a depth of 8 inches, appears to have been to increase the turnip crop by 6½ tons, the potatoes by 15 cwt., and the barley by 7 bushels of grain and 8 cwt. of straw.

2. Mr Maclean of Braidwood, near Penicuik, made a similar experiment with turnips and barley, with the following results:—

	TURNIPS.	BARLEY.	
		Grain.	Straw.
	tons cwt.	qrs.	stones.
Ploughed 8 inches deep	19 15	6¾	168½
Subsoiled to 15 inches	23 17	7⅜	206½
Difference	4 2	⅝	38

The turnip crop in this experiment was increased 4 tons, and the barley crop by ⅝th quarter of grain, and 38 stones of straw.

It has been observed, also, that the effects of the subsoiling do not cease with the first crop. In one case, in which an accurate account of the produce was kept, the profit was estimated at 6s. an acre, *for five successive years after the operation.* There is reason, therefore, to anticipate general good from the careful introduction of this practice; though it is exceedingly desirable, at the same time, that the causes of its failure, wherever it is found to fail, should be rigorously investigated.

Deep Ploughing.—*Deep ploughing*, like subsoiling, aids the effect of the drains, and so far—where it goes nearly as deep—even more completely effects the same object. Deep ploughing is no longer regarded with such favour as was at one time the case. We now know that the best soil is at the top, and that the micro-organic life which exercises such an important function in promoting the process of plant-growth is chiefly to be found in the surface portion, and cannot develop freely in the deeper soil-layers. It is true that certain substances, such as lime, when applied to the soil, have a tendency to sink down, and that deep ploughing serves to bring them to the surface. Nevertheless the custom of deep ploughing is gradually now coming to be regarded as a mistake. Subsoiling, combined with moderate ploughing, is the best treatment for heavy soils.

In Germany, theory has pointed out the growing of an occasional *deep-rooted* crop in light soils to effect the same end. The deep roots bring up again to the surface the substances which had naturally sunk, and open up and loosen the subsoil—in fact, they "subsoil-plough" it.

It is the want of drainage, however, and of the free access of air, that most frequently renders subsoils for a time injurious to vegetation. Let the lands be well drained—let the subsoils be washed for a few years by the rain-water passing through them—and there are few of those which are clayey in their nature that may not ultimately be brought to the surface, not only with safety, but with advantage to the upper soil.

TRENCHING with the spade more fully and effectually performs what the trench-plough is intended to do. The spade more completely turns over the soil than the plough does; and in the hands of an industrious labourer, many think it the more economical instrument of the two.

It is chiefly because the spade or the fork divides and separates the soil more completely, or to a greater depth, that larger crops have been obtained in many districts by the introduction of spade-husbandry than by the ordinary mode of culture with the plough. But all these benefits, which a thorough working of the soil is fitted to confer, are only fully realised where the land is naturally dry, or by artificial drainage has been freed from superfluous water.

Chemical Effects of Ploughing.—Other benefits, again, attend upon the ordinary ploughings, hoeings, and working of the land. Its parts are more minutely divided—the air gets access to every particle—it is rendered lighter, more open, and more permeable to the roots. The vegetable matter it contains decomposes more rapidly by a constant turning of the soil, so that wherever the fibres of the roots penetrate, they find organic food provided for them, and an abundant supply of the oxygen of the atmosphere to aid in preparing it. The production of ammonia and of nitric acid also, and the absorption of these and of watery vapour from the air, take place to a greater extent the finer the soil is pulverised, and the more it has been exposed to the action of the atmosphere. The promotion of the process of nitrification must be regarded as one of the most important benefits conferred on the soil by tillage operations, such as ploughing, &c. All soils contain, likewise, an admixture of fragments of those minerals of which the granitic and trap rocks are composed, which, by their decay, yield new supplies of inorganic food to the growing plant. The more frequently they are exposed to the air, the more rapidly do these fragments crumble away and decompose. The general advantage, indeed, to be derived from the constant working of the soil, may be inferred from the fact, that Tull reaped twelve successive crops of wheat from the same land by the repeated use of the plough and the horse-hoe. There are few soils so stubborn as not to show themselves grateful in proportion to the amount of this kind of labour that may be bestowed upon them.

Improvement of Soils by Mixing.—It has been already shown that the physical properties of the soil have an important influence upon its average fertility. The admixture of pure sand with clay soils produces an alteration which is often beneficial, and which is almost wholly physical. The sand opens the pores of the clay, and makes it more permeable to the air.

The admixture of clay with sandy or peaty soils, however, produces both a physical and a chemical alteration. The clay not only consolidates and gives body to the sand or peat, but it also mixes with them certain earthy and saline substances, useful or necessary to the plant, which neither the sand nor peat might originally contain in sufficient abundance. It thus alters its chemical composition, and fits it for nourishing new races of plants.

Such is the case also with admixtures of marl, of shell-sand, and of lime. They slightly consolidate the sands and open the clays, and thus improve the mechanical texture of both kinds of soil; but their main operation is chemical; and the almost universal benefit they produce depends mainly upon the new chemical element they introduce into the soil.

The cost of applying clay to light land is given as follows in the second volume of the 'Journal of the Royal Agricultural Society of England':—

	£	s.	d.
Digging and spreading 150 yards of clay, at 4½d. per yard	£2	16	3
4 horses, at 2s. 6d. each per day for 4 days	2	0	0
Drivers	0	10	0
Various expenses, including allowance for wear and tear	0	3	0
	£5	9	3

It is stated that the operation proved a financial success. It should, however, be observed, that it will hardly pay in those days of high-priced labour to transport clay from a long distance for the purpose of mixing soils. In the drainage of Whittlesea Mere, a portion of adjacent bog-land was reclaimed by spreading over it a layer of soil, on the average 5 inches deep. The soil was taken from the bed of the Mere, a distance of two miles. The cost of claying to the depth of 4 inches proved to be between £15 and £16 per acre, and £18 when the layer was six inches deep. The bog, which previously was worthless, was after its reclamation let at 30s. per acre, so that the operation, costly as it proved, was a remunerative one. Mr W. Wells states ('Journal of the Royal Agricultural Society of England,' vol. vi. second series, 1870) that bog-land reclaimed by mixing with clay should not too early be brought under a system of crop rotation. He recommends cole-seed to be sown early in July, and to feed sheep on the crop, giving them in addition oilcake. In the following winter the land should be ploughed, and in the spring oats sown, not too early. In May a mixture of red and white clover, timothy, pacey, trifolium, and Italian ryegrass should be sown and trodden in; but they should not be kept longer than a year.

It is a matter of almost universal remark that in our climate soils are fertile—clayey or loamy soils, that is—only when they contain an appreciable quantity of lime. In whatever way it acts, therefore, the mixing of lime in any of the forms above mentioned, with a soil in which little or no lime exists, is one of the surest practical methods of bringing it nearer in composition to those soils from which the largest returns of agricultural produce are usually obtained.

CHAPTER XVI.

IMPROVEMENT OF SOILS BY THE AGENCY OF VEGETATION.

There are certain modes of improving the soil, which, though involving only simple mechanical operations on the part of the improver, produce their effects through the agency of refined scientific causes. Such are the improvements produced by planting and laying down to grass. These shall be briefly considered in the present chapter.

Improvement of the Soil by Planting.—It has been observed that lands which are unfit for arable culture, and which yield only a trifling rent as natural pasture, are yet in many cases capable of growing profitable plantations, and of being greatly increased in permanent value by the prolonged growth of wood. Not only, however, do all trees not thrive alike on the same soil, but all do not improve the soil on which they grow in an equal degree.

Under the Scotch fir, for example, the pasture which springs up after a lapse of years is hardly worth more per acre than before the land was planted. Under the beech and spruce it is worth even less than before, though the spruce affords excellent shelter; under the ash it gradually acquires an increased value per acre. In oak copses it becomes worth even more, but only during the last eight years (of the twenty-four) before the oak copse is cut down. But under the larch, after the first thirty years, when the thinnings are all cut, land increases very much in value per acre for permanent pasture.

1. The main cause of this improvement is to be found in the nature of the soil, which gradually accumulates beneath the trees by the shedding of their leaves. The shelter from the sun and rain which the foliage affords prevents the vegetable matter which falls from being so speedily decomposed, or from being so much washed away, and thus permits it to collect in larger quantities in a given time than where no such cover exists. The more complete the shelter, therefore, the more rapid will the accumulation of soil be, in so far as it depends upon this cause.

2. But the quantities of leaves which annually fall, as well as the degree of rapidity with which, under ordinary circumstances, they undergo decay, have also much influence upon the extent to which the soil is capable of being improved by any given species of tree. The broad leaves of the beech and oak decay more quickly than the needle-shaped leaves of the pine

tribes, and this circumstance may assist in rendering the larch more valuable as a permanent improver.

3. We should expect, likewise, that the quantity and quality of the inorganic matter contained in the leaves brought up year by year from the roots, and strewed afterwards uniformly over the surface where the leaves are shed, would materially affect the value of the soil they form. The dry leaves of the oak, for example, contain about 5 per cent of saline and earthy matter, while those of the Scotch fir contain less than two per cent; so that, supposing the actual weight of leaves which falls from each kind of tree to be equal, we should expect a greater depth of soil to be formed in the same time by the oak than by the Scotch fir. The leaves of the larch in the dry state contain from 5 to 6 per cent of saline matter, so that they may enrich the surface on which they fall in at least an equal degree with those of the oak. Much, however, depends upon the actual weight of leaves shed by each kind of tree, in regard to which we possess no precise information.

The improvement of the land, therefore, by the planting of trees, depends in part upon the quantity of *organic* food which the trees can extract from the air, and afterwards drop in the form of leaves upon the soil, and in part upon the kind and quantity of *inorganic* matter which the roots can bring up from beneath, and in like manner strew upon the surface. The quantity and quality of the latter will, in a great measure, determine the kind of grasses which will spring up, and the consequent value of the pasture in the feeding of stock.

The action of a tree, therefore, in improving the soil, is twofold:—

(1.) It causes vegetable matter to accumulate on the surface; and,

(2.) It brings up from beneath certain substances which are of vital importance to the growth of plants, but in which the upper soil may have been deficient.

In a previous chapter we have described the *black earth* of Central Russia, which presents probably the most remarkable example now existing of the fertilising effect of a long-continued growth of trees. The cotton soil of Central and Southern Hindostan owes its richness to a similar cause.

Improvement of Soils by Meadowing and Pasturing them.—On this subject, two facts seem to be pretty generally acknowledged.

First, That land laid down to artificial grasses for one, two, three, or more years, is in some degree rested or recruited, and is fitted for the better production of after-crops of corn. Letting it lie a year or two longer in grass, therefore, is one of the received modes of bringing back to a sound condition a soil that has been exhausted by injudicious cropping.

Second, That land thus laid down with artificial grasses diminishes in value again after two, three, or five years —more or less—and only by slow degrees acquires a thick sward of rich, nourishing, natural herbage. Hence the opinion that grass-land improves in quality the longer it is permitted to lie—the unwillingness to plough up old pasture—and the comparatively high rents which, in some parts of the country, old grass-land is known to yield.

Granting that grass-land does not *generally* increase in value, three important facts must be borne in mind before we attempt to assign the cause of this improvement, or the circumstances under which it is likely to take place for the longest time and to the greatest extent.

1. The value of the grass in any given spot may increase for an indefinite period, but it will never

improve beyond a certain extent — it will necessarily be limited, as all other crops are, by the quality of the land. Hence the mere laying down to grass will not make *all* land *good*, however long it may lie. The extensive commons, heaths, and wastes, which have been in grass from the most remote times, are evidence of this. They have, in most cases, yielded so poor a natural herbage as to have been considered unworthy of being enclosed as permanent pasture.

2. Some grass-lands will retain the good condition they thus slowly acquire for a very long period, and *without manuring*—in the same way, and upon nearly the same principle, that some rich corn-lands have yielded successive crops for 100 years without manure. The rich grass-lands of England, and especially of Ireland, many of which have been in pasture from time immemorial, without receiving any known return for all they have yielded, are illustrations of this fact.

3. But others, if grazed, cropped with sheep, or cut for hay, will gradually deteriorate, unless some proper supply of manure be given to them — which required supply must vary with the nature of the soil, with the kind of stock fed upon it, and with the kind of treatment to which it has been subjected.

How Grasses improve Soils. — In regard to the acknowledged benefit of laying down to grass, then, two points require consideration.

1. What form does it assume, and how is it effected? The improvement takes place by the gradual accumulation of a dark-brown soil rich in vegetable matter, which soil thickens or deepens in proportion to the time during which it is allowed to lie in grass. It is a law of nature, that this accumulation takes place more rapidly in the temperate than in tropical climates, and it would appear as if the consequent darkening of the soil were

intended, among other purposes, to enable it to absorb more of the sun's warmth, and thus more speedily to bring forward vegetation where the average temperature is low and the summers comparatively short.

If the soil be very light and sandy, the thickening of the vegetable matter is sooner arrested; if it be moderately heavy land, the improvement continues for a longer period; and some of the heaviest clays in England are known to bear the richest permanent pastures.

The soils formed on the surface of all our rich old pasture-lands, thus come to possess a remarkable degree of uniformity—both in physical character and in chemical composition. This uniformity they gradually *acquire*, even upon the stiff clays of the lias and Oxford clay, which originally, no doubt, have been left to natural pasture—as many clay-lands still are—from the difficulty and expense of submitting them to arable culture.

2. How do they acquire this new character, and why is it the work of so much time?

a. When the young grass throws up its leaves into the air, from which it derives so much of its nourishment, it throws down its roots into the soil in quest of food of another kind. The leaves may be mown or cropped by animals, and carried off the field; but the roots remain in the soil, and, as they die, gradually fill its upper part with vegetable matter. On an average, the *annual* production of roots on old grass-land is equal to one-third or one-fourth of the weight of hay carried off—though no doubt it varies much, both with the kind of grass and with the kind of soil. When wheat is cut down, the quantity of straw left in the field, in the form of stubble and roots, is sometimes greater than the quantity carried off in the sheaf. Upon a grass-field two or three tons of hay may be reaped from an acre, and therefore, from half a ton to a ton of dry roots is annually produced and left in the soil. If anything like this weight of roots dies every year, in land kept in pasture, we can readily understand how the vegetable matter in the soil should gradually accumulate. In arable land this accumulation is prevented by the constant turning up of the soil, by which the fibrous roots, being exposed to the free access of air and moisture, are made to undergo a more rapid decomposition. The increase in the percentage of nitrogen in a soil laid down to pasture is illustrated by the results of analyses by Lawes and Gilbert of Rothamsted soils:[1]—

	Age of Pasture.	Nitrogen in first 9 inches.
Arable land . .	...	.140
Barn-field pasture . .	8	.151
Apple-tree pasture . .	18	.174
Dr Gilbert's meadow .	30	.241

Thus it will be seen that in 20 years the nitrogen in the soil of a field under pasture may be practically doubled in amount. It has been calculated by Lawes and Gilbert that the surface-soil of a pasture may increase at the rate of 50 lb. per acre per annum. This only up to a certain time. No increase seems to take place when a pasture gains a certain age.

b. But the roots and leaves of the grasses contain earthy and saline matters also. Dry hay leaves from an eighth to a tenth part of its weight of ash when burned. Along with the dead vegetable matter of the soil, this inorganic matter also accumulates in the form of an exceedingly fine earthy powder; hence one cause of the universal fineness of the surface-mould of old grass-fields. The earthy portion of this inorganic matter consists chiefly of silica, lime, and magnesia, with scarcely a trace of alumina; so that, even on the stiffest

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[1] See Aikman's 'Manures and the Principles of Manuring,' p. 148.

clays, a surface-soil may be ultimately formed, in which the quantity of alumina—the substance of clay—is comparatively small.

c. There are still other agencies at work, by which the surface of stiff soils is made to undergo a change. As the roots of the grasses penetrate into the clay, they more or less open up a way into it for the rains. Now the rains in nearly all lands, when they have a passage downwards, have a tendency to carry the clay along with them. They do so, it has been observed, on sandy and peaty soils, and more quickly when these soils are laid down to grass. Hence the mechanical action of the rains—slowly in many localities, yet surely—has a tendency to lighten the surface-soil, by removing a portion of its clay. They constitute one of those natural agencies by which, as elsewhere explained, important differences are ultimately established, almost everywhere, between the surface crop-bearing soil and the subsoil on which it rests.

d. But further, the heats of summer and the frosts of winter aid this slow alteration. In the extremes of heat and of cold, the soil contracts more than the roots of the grasses do; and similar, though less visible, differences take place during the striking changes of temperature which are experienced in our climate in the different parts of almost every day. When the rain falls, also, on the parched field, or when a thaw comes on in winter, the earth expands, while the roots of the grasses remain nearly fixed; hence the soil rises up among the leaves, mixes with the vegetable matter, and thus assists in the slow accumulation of a rich vegetable mould.

The reader may have witnessed in winter how, on a field or by a wayside, the earth rises above the stones, and appears inclined to cover them; he may even have seen, in a deserted and undisturbed highway, the stones gradually sinking and disappearing altogether, when the repetition of this alternate contraction and expansion of the soil for a succession of winters has increased, in a great degree, the effects which follow from a single accession of frosty weather.

So it is in the fields. And if a person skilled in the soils of a given district can make a guess at the time when a given field was laid down to grass, by the depth at which the stones are found beneath the surface, it is partly because this loosening and expansion of the soil, while the stones remain fixed, tends to throw the latter down by an almost imperceptible quantity every year that passes.

e. Such movements as these act in opening up the surface-soil, in mixing it with the decaying vegetable matter, and in allowing the slow action of the rains gradually to give its earthy portion a lighter character. But with these, among other causes, conspires also the action of living animals. Few persons have followed the plough without occasionally observing the vast quantities of earth-worms with which some fields seem to be filled. On a close-shaven lawn, many have noticed the frequent little heaps of earth which these worms during the night have thrown out upon the grass. These and other minute animals are continually at work, especially beneath an undisturbed and grassy sward—and they nightly bring up from a considerable depth, and discharge on the surface, their burden of fine fertilising loamy earth. Each of these burdens is an actual gain to the rich surface-soil; and who can doubt that, in the lapse of years, the unseen and unappreciated labours of these insect tribes must both materially improve its quality and increase its depth?

f. In most localities, also, the winds may be mentioned among the natural agencies by which the soil on grass-lands is slowly improved. They seldom sweep over any considerable extent of arable land without bearing with them particles of dust and sand, which they drop in sheltered places, or leave behind them when sifted by the blades of grass, or by the leaves of an extensive forest. In hot summers, in dry springs, and even in winter, when the snow is drifting, the ploughed lands and dusty roads are more or less bared of their lighter particles of soil, which are strewed by the winds as a natural top-dressing over the neighbouring untilled fields.

In some countries the agency of the winds is more conspicuous than among ourselves. Thus, on the banks of the Kuruman and Orange rivers in South Africa, the winds blow during the spring months—August to November in that climate—from the Kulagare desert, bearing with them light particles of dust, which make the air seem as if dense with smoke, and which are so exquisitely fine as to penetrate through seams and cracks which are almost impervious to water.[1] Forest-trees and waving grass sift this thick air, and enrich the soils on which they grow by the earthy particles they arrest.

In countries where active volcanoes exist, these also exercise an appreciable influence of a similar kind upon the surface-soil. Showers of dust and ashes are sprinkled widely over the land by which its natural agricultural capabilities are materially interfered with. Vesuvius is said, in this way, to scatter its ashes over the adjoining country, so as, on an average, to destroy the crop every eighth year. But to this circumstance the remarkable general richness of the soil is ascribed—(Mohl). So does good arise from seeming evil.

There are natural causes, then, which we *know* to be at work, that are sufficient to account for nearly all the

[1] Moffat's 'Missionary Labours,' p. 333.

facts that have been observed in regard to the effect of laying land down to grass. Stiff clays will gradually become lighter on the surface, and, if the subsoil be rich in all the kinds of inorganic food which the grasses require, will go on improving for an indefinite period without the aid of manure. Let them, however, be deficient in, or let them gradually become exhausted of, any one kind of this food, and the grass-lands will either gradually deteriorate after they have reached a certain degree of excellence, or they must be supplied with that one ingredient, that one kind of manure, of which they stand in need. It is doubtful if any pasture-lands are so naturally rich as to bear to be cropped for centuries without the addition of manure, and at the same time without deterioration. Where they appear to be so, they probably receive from springs, from sea-drift, or from some other unobserved source, those perennial supplies which reason pronounces to be indispensable.

On soils that are light, again—which naturally contain little clay—the grasses will thrive more rapidly, and a thick sward will be sooner formed, but the tendency of the rains to wash out the clay may prevent them from ever attaining that luxuriance which is observed upon the old pastures of the clay lands.

On undrained heaths and commons, and generally on any soil which is deficient in some fertilising element, neither abundant herbage, nor good crops of any other kind, can be expected to flourish. Laying such lands down, or permitting them to remain, in grass, may prepare them for by-and-by yielding one or two average crops of corn, but cannot be expected *alone* to convert them into valuable pasture.

Finally, plough up the old pastures on the surface of which this light and most favourable soil has been long accumulating, and the heavy soil from beneath will be again mixed up with it, the vegetable matter will disappear rapidly by exposure to the air during the frequent ploughings; and, if again laid down to grass, the slow changes of many years must again be begun through the agency of the same natural causes, before it become capable a second time of bearing the same rich herbage it was known to nourish while it lay undisturbed.

Many have supposed that, by sowing down with the *natural* grasses, a thick and permanent sward may at once be obtained; and on light loamy land, rich in vegetable matters, this method may, to a certain extent, succeed; but on heavy land in which stiff clay abounds and vegetable matter is defective, disappointment will often follow the sowing of the most carefully selected seeds. By the agency, among other causes, of those above adverted to, *the soil gradually changes*, so that it is unfit, when first laid down, to bear those grasses which, ten or twenty years afterwards, will spontaneously and luxuriantly grow upon it. Nature is not regulated by one principle in the growth of corn and by another in growing grass; the apparent difference in her procedure arises from real differences in our practice.

CHAPTER XVII.

LIME: ITS USES IN AGRICULTURE.

The use of lime is of the greatest importance in practical agriculture. It has been employed in the forms of marl, shells, shell-sand, coral, chalk, limestone, limestone gravel, quicklime, &c., in almost every country, and from the most remote period. Many of the older views respecting the nature of the action of lime are exploded. We now see that its action is in most cases more or less indirect. It is probably seldom that a soil lacks the necessary amount of lime required as a plant food for the crops that grow upon it. Its chief action is in ameliorating the mechanical properties of the soil, and in setting free other plant foods such as potash, &c. The fact that it is very destructive on the organic matters of the soil is another consideration which should render us very cautious in applying it indiscriminately. Instead of applying lime, in many cases, it is found better policy to apply artificial manures. Great though the benefits of lime undoubtedly are, it will be best to apply it chiefly to soils whose mechanical conditions are such as will greatly be improved by it, to new land where it is simply indispensable, and to soils extremely rich in peat and organic matter. Its use, on the other hand, to land in a high state of cultivation, except in very small quantities, is not to be recommended as a rule.

Composition of Limestones and Chalks. — When diluted muriatic acid, or strong vinegar, is poured upon pieces of limestone, chalk, common soda, or common pearl-ash, effervescence takes place, and carbon dioxide gas is given off. If a current of this gas be made to pass through lime-water (see fig. 23), the liquid becomes milky, and a white powder falls, which is pure *calcium carbonate.* It consists of—

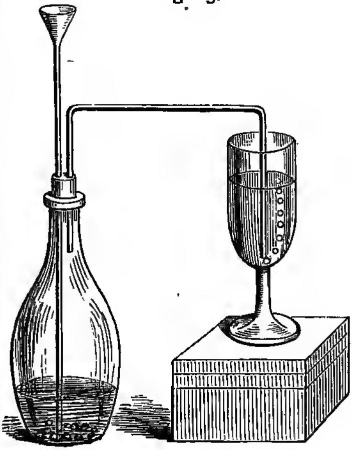
	Per cent.
Carbon dioxide (CO_2)	44
Lime (CaO)	56
	100

Limestone, marble, and chalk consist, for the most part, of calcium carbonate. In soft chalk, the particles are held more loosely together; in the hard chalks and in limestones, the minute grains have been pressed or otherwise brought more closely together, so as to form a more solid and compact mass.

In regard to limestones and chalks, there are several circumstances which it is of importance for the practical man to know. For example—

a. That they are not composed entirely of mineral or inorganic particles, such as are formed by the passage of a current of carbonic acid through the lime-water. They consist in great part, sometimes almost entirely, of minute microscopic shells, of the fragments of shells of larger size, or of solidified masses of corals, which formed coral-reefs in ancient seas which once covered the surface where the limestones are now met with. The blue mountain-limestones contain many of these coral-reefs, while in our chalk-rocks vast quantities of microscopic shells and fragments of shells appear.

Fig. 23.



b. Being thus formed at the bottom of masses of moving water, the chalks and limestones are seldom free from a sensible admixture of sand and earthy matter. Hence, when they are treated with diluted acid, though the greater part dissolves and disappears, yet a variable proportion of earthy matter always remains behind in an insoluble state. This earthy matter is sometimes less than half a per cent of the whole weight, though sometimes it amounts to as much as 30 or 40 per cent.

c. All animals hitherto examined contain in certain parts of their bodies traces more or less distinct of phosphoric acid, generally in combination with lime, forming *calcium phosphate.* This calcium phosphate, their remains, when dead, retain in whole or in part. It thus happens that limestones very frequently contain phosphoric acid, and that the proportion of it usually increases with that of the visible remains of animals, shells, corals, &c., which occur in it. In the magnesian limestones of the county of Durham, the proportion of calcium phosphate is found to be as small as 0.07 to 0.15 per cent; while in a limestone from Lanarkshire (Carluke), it amounted to 1¼ per cent; or 100 lb. of the burned lime contained as much as 2⅓ lb. of calcium phosphate—(Johnston).

d. The parts of animals also contain sulphur, and this has given rise to the presence of sulphuric acid in chalks and limestones. This acid exists in them in combination with lime—in the state of gypsum. The proportion of this gypsum hitherto found in native chalks and limestones is small, varying from one-third to four-fifths of a per cent.

e. Magnesium carbonate, the common magnesia of the shops, is also present, almost invariably, in all our limestone and chalk rocks. In the purest it forms 1 or 2 per cent, in the most impure from 40 to 50 per cent, of the whole weight. The rocks called *dolomites*, or magnesian limestones, are characterised by the presence of a large proportion of magnesium carbonate. In the Old Red Sandstone formation also, beds of limestone occur which are rich in magnesia. Such limestones are usually considered less valuable for agricultural purposes.

They can be applied less freely and abundantly to the land, and possess what practical men call a burning or scorching quality. They are, however, preferred to purer limes in some districts, as in the highlands of Galloway, for application to hill-pastures.

ANALYSES OF LIMESTONES FOR PENRITH FARMER'S CLUB, BY PROFESSOR ANDERSON, GLASGOW.

(4 out of 10 specimens.)

Quarry.	Calcium carbonate.	Magnesium carbonate.	Iron oxide and alumina.	Insoluble matter.
Lowther village .	84.50	0.88	0.82	13.80
Alston Moor . .	97.31	1.43	0.18	1.08
Ravenstonedale .	95.20	1.67	0.56	2.57
Brampton . .	94.80	2.36	0.81	2.03

No phosphate or sulphate of calcium could be found.

Composition of Corals, Shell-sands, and Marls.—1. *Corals*, as they are gathered fresh from the sea on the Irish (Bantry Bay) and other coasts, contain, besides calcium carbonate, a small percentage of calcium phosphate, and sometimes not less than 14 per cent of animal matter. This animal matter adds considerably to the fertilising value of coral-sand, when laid upon the land in a recent state, or when made into compost.

2. *Shell-sand* consists of the fragments of broken shells of various sizes, mixed with a variable proportion of sea-sand. It contains less animal matter than the recent corals, and its value is diminished by the admixture of sand, which varies from 20 to 70 per cent of the whole weight. On the shores of many of the Western Islands, shell-sand is found in large quantities, and is extensively and beneficially applied, especially to the hillside pastures and to peaty soils.

3. *Marls* consist of calcium carbonate—generally the fragments of shells—mixed with sand, clay, or peat, in various proportions. They contain from 5 to as much as 80 or 90 per cent of calcium carbonate, and are con-

sidered more or less rich and valuable for agricultural purposes as the proportion of lime increases. They are formed, for the most part, from accumulations of shells at the bottom of fresh-water lakes which have gradually been filled up by clay or sand, or by the growth of peat.

The Burning and Slaking of Lime.—1. *Burning.*—Limestones, when of a pure variety, consist almost entirely of calcium carbonate, which, as we have seen, contains 56 per cent of lime, or 11¼ cwt. to the ton.

When this limestone is put into a kiln, with as much coal as, when set on fire, will raise it to a sufficiently high temperature, the carbonic acid is driven off in the form of gas, leaving the pure lime behind.

In this state it is known as burnt lime, lime-shells, caustic lime, and quicklime, and possesses properties very different from those of the unburnt limestone. It has a hot, alkaline flavour, absorbs water with great rapidity, falls to powder, or slakes, and finally dissolves in 760 times its weight of cold water. This solution is known by the name of lime-water.

2. *Slaking.*—Its tendency to combine chemically with water is shown in the process of slaking. Almost every one is familiar with the fact that, when water is poured upon quicklime, it heats, emits steam, swells, cracks, and at last falls to a fine, usually white, powder, which is two or three times as bulky as the lime in its unslaked state. When thus fully slaked and cool, the fine powder consists of—

Lime	76 per cent (nearly).
Water	24 "
	100

Or 20 cwt. of pure burnt lime absorb and retain in the solid state 6⅓ cwt. of water, forming 26⅓ cwt. of slaked lime, called calcium *hydrate* by chemists.

When quicklime is left exposed to the air, even in dry weather, it gradually absorbs moisture from the atmosphere, and falls to powder without the artificial addition of water. In this case, however, it does not become sensibly hot, as it does when it is slaked rapidly by immersion, or by pouring water upon it. Some chemists state that this powder contains both hydrate and carbonate of calcium.

Effects of exposing Lime to the Air.—When lime from the kiln is slaked by means of water, it still retains its quick or caustic quality. But if, after it has fallen to powder, it be left uncovered in the open air, it gradually absorbs carbonic acid from the atmosphere, gives off its water, and becomes reconverted into dry calcic carbonate.

When lime is allowed to slake spontaneously in the air, it first absorbs water, and slakes and falls to powder, and then absorbs carbonic acid and is changed into carbonate.

But as soon as a portion of the lime slakes, it begins to absorb carbonic acid, probably long before the whole is slaked. Thus the two processes go on together; so that, in lime left to slake spontaneously, as it often is on our fields and headlands, the powder into which it falls consists in part of caustic hydrate, and in part of mild calcium carbonate. Its composition is nearly as follows :—

			Per cent.
Calcium carbonate			57.4
Calcium hydrate	lime	32.4	42.6
	water	10.2	
			100.00

When it reaches this stage or composition, the remainder of the hydrate absorbs carbonic acid much more slowly, so that, when spread upon or mixed with the soil, it takes a much longer time to convert it into carbonate. At last, however, after a longer or shorter period of time, the whole of the lime becomes saturated with carbonic acid, and is brought back to the same state of mild *un*-caustic carbonate in which it existed in the native chalk or limestone before it was put into the kiln.

Advantages of Burning Lime.—If the lime return to the same chemical state of carbonate in which it existed in the state of chalk or limestone, what is the benefit of burning it?

The benefits are partly mechanical and partly chemical.

a. We have seen that, on slaking, the burnt lime falls to an exceedingly fine bulky powder. When it afterwards becomes converted into carbonate, it still retains this exceedingly minute state of division; and thus, whether as caustic hydrate or as a mild carbonate, can be spread over a large surface, and be intimately mixed with the soil. No available mechanical means could be economically employed to reduce our limestones, or even our softer chalks, to a powder of equal fineness.

b. By burning, the lime is brought into a caustic state, which it retains, as we have seen, for a longer or shorter period, till it again absorbs carbonic acid from the air or from the soil. In this caustic state, its action upon the soil and upon organic matter is more energetic than in the state of mild lime; and thus it is fitted to produce effects which mere powdered limestone or chalk could not bring about at all, or to produce them more effectually, and in a shorter period of time.

c. Limestones often contain sulphur in combination with iron (iron pyrites). The coal or peat, with which it is burnt, also contains sulphur. During the burning, a portion of this sulphur (oxidised) unites with the lime to form gypsum, by this means adding to the proportion of this substance, which naturally exists in the limestone.

d. Earthy and silicious matters are sometimes present in considerable quantity in our limestone rocks. When burnt in the kiln, the silica of this earthy matter unites with lime to form *calcium silicate.*

Thus the benefits of burning are, as we have seen, partly mechanical and partly chemical. They are mechanical, inasmuch as, by slaking, the burnt lime can be reduced to a much finer and more bulky powder than the limestone could be by any mechanical means; and they are chemical, inasmuch as, by burning, the lime is brought into a more active and caustic state.

Quantity of Lime applied per Acre.—The quantity of quicklime laid on at a single dressing, and the frequency with which it may be repeated, depend upon the kind of land, upon the depth of the soil, upon the quantity and kind of vegetable matter which the soil contains, and upon the species of culture to which it is subjected. If the land be wet, or badly drained, a larger application is necessary to produce the same effect, and it must be more frequently repeated. But when the soil is thin, a smaller addition will thoroughly impregnate the whole, than where the plough usually descends to the depth of 8 or 10 inches. On old pasture-lands, where the tender grasses live in 2 or 3 inches of soil only, a feeble dressing, more frequently repeated, appears to be the more reasonable practice; though in reclaiming and in laying down land to grass, a heavy first liming is often indispensable. In some parts of Scotland lime is applied only every nineteen years; in other parts more frequently every twelve, eight, six, or five years. The amount of application in these cases varies from 200 bushels to 40 bushels per acre, giving an average of from 8 to 10 bushels per acre per annum.

In arable culture, larger and less frequent doses are admissible, both because the soil through which the roots penetrate must necessarily be deeper, and because the tendency to sink beyond the reach of the roots is generally counteracted by the frequent turning up of the earth by the plough. Where vegetable matter abounds, much lime may be usefully added; and on stiff clay lands, after draining, its good effects are very remarkable. On light land, chiefly because there is neither moisture nor vegetable matter present in sufficient quantity, very large applications of lime are not so usual, and it is generally preferable to add it to such land in the state of compost only.

The largest doses, however, which are applied in practice, alter in a very immaterial degree the chemical composition of the soil. The best soils generally contain a natural proportion of lime, not fixed in quantity, yet scarcely ever wholly wanting. But an ordinary liming, when well mixed up with a deep soil, will rarely amount to *one per cent* of its entire weight. It requires about 400 bushels (12 to 15 tons) of burnt lime per acre to add one per cent of lime to a soil of 12 inches in depth. If only mixed to a depth of 6 inches, this quantity would add about two per cent to the soil.

Though the form in which lime is applied, the dose laid on, and the interval between the doses, varies, yet in Great Britain, at least in those places where lime can be obtained at a reasonable rate, the quantity applied amounts, on an average, to from 7 to 10 bushels a-year.

Improvements produced by Lime.—The most remarkable visible alterations produced by lime are,—

upon *pastures*, a greater fineness, sweetness, closeness, and nutritive character of the grasses—on *arable lands*, the improvement in the texture and mellowness of stiff clays, the more productive crops, their better quality and the earlier period at which they ripen, compared with those grown upon soils to which no lime has ever been added. It is said to destroy sorrel.

This influence of lime is well seen when limed is compared with unlimed land, or when soils which are naturally rich in lime are compared with such as contain but little. Barley grown on the former is of better malting quality. The turnips of well-limed land are more feeding for both cattle and sheep. And the hill-pastures on limestone soils, like those of Derbyshire, continue longer green in autumn, and yield a greater yearly return of milk and cheese, than the soils which are produced from sandstone rocks.

Repeated Applications of Lime.—The superior condition produced in the soil by liming gradually diminishes year by year, in land artificially limed, till it returns again nearly to its original condition. On analysing the soil when it has reached this state, the lime which had been added is found to be in a great measure gone. In this condition the land must either be limed again, or must be left to produce sickly and unremunerative crops.

This removal of the lime arises from several causes.

1. *The lime naturally sinks*,—more slowly perhaps in arable than in pasture or meadow land, because the plough is continually bringing it to the surface again. But even in arable land, it gets at last beyond the reach of the plough, so that either a new dose must be added to the upper soil, or a deeper ploughing must bring it again to the surface.

2. *The crops carry away a portion of lime from the soil.*

—Thus the following crops, including grain and straw, or tops and bulbs, carry off respectively—

		Of lime.
25 bushels	wheat, about	13 lb.
40 "	barley	17 "
50 "	oats	22 "
20 tons	of turnips, about	118 "
8 "	potatoes	40 "
2 "	red clover	77 "
2 "	rye-grass	30 "

The above quantities are not constant, and much of the lime is no doubt returned to the land in the straw, the tops, and the manure; yet still the land cannot fail to suffer a certain annual loss of lime from this cause.

3. *The rains wash out lime from the land.*—The rain-water that descends upon the land holds in solution carbonic acid which it has absorbed from the air. But water charged with carbonic acid is capable of dissolving carbonate of calcium; and thus year after year the rains, as they sink to the drains, or run over the surface, slowly remove a portion of the lime which the soil contains. Acid substances are also formed naturally by the decay of vegetable matter in the land, by which another portion of the lime is rendered easily soluble in water, and therefore readily removable by every shower that falls. It is a necessary consequence of this action of the rains, that lime must be added more frequently, or in larger doses, where much rain falls than where the climate is comparatively dry.

Circumstances which modify the Effects of Lime.—There are four circumstances of great practical importance in regard to the action of lime which cannot be too carefully borne in mind. These are :—

1. That lime has not such a marked effect upon soils in which organic—that is, animal or vegetable—matter is greatly deficient. To this, however, an exception

must be made, and this with regard to heavy, clayey soils, on which the mechanical effect of lime is very striking.

2. That its apparent effect is inconsiderable during the first year after its application, compared with that which it produces in the second and third years.

3. That its effect is most sensible when it is kept near the surface of the soil, and gradually becomes less as it sinks towards the subsoil. And,

4. That under the influence of lime the organic matter of the soil disappears more rapidly than it otherwise would do, and that, as this organic matter becomes less in quantity, fresh additions of lime produce a less sensible effect.

Chemical Effects of Lime upon the Soil.—The chemical effects of lime upon the soil in the caustic and mild states are chiefly the following :—

a. When laid upon the land in the *caustic* state, the first action of lime is to combine immediately with every portion of free acid matter it may contain, and thus to sweeten the soil. Some of the compounds it thus forms being soluble in water, enter into the roots and feed the plant, or are washed out by the springs and rains ; while other compounds which are insoluble remain more permanently in the soil.

b. Another portion decomposes certain saline compounds of iron, manganese, and alumina, which naturally form themselves in the soil, and thus renders them unhurtful to vegetation. A similar action is exerted upon some of the compounds of potash, soda, and ammonia—the double silicates—by which these substances are set at liberty, and placed within the reach of the plant.

c. Its presence in the caustic state further disposes the organic matter of the soil to undergo *more rapid* decomposition—it being observed that, where lime is present in readiness to combine with the substances produced during the decay of organic matter, this decay, if other circumstances be favourable, will proceed with much greater rapidity. The reader will not fail to recollect that, during the decomposition of organic substances in the soil, many compounds are formed which are of importance in promoting vegetation.

d. It has already been pointed out that much of the nitrogen which naturally exists in the decaying vegetable matter of the soil is in a state in which it is very sparingly soluble, and therefore becomes directly available to plants with extreme slowness. The application of lime, especially caustic lime, renders the nitrogen available to the plant by promoting its conversion into ammonia and nitric acid.

e. Further, quicklime has the advantage of being soluble to a considerable extent in cold water, forming lime-water. Thus the complete diffusion of lime through the soil is aided by the power of water to carry it in solution in every direction.

Chemical Effects of Mild Lime applied to the Soil.—When it has absorbed carbonic acid, and become reconverted into carbonate, the original caustic lime has no *chemical* virtue over chalk or crushed limestone, rich shell-sand, or marl. It has, however, the important *mechanical* advantage of being in the form of a far finer powder than any to which we can reduce the limestone by art—in consequence of which it can be more uniformly diffused through the soil, and placed within the reach of every root, and of almost every particle of vegetable matter that is undergoing decay. We shall mention only three of the important purposes which, in this state of *carbonate*, lime serves upon the land.

a. It directly affords food to the plant in such soils as are deficient in it. It serves also to convey other food to the roots in a state in which it can be made available to vegetable growth.

b. It neutralises (removes the *sourness* of) all acid substances as they are formed in the soil, and thus keeps the land in a condition to nourish the tenderest plants. This is one of the important agencies of shell-sand, when laid on undrained grass or boggy lands; and this effect it produces, in common with wood-ashes and many similar substances. Carbonate of lime keeps clay coagulated, and renders soil more friable. It also increases the absorbent power of clays.

c. During the decay of organic matter in the soil, it aids and promotes the production of nitric acid by the process of nitrification. We have already referred to the important *rôle* performed by lime in the soil in connection with this process, in furnishing a salifiable base for the nitric acid. It is in the form of calcium nitrate that nitrogen probably is chiefly absorbed by the plants' roots.

Over-liming and its Remedy.—It is known that the frequent addition of lime, even to comparatively stiff soils long kept in arable culture, will at length so open them that the wheat crop becomes uncertain.

To lighter soils, again, and especially to such as are reclaimed from a state of heath, and contain much vegetable matter, the addition of a large dose of lime opens and loosens them, often to such a degree that they sound hollow, and sink under the foot. This effect is usually ascribed to an overdose of lime, and the land is commonly said to be *over-limed.* In this state it refuses to grow oats and clover, though turnips and barley thrive well upon it.

Analyses of over-limed soils have shown that it is not an excess of lime which produces the evil, but a too porous or loose condition of the soil, which admits of the following remedies:—

a. To eat off the turnips produced upon such soils with sheep; or,

b. To consolidate the loose and open soil by the use of a heavy roller, a clod-crusher or peg-roller, or other similar mechanical means; or,

c. To use the cultivator as much as possible instead of the plough, and thus to avoid the artificial loosening of the soil which is caused by frequent ploughing.

The way in which lime acts on the texture of a soil is a most interesting, but as yet little understood, subject. The chief difficulty in understanding it is owing to the complicated nature of this action.

One of the most important properties of lime is the power it has of lessening the puddling tendency of a clayey soil. This it does by coagulating the finely divided clayey particles—a property which has led to the use of lime as a precipitant of sewage.

Exhausting Effects of Lime.—The exhausting effects of lime have been remarked from the earliest times. It causes larger crops to grow for a certain number of years, after which the produce diminishes, till at length it becomes less than before lime was applied to it. Hence the origin of the proverb that "Lime enriches the fathers and impoverishes the sons."

Two interesting questions, therefore, suggest themselves in connection with this circumstance. How is this exhaustion produced? Is it a necessary consequence of the addition of lime, or can it be prevented?

It has already been stated that lime promotes those chemical changes of the organic part of the soil by which it is rendered more serviceable to the growth of plants. But in consequence of this action, the proportion of organic matter in the soil gradually diminishes under the prolonged action of lime, and thus the soil becomes less rich in those substances of organic origin on which its fertility in various ways depends.

Again, lime acts also on the mineral matter of the soil, and prepares it for more abundantly feeding the plant.

Now, as the crops we reap carry off not only organic but mineral matter also from the soil, anything which prepares that mineral matter more abundantly for the use of the plant must cause also a more rapid diminution of those mineral substances on which, as well as upon its organic matter, the fruitfulness of the soil is dependent.

By this mode of action, therefore, arises the exhaustion which universal experience has ascribed to the use of lime.

But without reference to the chemical processes by which it is brought about, a common-sense view of the question sufficiently explains how the exhaustion arises.

It is conceded that the crops we grow rob the soil both of organic and inorganic matter. A double crop will take twice as much, a triple crop three times as much, and so on. And the more we take out in one year, the more rapidly will the land be exhausted. Now, if lime, by its mode of action, enables us in the same time to extract three or four times as much matter from the soil in the form of increased crops, it must so much the more rapidly exhaust the soil, in the same way as we should drain a well sooner by taking out fifty than by removing only five gallons a-day.

But we can restore to the soil what crops carry off. By farmyard manure, and by saline applications, we can return everything which lime enables us thus to extract, and we can thus preserve its fertility unimpaired. Manure, therefore, in proportion to the crops taken off, and lime, will cease to be exhausting. There is much wisdom in the rhyme—

> "Lime and lime *without manure*,
> Will make both land and farmer poor."

Application of Lime along with other Manures.—A word of caution must be added with regard to using lime along with other manures. Lime, especially caustic, ought never to be used along with a manure containing ammonia in any form. The reason of this is, that the ammonia when brought into contact with lime is at once set free and escapes into the air and is lost. The only forms in which lime may be safely mixed with ammonia salts is when it is in the form of phosphate or sulphate. The latter form—viz., gypsum—is an extremely valuable fixer of ammonia, and prevents its tendency to volatilise.

Summary of the ways in which Lime acts.—In conclusion, we may briefly sum up the different ways in which lime acts: "Its action is mechanical, chemical, and biological. It acts on the texture of the soil, rendering clay soils more friable, and exerting a certain binding effect on loose soils. It decomposes the minerals containing potash and other food constituents, and renders them available for the plant's needs. It further decomposes organic matter, and promotes the important process of nitrification. It increases the power of a soil to fix such valuable food constituents as ammonia and potash. It neutralises sourness, and prevents the formation of poisonous compounds in the soil. It increases the capillary condition of the soil, prevents fungoid diseases, and promotes the growth of the more nutritive herbage in pasture-land."[1]

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[1] See Aikman's 'Manures and the Principles of Manuring.'

CHAPTER XVIII.

IMPROVEMENT OF SOILS BY PARING AND BURNING THEIR SURFACE.

A mode of improvement more often formerly resorted to than now on poor lands, is the paring and burning of the surface. The effect of this treatment is easily understood. The matted sods consist of a mixture of much vegetable with a comparatively small quantity of earthy matter. When these are burnt, the ash only of the plants is left, intimately mixed with the calcined earth. To strew this mixture over the soil is much the same as to dress it with peat or wood ashes, the beneficial effects of which are almost universally recognised. And the favourable influence of the ash itself is chiefly due to the ready supply of inorganic food it yields to the seed, and to the effect which the potash and soda, &c., which it contains, exercise either in preparing organic food in the soil, or in assisting its assimilation in the interior of the plant.

Another part of this process is, that the roots of the weeds and poorer grasses are materially injured by the paring, and that the subsequent dressing of ashes is unfavourable to their further growth.

It is besides alleged, that poor old grass-land, when ploughed up, is sometimes so full of insects that the success of any corn or green crop put into it becomes very doubtful. When pared, these insects collect in the sod, and are destroyed by the subsequent burning.

Chemical Changes produced by Burning Clays.—When a soil is burnt, the organic portion of it is altogether, or nearly altogether, destroyed; the combustible (volatile) portion escapes into the atmosphere in the form of water, carbonic acid, &c.; whilst its earthy and saline constituents remain in the soil in the form of a powder more or less fine. The soil loses nearly all its nitrogen in this way, and hence burning must be regarded as only advisable in very exceptional cases. In fact this method of improving soil is very rarely had recourse to nowadays, as there are other more suitable and economical methods in use. Nevertheless it may be of advantage to describe the nature of the relations which take place in such treatment of soils. The saline and earthy substances derived from the combustion of the organic matter are, of course, identical with the mineral constituents of plants: being in a pulverulent condition, they are the more readily absorbed by the growing vegetables.

In all soils capable of nourishing even the most worthless weed, there must be potash. This substance exists in soils for the most part in combination with silica, and in such a form as to be insoluble in the solvents present in soils. That is, though there may be abundance of potash in the soil, yet it is mostly insoluble, and not immediately available for the nourishment of plants. By the action of frosts and by other agents, the rocky portions of the soil in which the potash is bound up become broken up and reduced to powder: during this operation potash is gradually set free, so to speak, and placed at the disposal of the plant. Burning the soil expedites its disintegration and liberates not only its potash, but some of its other constituents. In an experiment made by Dr Voelcker, he found that unburnt clay contained 0.269 per cent of soluble potash, whilst the same clay after burning contained 0.941 per cent of potash soluble in acidulated water. One most important change produced in soils by burning is therefore a great increase in the amount of soluble potash.

It would appear that it is lime which displaces potash from its combination with silica, when the potassium silicate of soils is highly heated. Burning, therefore, diminishes the amount of calcium carbonate in soils. In the first place, carbonic acid is expelled from the carbonate ($CaCO_3 = CaO \times CO_2$), and caustic lime thereby formed decomposes the silicate of potassium, producing free potash and calcium silicate. It may happen, too, that part of the calcium carbonate directly decomposes the silicate, forming, by double decomposition, calcium silicate and potassium carbonate, as suggested by Voelcker. Soda is not in general so abundant in soils as potash; but, when it is present, its soluble portion is increased by the operation of burning. Where much limestone is present in a soil, burning, by effecting its disintegration, renders any phosphates it may contain more available.

Mechanical Effects of Burning Soils.—Clays which require to be burnt are usually very stiff and tenacious. They are cultivated with difficulty and at considerable cost. When burnt these soils become loose, friable, and easily worked. Stiff soils are cold and wet. Air circulates slowly throughout their interior, and water stagnates in them. These defects are obviously remedied by burning. Stiff soils which for purely mechanical reasons are not adapted for the growth of green crops may be rendered so by burning. On the other hand, soils which consist nearly altogether of insoluble peaty matter, may be converted into good soil by the combustion of their organic ingredients.

Over-burning Soils.—When the soil is burnt at too high or too prolonged a temperature, it is not much improved by the operation. Voelcker found that the amount of soluble potash in clay was increased from 0.269 to 0.941 per cent by moderate burning, and only to 0.544 by a high and prolonged heat. Over-burnt clay, instead of being pulverulent, is in the form of hard lumps like pieces of brickbat. One ton of coal should suffice to burn 50 cubic yards of clay; but wood or peat (turf) are probably better kinds of fuels to use, as they do not produce by their combustion so high a temperature as coal does.

Soils fit for Burning.—Stiff, intractable clays are those which alone (with the exception of peats) are suitable for burning. If they do not contain a sensible amount of lime, the chemical changes necessary to an increase of their fertilising power cannot take place. The deficiency of lime must therefore be made up. Lime is often added to burnt clay, but it is better to mix it with the soil before it is burnt. When a soil is properly burnt, it is not necessary to repeat the operation.

Fertility of Burnt Clays.—There is abundant evidence as to the fertility of burnt clay. Mr C. Randell, in the 'Journal of the Royal Agricultural Society of England,' vol. xxiv. (1863), states, that twenty-two years' experience of the effects of burning land have convinced him of the great benefits derivable from that operation. He refers to several fields which had been burnt twenty years previously, and in which the improvement thereby effected had continued undiminished in the slightest degree. Mr Pusey found a dressing of burnt Oxford clay to increase his wheat crop from 37¾ to 45½ bushels per imperial acre. And Mr Danger, who farms on the New Red Sandstone, near Bridgewater, says, that a soil which he found "quite sterile, has, by the application of burnt clay, become totally changed."[1]

It is equally true, however, that burnt clay has often failed to do any good—that the practice of burning clay, which is common in some districts, is for this reason never adopted in others—and that clay from the same

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[1] 'Journal of Royal Agricultural Society,' vi. 477, and xii. 509.

locality may or may not do good according to the method of burning. All this is easily explained when the true cause of the chemical action of burnt clay is understood.

50 to 100 tons of burnt clay to an acre was not an unusual application. Now, at 36 lb. to the ton, the largest dose would yield to water not less than 3600[1] lb. of soluble mineral matter; while the whole quantity of such matter carried off in a four-years' rotation, from our best farms, is only 1300 lb. It is not surprising, therefore, knowing as we do how applications of saline matter increase the crops, that so great and ready a supply of such matter in the burnt clay should produce a marked effect upon the fertility of the land upon which it is spread.

But, further, all clays have not the same composition. Some contain more lime, others more magnesia, others more potash or soda, and others more phosphoric acid; while some, again, contain so little of any of these substances as to produce no sensible effect when burnt and laid upon the land. Thus the chemical composition of a clay determines whether or not it can be burnt and applied with advantage.

Advantage is taken of the porous quality of burnt clay by some English farmers—as, for example, by Mr Randell of Chadbury, near Evesham—to absorb and preserve the droppings of sheep. Under house-fed sheep, kept upon boards or otherwise, a layer of burnt clay is spread, upon which the droppings fall: from time to time fresh layers are added to the surface, till it becomes necessary to remove the whole. In this way, the odour of the dung never becomes excessive, and the clay is rendered so rich that 10 tons of it are found equal (it is stated), in the raising of turnips, to 4 cwt. of guano.

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[1] 'Experimental Agriculture,' 261.

CHAPTER XIX.

THE IMPROVEMENT OF THE LAND BY IRRIGATION.

Only a small quantity of land is irrigated in the United Kingdom; but this practice is more prevalent in many Continental States.

The irrigation of the land is, in general, only a more refined method of manuring it. The nature of the process itself, however, is different in different countries, as are also the kind and degree of effect it produces, and the theory by which these effects are to be explained.

In dry and arid climates, where rain rarely falls, the soil may contain all the elements of fertility, and require only water to call them into operation. In such cases —as in the irrigations practised so extensively in Eastern countries, and without which whole provinces in India and Southern America would lie waste—it is unnecessary to suppose any other virtue in irrigation than the mere supply of water it affords to the parched and cracking soil.

But in climates such as our own, there are several other beneficial purposes in reference to the soil, which irrigation may, and some of which at least it always does. serve—thus,

The occasional flow of *pure* water over the surface, as in our irrigated meadows, and its descent into the drains, where the drainage is perfect, washes out acid and other noxious substances naturally generated in the soil, and thus purifies and sweetens it. The beneficial effect of such washing will be readily understood in the case of peat-lands laid down in water-meadow, since, as every one knows, peaty soils abound in matters unfavourable to general vegetation. These substances are usually in part drawn off by drainage, and in part destroyed by lime and by exposure to the air, before boggy lands can be brought into profitable cultivation.

Nature of Drainage Waters.—But it seldom happens that perfectly *pure* water is employed for the purposes of irrigation. The waters of rivers, as they are diverted from their course for this purpose, are more or less loaded with mud and other fine particles of matter, which are either gradually filtered from them as they pass over and through the soil, or, in the case of floods, subside naturally when the waters come to rest. Or in less frequent cases, the drainings of towns and the water from common sewers, or from the little streams enriched by them, are turned with benefit upon the favoured fields. These are evidently cases of gradual and uniform manuring.

Even where the water employed is clear and apparently undisturbed by mud, it almost always contains ammonia, nitric acid, and other organic and saline substances grateful to the plant in its search for food, and which plants always contrive to extract, more or less copiously, as the water passes over their roots. The purest spring-waters and mountain-streams are never entirely free from impregnations of mineral and vegetable or animal matter. Every fresh access of water, therefore, affords the grass in reality another liquid manuring.

The kind of saline substances which spring-water or that of brooks contains depends upon the nature of the rocks or soils from which it issues or over which it runs. In countries where granite or mica-slate abounds, potash and soda, and even magnesia, may be expected in notable quantities; while in limestone districts the waters are generally charged with lime. The value of the mountain-streams for the purpose of irrigation in limestone districts is so well known, that some have been inclined to undervalue all the constituents of natural waters, and to ascribe little worth as irrigators to the clear waters of brooks and springs which are not rich in lime. This opinion, however, is not in accordance with the results of the analyses of waters which have been profitably employed for irrigation.

Flowing water also drinks in from the air, as it passes along, a portion of the oxygen and carbonic acid of which the atmosphere in part consists. These gaseous substances it brings in contact with the leaves at every moment, or it carries them down to the roots in a form in which they can be readily absorbed by the parts of the plant. It is not unlikely that, in consequence of this mode of action, even *absolutely* pure water would act beneficially if employed in irrigating the soil.

Further, the constant presence of water keeps all the parts of the plant in a moist state, allows the pores of the leaves and stems to remain open, retards the formation of hard woody fibre, and thus enables the growing vegetable, in the same space of time, to extract a larger supply of food, especially from the air. In other words, it promotes and enlarges its growth.

In the refreshment continually afforded to the plant by a plentiful supply of water—in the removal of noxious substances from the soil—in the frequent additions of enriching food, saline, organic, or gaseous, to the land—in the soft and porous state in which it retains the parts of the plant, the efficiency of irrigation seems almost entirely to consist.

It is known that waters which have passed over the surface of a field become sensibly less fertilising. This is easily explained by the reasonable supposition that the plants among which they have flowed have deprived them of a portion of their enriching matter.

Waters vary in their Fertilising Properties.—But in the same neighbourhood, it has been often observed that waters from natural springs which are perfectly alike in appearance, yet differ remarkably in their value for irrigation. Such is the case among the mountains of the Vosges, where irrigation is much attended to. The same quantity of water, from two neighbouring springs, for example, employed on two adjoining meadows of similar quality, gave of hay per acre—

	1st cutting.	2d cutting.	Total.
Good spring . .	58 cwt.	24 cwt.	82 cwt.
Bad spring . .	14 "	7½ "	21½ "

Or the good spring produced nearly four times as much hay as the bad one.

A chemical examination of the waters of the two springs satisfied the experimenters (Chevandier and Salvetat) that this difference was not due, either

a. To the quantity or kind of the gases which the two waters held in solution; nor

b. To the quantity or kind of the mineral matters, in which both were nearly equally rich; nor

c. To the quantity of organic matter, of which the bad water in reality contained the most; nor

d. To the absolute quantity of nitrogen contained in this organic matter—for the bad water actually spread the larger quantity over the soil; but

e. To the circumstance that the organic matter, though smaller in quantity, was richer in nitrogen. It contained 6 per cent of this constituent, while that of the poor water contained only 2 per cent.

This result is in entire harmony with all we have known on the subject of manures—of the necessity of nitrogen to the growth of plants—of the tendency of such as are rich in nitrogen especially to promote growth—and of the influence of organic matters, rich in nitrogen, in enabling plants to work up the mineral and other ingredients in a mixed manure or in the soil which may happen to be within their reach; or *vice versâ*, since it has been found that the green parts of water-plants cease to decompose carbonic acid when the water is deficient in the salts which natural waters contain.—(Moleschott.) Irrigation, however, is only suited for warm climates. In cold, damp climates, with heavy, clayey soils, its effects are far from favourable.

CHAPTER XX. 20

RETENTION OF SOLUBLE SALTS BY SOILS—THE COMPOSITION OF DRAINAGE WATER.

The substances which are most abundant in the ashes of plants form but a very small proportion of the weight of soils. Potassium salts and compounds of phosphoric acid make up by far the greater portion of the so-called mineral part, or ash, of vegetables; whilst those compounds sometimes do not constitute more than 1 per cent of the weight of the soil. We have seen that the water which percolates through the ground carries away into the drains, rivers, &c., a certain amount of the mineral and other constituents of the soil. Now, as the quantity of water which flows annually through the ground is enormous, and as the amount of that portion of the soil which the growing crops most stand in need of is comparatively very small, might we not naturally apprehend that sooner or later all the fertilising matter would be washed out of our fields? Such an exhaustion of useful soil constituents by means of drainage would indeed have occurred long ago, were it not that the soil possesses the power of retaining potash and other salts, even when large quantities of water are filtered through it. Were it not that the soil-particles have this power to retain certain useful fertilising constituents, the loss of soil fertility would go on at a very considerable rate. In the capacity soils have of retaining the different fertilising constituents, a considerable difference exists. Certain salts are not retained by the soil. Of these the most important are nitrates. Other salts are the chlorides and sulphates of calcium and sodium. Calcium carbonate is also largely removed from the soil by drainage waters. The loss of nitrates from heavily manured land in wet weather may amount to a considerable quantity; and this, it need scarcely be pointed out, is a matter of great importance to the farmer. Such a loss, however, is likely only to take place in wet weather. When the weather is dry, the evaporation going on from the surface-soil tends to bring the nitrates to the surface of the soil. Even the occurrence of intermittent showers would fail to cause much loss. The presence of a growing crop will also tend to minimise it, as a greater amount of evaporation goes on under such conditions. Loss of nitrates, therefore, is greatest in the case of bare fallow. Ammoniacal salts, too, which *outside* the soil are so readily soluble in water, are not permitted, so to speak, to be dissolved by liquids *within* the recesses of the soil. By the term *absorptive power of the soil*, we understand its capability of withdrawing certain substances from their solutions, and of retaining those substances when subjected to the influence of flowing water.

Thompson's and Way's Experiment.—The earliest experiments in reference to the absorptive power of soils were made in 1845 by Messrs Thompson and Spence. They proved that soils possessed the property of absorbing and retaining ammonia from a solution of its carbonate or sulphate, when filtered through them. In 1850, 1852, and 1855, Mr Way published papers in the Journal of the Royal Agricultural Society of England, on the power of soils to absorb and retain manure. The nature of Way's experiments, which are in the highest degree interesting and important, may be briefly described as follows: A number of solutions of various substances, such as common salt, sal-ammoniac, potassium nitrate, &c., were filtered through a layer of clay, 10 or more inches in depth. Each solution, after filtration, was carefully analysed, and with few exceptions was found to have lost all, or a portion, of the solid substance which it had contained previous to being filtered. It was found that carbonate and phosphate of ammonia, and "superphosphate of lime," were altogether removed from solution by the soil; whilst, on the other hand, the nitrates, sulphates, and chlorides of ammonium, potassium, sodium, &c., left only their bases in the soil, their solutions after filtration containing only sulphuric, nitric, or hydrochloric acid, according to the nature of the salt. Way found that, as a rule, it was the base, and not the acid of a salt, which soils had the power of absorbing from solution.

In Way's experiments the various solutions were not only filtered through layers of soil, but were also shaken up with weighed portions of the latter. The latter process is generally adopted by recent investigators into the absorptive power of soils.

All Soils have not equal Power in Absorbing Manure.—Every kind of soil possesses the power of absorbing bases from their solution, but in some, this faculty is developed in a higher degree than in others.

Porous arable soils act more powerfully than very stiff, adhesive clays. Peaty soils are tolerably absorbent. According to Voelcker (Journal of Royal Agricultural Society, vol. xxi., 1860) there is not very much difference between the absorptive powers of a sandy soil as compared with a calcareous or clay one. The general results of experiments show, however, that sands are not equal to loams as absorbents of manures.

A soil has not an unlimited capacity for absorbing manurial matters. If a solution of, say, ammonium phosphate be passed for some time through a weighed quantity of soil, it will, after a certain time, pass through unchanged. If, however, we filter one pint of solution of ammonium phosphate through a portion of soil, the ammonia and phosphoric acid retained by the latter will not even, except in very small part, be removed by filtering through the soil a pint of pure water. In other words, the soil has a greater power of removing ammonia, &c., from solution than water has of removing ammonia, &c., from the soil.

Certain Substances Absorbed in larger Quantities than others.—Some bases are taken up by the soil in larger quantities than others. According to Kullenberg, the order in which they stand in this respect is as follows: ammonia, potash, magnesia, lime, and soda. The well-known manure, nitrate of soda, is not retained by soils. It seems well established that phosphates and carbonates of bases are the salts absorbed in greatest quantities.

Theory of Absorptive Power of Soils.—At first Way believed that the fixation of bases in the soil was due to the action of lime; but subsequently he advanced the following theory: In soils there are double silicates (aluminium silicate combined with calcium silicate, &c.) If potash be brought into contact with this double silicate, it replaces the lime. Potassium sulphate, and double silicate of aluminium and calcium, produce calcium sulphate and double silicate of aluminium and potassium. Aluminium silicate appears to combine with most avidity with ammonium, and least so with sodium. Many chemists, whilst admitting that aluminium silicate really does absorb ammonia, contend that the hydrated ferric oxide ($Fe_2O_3,3H_2O$) usually present, and to a large extent, in the soil, also takes up ammonia, &c. It is further advanced that hydrated alumina ($Al_2O_3,3H_2O$) exists in soils, and that it acts as an absorbent; but it is very doubtful whether or not uncombined alumina exists in ordinary soils. Warington, Peters, and others, have with great show of reason claimed for ferric oxide (red oxide of iron) great absorptive powers. That it acts upon the manure termed "superphosphate" there is but little doubt. The soluble phosphate, when placed in the soil, is rendered insoluble by the action of lime, iron, and alumina; by which substances it is precipitated and converted into an insoluble condition. The theory of some chemists that the absorptive power of soils is purely a physical, and not also a chemical property, appears untenable; but no doubt the carbonaceous matters in peaty soils do absorb manure *apparently* much in the same way as charcoal takes up colouring matters from solutions filtered through it. The absorptive power of a soil, therefore, seems to be due to the presence of the hydrated silicates of aluminium, the hydrates of ferric oxide and alumina, and the humus.

A property possessed by soils which is of the highest importance, and which is associated with its absorptive power, is its capacity to absorb gases from the air, more especially ammonia. The amount of ammonia absorbed in this way from recent experiments by Schloesing seems to be very considerable.

Analyses of Drainage Waters.—The composition of drainage waters has been investigated by several chemists. The following analyses have been made by Zöller :—

COMPOSITION OF DRAINAGE WATER ACCORDING TO ZÖLLER.

A million parts of water contain	1.	2.	3.	4.	5.
Solid matters . .	472.32	254.64	292.64	305.20	291.50
Ash therein .	317.62	176.74	196.78	214.50	212.16
Potash . . .	6.50	2.37	2.03	5.46	3.82
Soda . .	7.11	5.60	7.43	23.74	6.02
Lime . . .	145.86	57.60	70.80	68.41	92.34
Magnesia . . .	20.52	8.80	0.32	2.93	5.12
Ferric oxide . .	1.32	6.35	8.26	5.76	4.30
Chlorine . . .	57.49	9.52	20.87	39.46	35.27
Phosphoric acid .	2.23	...	...	...	...
Sulphuric acid . .	17.47	27.13	27.82	29.30	33.49
Silica . . .	10.46	11.35	17.46	9.50	9.36

1. From manured lime soil with vegetation; 2. Rough clay soil with vegetation; 3. Rough clay soil without vegetation; 4. Manured clay soil without vegetation; 5. Manured clay soil with vegetation.

Way's Experiments on Drainage.—Mr Way has published, in the 17th volume of the Journal of the Royal Agricultural Society of England, the following analyses of drainage water :—

COMPOSITION OF DRAINAGE WATER.

	Grains of Mineral Matter per gallon.						
	1.	2.	3.	4.	5.	6.	7.
Potash	trace	trace	0.02	0.05	trace	0.22	trace
Soda	1.00	2.17	2.26	0.87	1.42	1.40	3.20
Lime	4.85	7.19	6.05	2.26	2.52	5.82	13.00
Magnesia	0.48	2.32	2.48	0.41	0.21	0.93	2.50
Oxide of Iron and Alumina	0.40	0.05	0.10	none	1.30	0.35	0.50
Silica	0.95	0.45	0.55	1.20	1.80	0.65	0.85
Chlorine	0.70	1.10	1.27	0.81	1.26	1.21	2.62
Sulphuric Acid . .	1.65	5.15	4.40	1.71	1.29	3.12	9.51
Phosphoric Acid . .	trace	0.12	trace	trace	0.08	0.06	0.12

Nos. 1 and 2 drainages were collected from fields which had been well manured, but which a few years previously had been in very bad condition. No. 3 was collected from land which shortly before had formed part of a common. It had been manured only for a couple of years. No. 4 drainage flowed from a dirty gravel lying upon *gault*. For some years past it had been manured and limed. No. 5 drainage was obtained from land somewhat resembling that last described. No. 6. was derived from a heavily manured loam, 3 to 8 feet deep, and resting upon gravel. No. 7 was procured from a field which had been drained about nine years previously, and which originally had formed part of a larch plantation.

The small quantities of potash and phosphoric acid, and the large proportions of lime and sulphuric acid, present in these drainage waters are remarkable features in their composition. Much of the sulphuric acid was probably obtained from superphosphate of lime, which it appears had been applied to all the soils. From this source also a portion of the lime was no doubt derived, and the rest from the soil or from lime which had been added to it.

Nitrogen in Drainage Waters.—Mr Way found the soluble organic matter to vary from 3.8 to 12 grains per gallon, the ammonia from 0.006 to 0.018 grain, and the nitric acid from 3.91 grains to 14.74 grains per gallon. The amount of nitrogen which passes out of the soil in the form of ammonia is insignificant, but perfectly oxidised nitrogen (nitric acid) goes off in large quantities in drainage. Frankland and Voelcker have analysed many specimens of drainage water from parts of Sir John Lawes' experimental farm. Some of these results are given in the following table:—

COMPOSITION OF DRAINAGE WATER FROM PLOTS DIFFERENTLY MANURED, BROADBALK FIELD, ROTHAMSTED.

The samples were collected at different periods of the year in 1866, 1867, 1868, 1872, and 1873.

Plots.		Nitrogen as Nitrates and Nitrites, per 100,000 parts of Drainage Water.					
		Dr Voelcker's Results.		Dr Frankland's Results.		Mean.	
		Experiments.		Experiments.		Experiments.	
2	14 tons farmyard manure, every year .	2	1.606	4	0.922	6	1.264
3-4	Without manure, every year . .	5	0.390	6	0.316	11	0.353
5	Mineral manure alone	5	0.506	6	0.349	11	0.428
6	" " and ammonia-salts (41 lb. nitrogen) . .	5	0.853	6	0.793	11	0.823
7	Mineral manure and ammonia-salts (82 lb. nitrogen) . .	5	1.400	6	1.477	11	1.439
8	Mineral manure and ammonia-salts (123 lb. nitrogen) . .	5	1.679	6	1.951	11	1.815
9	Mineral manure and nitrate soda (82 lb. nitrogen) . .	5	1.835	5	1.039	10	1.437

The following are some of the more recent of the Rothamsted results on the composition of drainage water:—

[TABLE.

AMOUNT OF DRAINAGE AND NITROGEN AS NITRATES IN DRAINAGE WATER FROM UNMANURED BARE SOIL, 20 AND 60 INCHES DEEP—AVERAGE OF THIRTEEN YEARS (1877-1890).

	Rain-fall.	Amount of Drainage.		Nitrogen as Nitrates.			
				Per million of water.		Per acre.	
		20-inch gauge.	60-inch gauge.	20-inch gauge.	60-inch gauge.	20-inch gauge.	60-inch gauge.
	Inches.	Inches.	Inches.			lb.	lb.
March . .	1.70	0.85	0.94	7.3	8.9	1.41	1.89
April . . .	2.25	0.72	0.79	8.3	9.0	1.35	1.61
May . . .	2.48	0.80	0.79	8.4	9.1	1.53	1.63
June . .	2.59	0.78	0.78	9.2	9.1	1.62	1.60
July . . .	2.85	0.68	0.62	13.5	11.8	2.08	1.66
August . .	2.69	0.84	0.76	15.1	13.3	2.87	2.28
September .	2.70	0.97	0.82	17.7	13.4	3.86	2.50
October .	3.12	1.86	1.68	13.8	11.9	5.83	4.53
November .	3.20	2.44	2.32	11.8	11.4	6.50	5.98
December . .	2.34	1.88	1.88	9.5	10.6	4.06	4.51
January .	2.13	1.79	1.93	7.4	8.9	2.99	3.88
February .	2.16	1.84	1.74	7.7	9.1	3.19	3.57
March-June .	9.02	3.15	3.30	8.3	9.0	5.91	6.73
July-September .	8.24	2.49	2.20	15.6	13.0	8.81	6.44
October-February	12.95	9.81	9.55	10.2	10.4	22.57	22.47
Whole year .	30.21	15.45	15.05	10.7	10.5	37.29	35.64

CHAPTER XXI.

THE EXHAUSTION OF SOILS.

Stock of Plant Food in Soils.—In a state of nature there is a process of enrichment going on in every soil The surface-soil becomes enriched by a steady accumulation of the elements of fertility. This is due to the fact that the plants growing on the soil collect, by means of their roots, fertilising matter from the deeper soil-layers. At the same time, a certain increase in the total nitrogen of the soil takes place, due to that coming from the atmosphere. This process of enrichment of a soil in nitrogen may go on for a long time. It would seem, however, that there comes a time when the loss by drainage becomes equal to the amount gained from the air, and the amount of nitrogen in the soil no longer increases. When, however, land is under arable cultivation, there is a constant loss of fertilising constituents due to that removed in crops. But the quantity of mineral matter which even the most exhaustive crop removes from the soil is extremely small when compared with the amount which the crop leaves untouched. If, however, crop after crop be taken from the soil, and if no manure be given in return for the matters abstracted therefrom, can such a system be carried on for an indefinite period? Baron Liebig was one of the first to point out that it could not, and that such a system must inevitably, in a state of nature, result in the exhaustion of the land. Indeed in many of his valuable works the great German chemist has drawn very gloomy pictures of the future condition of agriculture in most civilised countries. Large quantities of food substances are consumed in towns, and the effete matters which result therefrom, instead of being returned to the soil from which they were procured, are in the form of sewage discharged into the ocean, and lost to agriculture.

Lois Weedon Experiments.—The Rev. Mr Smith of Lois Weedon, on the other hand, insisted that the quantity of plant food in the soil is so enormous as to be practically inexhaustible. To prove this assertion, he grew in the same field, for nearly twenty years in succession, and without the use of any manure, excellent crops of wheat. So far back as 1733, Jethro Tull, the inventor of the English horse-drill sowing-machine and other valuable innovations, advocated the importance of the thorough cultivation of the soil, asserting that tillage was a substitute for manure.

There is no doubt but that in even an indifferent soil a great number of successive wheat crops can be grown without manure, and even with but a very moderate amount of culture. It must, however, be borne in mind that the amount of potash and phosphoric acid, the only mineral substances of real value removed from the soil by a wheat crop, does not exceed 50 pounds, or about one-fourth of the quantity which a turnip crop removes, if wholly consumed off the fields which produced it. In all soils, as we have already pointed out, a certain amount of the fertilising constituents is in a very much more available condition than the rest. The percentage of this available plant food, which really constitutes the true fertility of a soil, is very small. If mangels or turnips were grown year after year in the same field, without being manured, their roots would soon degenerate, and become small and worthless.

Rothamsted Experiments on Soil-exhaustion.—The most extensive and accurately conducted experiments in relation to soil-exhaustion are those which have been carried on since 1843 up to the present by Sir J. B. Lawes, Bart., and Sir J. H. Gilbert, F.R.S., at Rothamsted, Harpenden, Hertfordshire.[1] Among the oldest of these experiments are those on the continuous growth of wheat for a period of fifty years, on the same soil without any manure. The average yield during the first ten years was 15¾ bushels per acre, during the second ten years 16½, during the third 12¾, and during the fourth 10¼. Continuous experiments with barley have also

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[1] The jubilee of these well-known experiments has this year (1893) been celebrated.

been in course for a period of about forty years. During the first nineteen years the average yield was 25⅝ bushels, while during the second nineteen years it had fallen to 18. The oat crop seems to diminish very rapidly when unmanured.

During twenty years, the wheat removed about 4700 lb. of mineral matter from the soil, of which about 253 lb. consisted of phosphoric acid and 360 lb. of potash. The soil at Rothamsted is a heavy loam, of medium quality. In a lighter soil it is probable that the available plant food would have become earlier exhausted.

The results of the Rothamsted experiments show that it is possible to grow cereal crops year after year without the use of manure, but after a short time with a constantly decreasing produce. It might probably be found that a greater degree of cultivation, a more minute pulverisation of the soil, would in the case of the Rothamsted plots retard the decrease of the produce; but no amount of tillage could indefinitely postpone the exhaustion of the soil. No doubt it would require a very long time to produce this exhaustion. It has been estimated that in many soils the amounts of phosphoric acid and potash are sufficient for the requirements of hundreds of crops; but even if a particular soil contained 20 or 30 times as much phosphoric acid as a crop required, such a soil certainly would be found in practice almost infertile. It would be unproductive, because the plants grown in it would find it difficult to gather up their food from a comparatively scanty supply. Although the roots of plants ramify in a wonderful manner, they cannot be expected to come into contact with every particle of the soil. The great fact established by Messrs Lawes and Gilbert is, that whilst it is possible by a severe, and in practice unusual, course of cropping to reduce soils to comparative infertility, yet that the system of agriculture followed in these countries is not leading to that utter ruin predicted so eloquently by the great German philosopher, Liebig.

Exports and Imports of Fertilising Manures.—The quantities of nitrogen, phosphoric acid, and potash annually sent out of a farm in the produce thereof, depend to some extent upon the system of agriculture adopted. Let us, however, suppose with Dr Paul the case of a field under the following four-course rotation: 1st year, turnips (10 tons); 2d year, barley (35 bushels); 3d year, clover-hay (5000 lb.), or beans (1500); 4th, wheat (30 bushels). The turnips and hay being consumed by cattle, and the straw of the barley and wheat being retained on the farm, the exports would consist of the grain, and the meat produced from the turnips and clover-hay. These would contain about 36 lb. of nitrogen, 30 lb. of phosphoric acid, and 19 lb. of potash. At this rate each acre would annually lose 9 lb. of nitrogen, 7½ lb. of phosphoric acid, and 4⁴/₅ lb. of potash. Although these quantities are not large, yet in process of time they might have a serious effect upon the fertility of the land if not compensated for in some way. A portion of the nitrogen, &c., comes back to the land in the form of town manure; but the quantity obtained from this source is not large. The fish consumed in country districts also furnish a trifling quantity of nitrogen and ash constituents to the soil. Only a few pounds of combined nitrogen are obtained by each acre every year from rain, snow, and dew; and probably a larger amount is absorbed directly from the atmosphere.[1] The losses which the soil sustains by drainage waters carrying off its nitrogen are,

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[1] Recent experiments by Schloesing show that considerable quantities of nitrogen in the combined form, more especially as ammonia, may be absorbed from the air by soils.

however, about compensated by the gain of nitrogen from the air. The substantial equivalent for the loss which the soil sustains by exporting a portion of its produce is the fertilising matter which it gains from imported foods and manures. Immense quantities of food are imported into these countries, and although when they are consumed the effete matters into which they are converted are chiefly discharged into sewers and rivers, still a portion is deposited in British soils. An enormous amount of oilcakes and other feeding-stuffs is consumed on the farms of these countries, and as only a small portion of their weight becomes permanently reorganised into animal substances, their nitrogen, phosphoric acid, and potash, for the most part, go into the soil. The losses by exports are also in great part compensated by the imports of guano, nitrate of soda, phosphates, and potash salts from foreign countries. The following table shows the extent of the gains from all these sources:—

IMPORTS INTO UNITED KINGDOM IN 1879.

ARTICLES.	CWT.	CONTAINING PER CENT OF—			TOTAL QUANTITIES IMPORTED IN CWT.		
		Nitrogen.	Phosphoric Acid.	Potash.	Nitrogen.	Phosphoric Acid.	Potash.
Meat[1] . . .	8,087,894	2.0	1.2	0.2	161,758	97,055	16,176
Cheese . .	1,789,721	4.0	0.3	0.5	71,589	5,369	8,949
Eggs[2] .	855,701	2.15	0.3	0.1	18,398	2,567	856
Fish	1,160,140	2.75	0.4	0.1	31,904	4,640	1,160
Grain and flour . . .	123,326,083	1.75	0.8	0.5	2,158,206	986,609	616,630
Rice . . .	6,857,300	0.98	0.17	0.6	67,202	11,657	41,144
Potatoes . .	9,357,179	0.25	0.18	0.5	23,393	16,843	46,786
Flax and rape seeds .	9,393,098	3.4	1.1	0.9	319,365	103,324	84,538
Grass and clover seeds .	1,477,693	3.0	1.0	1.25	44,331	14,777	18,471
Oilcakes	4,343,680	4.5	1.5	1.2	195,466	65,155	52,124
Guano . . .	1,540,300	8.5	15.0	2.0	130,925	231,045	30,806
Artificial manures[3] . . .	10,000,000	1.0	15.0	0.2	100,000	1,500,000	20,000
					3,322,537	3,039,041	937,640

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[1] Including 247,768 oxen, bulls, cows, and calves (assumed to weigh on the average 600 lb.); 944,888 sheep and lambs (assumed to weigh on the average 100 lb.); 4,917,631 cwt. of hams and bacon; and 812,237 cwt. fresh and salted beef.

[2] 638,995,600 in number, each egg being estimated at 2 oz.

[3] Artificial manures are partly prepared from imported phosphates, partly from English coprolites dug out of the ground. They also include "*sulphate of ammonia*" from gas-works, "*nitrate of soda*" from Peru, and potash salts from Germany and from certain manufactures from sea-water and sea-weeds. They are included amongst the imports, because not one particle of them comes out of British soils under cultivation. The estimate of half a million tons per annum is under the actual quantity, and their percentages of nitrogen, &c., are certainly not overestimated.

EXPORTS FROM UNITED KINGDOM IN 1879.

ARTICLES.	CWT.	CONTAINING PER CENT OF—			TOTAL QUANTITIES IMPORTED IN CWT.		
		Nitrogen.	Phosphoric Acid.	Potash.	Nitrogen.	Phosphoric Acid.	Potash.
Cheese	14,231	4.0	0.3	0.5	569	43	71
Horses[1] and colts (5018)	35,126	3.0	1.8	0.3	1,054	632	105
Guano	364,180	8.5	15.0	2.0	30,955	54,627	7,284
Rice	3,288,323	0.98	0.17	0.6	32,226	5,590	19,730
Grain and flour	1,329,968	1.75	0.8	0.5	23,274	10,640	6,650
Flax and rape seed	426,990	3.4	1.1	0.9	14,518	4,697	3,843
					102,596	76,229	37,683
	Imports				3,322,537	3,039,041	937,640
	Exports				102,596	76,229	37,683
	Balance in favour of imports				3,219,941	2,962,812	899,957

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[1] Assumed to weigh 7 cwt. each

There were in 1879 77,513,585 acres in the United Kingdom, of which about 11½ millions of acres were under corn crops, 5 millions under green crops, and 7 millions under rotation grass and clover crops. If we assume that each acre lost annually 9 lb. of nitrogen, 7½ lb. of phosphoric acid, and 4⁴/₅ lb. of potash, then the total losses sustained by these 23½ millions of acres would be 211,500,000 lb. of nitrogen, 176,250,000 lb. of phosphoric acid, and 112,800,000 lb. of potash.

If, of the imported articles enumerated in the table, we assume that only the nitrogen, phosphoric acid, and potash of the agricultural seeds, oilcakes, guano,[1] and artificial manures, were received in 1879 by the 23½ millions of acres under cultivation, then their soils must have received 83,396,768 lb. of nitrogen, 207,856,844 lb. of phosphoric anhydride, and 21,796,044 lb. of potash.

Although these figures are mere approximations to the actual numbers, yet we may safely infer from them that the soils of the United Kingdom receive in the form of imported agricultural seeds, manures, and feeding stuffs, more phosphoric acid than they lose in the produce removed from them. On the other hand, they receive from these sources not much more than two-fifths of the nitrogen and one-fifth of the potash, which are carried off in produce. To what extent these deficits in nitrogen and potash are supplied by the use of nitrate of soda, soot, town-manure, and by the local consumption of imported foods other than those already referred to (including Indian corn, locust-beans, &c., for cattle), it is difficult to form even a conjecture. It would, however, seem evident, that whilst more nitrogen is removed from the soil than phosphoric acid, far more phosphoric acid is returned to the soil in the form of

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[1] Deducting the exports of guano.

manure than nitrogen. The present Editor[1] has recently (1890) estimated that the total amount of barley, wheat, and oats grown in Great Britain in 1889 contained over 120,000 tons of nitrogen. This amount of nitrogen would be contained in about half a million tons of sulphate of ammonia, or three-quarters of a million tons of nitrate of soda. The above calculation gives some idea of the vast quantities of this most important element which our cereal crops remove from the soil. Fortunately, however, recent investigations have conclusively proved that leguminous crops have the power of making use of the free nitrogen of the air, and thus doing much to make good this enormous source of loss. The particulars of this most important discovery will be given in a succeeding chapter.

Rotation of Crops.—The experiments of Lawes and Gilbert show that soils become exhausted of certain of their constituents sooner than of others. The substance which disappears soonest in the case of certain kinds of cropping is nitrogen; but there are other crops which deal gently with the nitrogen, and draw largely upon some of the mineral ingredients of the soil. During the growth of leguminous crops, nitrogen accumulates in the surface-soil.

If two crops of unlike kinds be sown together, their roots retain the inorganic substances of the soil in different proportions,—the one more potash and phosphoric acid perhaps; the other more lime, magnesia, or silica. They thus interfere less with each other than plants of the same kind do—which require the same kinds of food in nearly the same proportions.

Or the two kinds of crop grow with different degrees

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[1] See 'Nitrogen: Its Sources and Uses in Agriculture,' by C. M. Aikman. (A Lecture delivered to the British Manure Manufacturers' Association in 1890.)

of rapidity, or at different periods of the year: while the roots of the one are busy drawing in supplies of inorganic nourishment, chiefly from great depths, those of the other are only able to take up food from the surface-soil.

If each crop demands special substances, or these substances in quantities peculiar to itself, or in some peculiar state of combination, the chances that the soil will be able to supply them are greater the more distant the intervals at which the same crop is grown upon it. Other crops do not demand the same substances in the same proportions; and thus they may gradually accumulate in the soil till it becomes especially favourable to the particular one we wish to grow.

Suppose the soil to contain a certain average supply of all those inorganic substances which plants require, and that the same corn crop is grown upon it for a long series of years, this crop will carry off some of these substances in larger proportion than others, so that year by year the quantity of those which are thus chiefly carried off will become relatively less. Thus at length the soil, for want of these special substances, will become unable to bear a good crop of this kind at all, though it may still contain a large store of the inorganic substances which other plants do not specially exhaust. Suppose bean or turnip crops raised in like manner for a succession of years, they would exhaust the soil of a certain set of substances till it became unable to grow them profitably, though still rich perhaps in those things which cereals especially demand.

But grow these crops alternately, then the one crop will draw especially upon one class of substances, the other crop upon another; and thus a much larger produce of each will be reaped from the same soil, and for a much longer period of time. On this principle the benefit of a rotation of crops in an important degree depends. An important consideration is also the capacity of different crops for obtaining their food constituents. It is, therefore, not merely the amount of these food constituents which the different crops remove from the soil that has to be taken into account in considering the effect of the rotation of crops, but also the capacity which they possess for absorbing their food from the soil, and in this respect crops differ very markedly. Another important point in considering the rotation of crops is the nature of the crop-residue. This is the chief source of the humus matter in the soil. In this respect crops differ very considerably. Those leaving the least amount of residue are the root-crops; while those leaving most are clover and grass. Cereals leave a considerable amount of residue, but the quality of this in fertilising constituents is poorer than in the case of grass, which enriches the soil to a very considerable extent in nitrogen.

CHAPTER XXII.

THE GERMINATION OF SEEDS.

When a seed is committed to the earth, if the warmth and moisture are favourable, it begins to sprout. It pushes a shoot upwards, it thrusts a root downwards, but, until the leaf expands and the root has fairly entered the soil, the young plant derives no nourishment other than water, either from the earth or from the air. It lives on the starch, gluten, and mineral matter contained in the seed. The seed, therefore, acts as a storehouse of concentrated food to nourish the plant until it is able to draw its nutrition from external sources. But these substances, though capable of being separated from each other by means of water, as already described, are neither of them soluble in water. Hence they cannot, without undergoing a previous chemical change, be taken up into the sap and conveyed along the vessels of the young shoot they are destined to feed. But it is so arranged in nature that, when the seed first sprouts, there is produced at the base of the germ a small quantity of a white soluble substance called *diastase*. This substance exercises so powerful an effect upon the starch as almost immediately to render it soluble in the sap, which is thus enabled to take it up and convey it by degrees, just as it is wanted, to the shoot or to the root. The starch, when thus changed and rendered soluble, becomes converted into dextrin and maltose, which we have already described. In the oily seeds which contain no starch, the mucilage and the oil take the place of starch in nourishing the young sprout. The oil is first decomposed into glycerine and fatty acids (*Schützenberger*). These substances, according to Sachs, are then replaced by carbohydrates.

As the sap ascends it becomes sweet—the dextrin formed from the starch is further changed into sugar. When the shoot first becomes tipped with green, this sugar again is changed into cellulose, or woody fibre, of which the stem of perfect plants chiefly consists. By the time that the food contained in the seed is exhausted—often long before—the plant is able to live by its own exertions, at the expense of the air and the soil.

This change of the sugar of the sap into cellular or woody fibre is observable more or less in all plants. When they are shooting fastest the sugar is most abundant—not, however, in those parts which are actually shooting up, but in those which convey the sap to the growing parts. Thus the sugar of the ascending sap of the maple and the alder disappears in the leaf and in the extremities of the twig; and the sugar-cane *sweetens* only a certain distance above the ground, up to where the new growth is proceeding: and thus also the *young* beet and turnip abound most in sugar,—while in all these plants the sweet principle diminishes as the year's growth draws nearer to a close.

In the ripening of the ear, also, the sweet taste at first so perceptible in young grain gradually diminishes, and finally disappears. The sugar of the sap is here changed into the *starch* of the grain, which, as above described, is afterwards destined, when the grain begins to sprout, to be reconverted into sugar for the nourishment of the rising germ.

In the ripening of fruits a different series of changes presents itself. The fruit is at first tasteless, then becomes sour, and at last sweet. In this case, either the acid of the unripe is changed into the sugar of the ripened fruit, or a portion of the other constituents of the fruit is converted into sugar and disguises the acid.

Does Light affect Germination?—It is a popular notion that seeds require to be protected from the action of light if it be intended that they should germinate. In nature, however, we find the seeds simply scattered over the surface of the soil, and fully exposed to light. The experiments of Hoffmann and other investigators have, moreover, proved that various kinds of seeds (all that were experimented with) freely germinated in the light. On the other side, Hunt many years ago stated, as the result of his experiments, that luminous rays prevent the germination of seeds.

Influence of Heat on Seeds.—Temperature of soil has a most marked influence on the rate of the germination of seed. The temperature differs for different kinds of seed. Thus, for example, rye, vetches, and peas begin to germinate at a soil temperature of 1° to 2° C. (33.8° F. to 35.6° F.); wheat, barley, and oats at 4° to 4.5° C.; maize at 8° to 10° C.; and tobacco at 13° C. The following table illustrates the influence of the temperature of the soil on the rate of germination for different seeds:—

DAYS REQUIRED FOR GERMINATION OF SEEDS, WITH DIFFERENT TEMPERATURES OF THE SOIL.

KIND OF PLANT.	4.38° C.	10.25° C.	15.75° C.	19.0° C.
	Days.	Days.	Days.	Days.
Red clover	7½	3	1¾	1
Pea	5	3	1¾	1¾
Horse-bean . .	7	6½	4¾	4¼
Tobacco	...	...	9	6¼
Hemp	8	4½	2	2
Poppy	10	4¾	2½	2
Rape	6	2	1	1
Sugar-beet	22	9	3¾	3¾
Maize . . .	...	11¼	3¼	3
Spring barley . .	6	3	2	1¾
Spring rye	4½	2	1½	1
Spring wheat	6	4	2	1¾

As a rule seeds do not germinate below 37° Fahr. (2.8° C.), or at a higher temperature than about 128° Fahr. (53.3° C.) They retain their vitality at very low temperatures, but when heated above 168° Fahr. they are, with rare exceptions, killed. Seeds which were left within the Arctic circle by an exploring expedition, and were some years subsequently brought to England (by the North Pole Exploration Expedition) in October 1876, germinated freely.

It is stated by Sachs that the best plants are produced when germination has taken place at medium temperatures—from 20° to 30° Centigrade (68° to 86° Fahr.)

Moisture necessary to Germination.—Seeds cannot germinate without water, but the requisite amount of this liquid varies according to the nature of the germ. In the case of the agricultural plants, germination is best effected when the soil is *moist*, but not *wet*.

Some seeds absorb during germination very large quantities of water, whilst others take up minute amounts. Thus R. Hoffmann found that mustard seeds absorbed 8 per cent, and white clover seeds 126.7 per cent, of water during germination. The seeds of the ordinary cereals take up about half their weight of water; whilst the seeds of grasses and legumes take up their own weight of moisture.

Hastening Germination.—Many suggestions have been made with the object of hastening and promoting germination. According to Böttger, this object is accomplished by the application of a moderately strong solution of potash or soda to the seeds. Weak solution of chlorine gas in water has been also recommended. It is alleged that camphor has a wonderful influence in favouring the germination of seeds, and that, unlike turpentine, which has been employed for the same purpose, it is never, even when used in excess, hurtful. The latter assertion is doubtful.

Proper Depth of Sowing.—Seeds should not in these climates be sown deeply. Hoffmann found that the seeds of 24 kinds of plants cultivated by farmers and market-gardeners perished when placed 12 inches below the surface. The depth at which seeds are best sown depends to some extent upon climate and soil. It depends also on the size of seed. Small seeds should not be buried so deep as larger ones. As a rule the best depth is 1½ to 3 inches.

Gases exhaled during Germination.—It is a curious fact that seeds do not germinate in pure oxygen gas; but if exposed to a mixture of 4 parts of nitrogen and 1 of oxygen (air being composed of 4 of nitrogen and 1 of oxygen) they germinate freely. Carbon dioxide is evolved in considerable quantity from germinating seeds, and oxygen is absorbed. It is asserted by Déhérain and Landrin that nitrogen is exhaled also, but only in an early stage of germination. Leclerc denies the accuracy of this statement, maintaining that any nitrogen which may be evolved during germination is merely a product of the decomposition of ungerminated seeds.

Malting Grain.—The malting of grain consists simply in germinating seeds of barley, &c., and allowing the development of the embryo plants to go on for a certain time, when they are killed by the application of heat. In germinating grain there is developed a small quantity of a white, insipid, nitrogenous substance termed *diastase.* This compound is a ferment, and it possesses the property of causing starch, which is naturally insoluble, to ferment and become soluble—*i.e.*, by being changed into dextrin and sugar. When the seeds have partly germinated, further chemical change in their composition is prevented by simply killing the embryo plants. This is effected by heating them up to a temperature of from 145° to 164° Fahr., according as the malt is required to be light or dark in colour. It is stated that one part of diastase is capable of converting 2000 parts of starch into sugar and dextrin. Payen and Persoz state that at 75° Cent. (167° Fahr.), diastase loses its property of rendering starch soluble. When, therefore, malt is intended for the brewer, or even as an addition to food for cattle, care should be taken not to heat it up to 167° Fahr.

A large amount of diastase formed during germination remains until the last stage of the process. It is this excess of diastase which enables the distiller to ferment molasses or starch, or unmalted corn, by mixing them with from 10 to 50 per cent of malted grain.

According to Dubrunfaut, a nitrogenous ferment, which he terms *maltin*, exists in malted barley and in all cereal grains. It is much more active than diastase; and Dubrunfaut suggests that the latter is probably only a product of the decomposition of the former, one part being capable of converting from one to two hundred thousand parts of starch into a soluble condition. It may be present in barley-malt to the extent of one per cent. Barley is chosen for brewing purposes because barley-malt contains larger proportions of ferments, such as diastase and maltin, than malt from other cereals.

Conclusion of Germination.—When the embryo contained in the seed has become developed into a young plant, it will be found that all the provisionary stores of food accumulated by the parent, and disposed in close contiguity with its offspring (in embryo), have become exhausted. The young plant is now, however, possessed of leaves and a root, and with these organs it at once commences to absorb nutriment from air and soil. As the plant develops, the assimilation of carbon from the carbonic acid of the air becomes greater until this in all probability is the sole source. With regard to the absorption of such important constituents as phosphoric acid, potash, and nitrogen by cereals, it may be pointed out that the last-named constituent is assimilated for a longer period than the other two, which cease to be assimilated at the period of full bloom.

CHAPTER XXIII.

THE ASSIMILATION OF CARBON, OXYGEN, AND HYDROGEN BY PLANTS.

Oxygen, hydrogen, carbon, and nitrogen are always found in every plant and animal; and as they constitute the great bulk of organic bodies, they have been termed the *organic* elements. These elements do not appear to be capable of direct absorption by plants; but in combination they are always present in the air and soil, and furnish plants with by far the greater portion of their food.

Absorption of Carbon Dioxide.—Two processes go on in the plant—the one, which is known as plant respiration, takes place both during the day and the night. This process, which resembles animal respiration, consists in the absorption of oxygen and the giving out of carbon dioxide. The other process, known as assimilation, takes place only during the daytime and under the action of light. As this process goes on to a much greater extent than the other, the latter process is not apparent during the daytime. The oxygen evolved in six hours' time under the action of moderately strong sunlight has been calculated to be as much as would be absorbed by the process of respiration in twenty-four hours. The changes which carbon dioxide undergoes whilst in the wonderful vegetable laboratory are not thoroughly understood. We know that a large portion of its oxygen is separated from it, and evolved in a pure state into the atmosphere. The influence of light in enabling plants to absorb and decompose carbon dioxide has been conclusively proved by numerous experimenters, but by none more strikingly than by Boussingault. He found that a bean seed weighing 0.922 gramme (a gramme is nearly 15½ grains) became in twenty-five days a plant which weighed (when dried) 1.293 grammes, being an increase in its weight of 0.371 gramme. This increase consisted of 0.1926 gramme of carbon, 0.02 gramme of hydrogen, and 0.1591 gramme of oxygen. At the same time another seed of a bean grown under similar circumstances, save complete exclusion of light, declined in weight from 0.926 gramme to 0.566 gramme; the loss of 0.360 gramme consisted of 0.1598 gramme of carbon, 0.0232 gramme of hydrogen, and 0.1766 gramme of oxygen.

According to Pfeffer the following table shows the relative activity of the different rays of light in promoting the decomposition of carbon dioxide in the leaf. The yellow rays are most active, and are reckoned at 100:—

Yellow . . .	100.0	Red . . .	25.4	Indigo . . .	13.5
Orange . . .	63.0	Blue . . .	22.1	Violet . . .	7.1
Green . . .	37.2				

The amount of carbon dioxide in pure air is in all probability on an average not more than 0.035 per cent. An increase of this proportion is found to be beneficial to plants. According to Godlewski, the maximum amount of carbon dioxide which he found to be beneficial to Glycerea was from 8 to 10 per cent; a larger proportion proved injurious. Some plants would, no doubt, be injured by exposure to air containing even 8 per cent of carbon dioxide.

Böhn in his experiments found that more than 2 per cent of carbon dioxide is injurious to plants, and that 20 per cent kills them.

As an indication of the enormous amount of carbon removed from the air by growing vegetation, it may be mentioned that an acre of a good wheat crop will remove in four months 1 ton of carbon, or as much as would be contained in a column of air three miles in height.

The action of light in enabling plants to decompose carbon dioxide is exerted in their green or chlorophyll-holding organs, and is chiefly the function of the leaves. Plants not possessing chlorophyll are not able to decompose carbon dioxide.[1] Such plants as the dodder and the broom-rape are familiar examples. These plants are parasites, and live on the juices of other plants. Fungi are other examples. They derive their carbon from the carbonaceous matter of the soil. C. Kraus suggests that chlorophyll decomposes carbon dioxide into carbon monoxide and oxygen ($CO_2 = CO + O$). The carbon monoxide thus formed, combining with water, produces a carbohydrate, of the formula of $C_6H_{12}O_6$. This carbohydrate by losing water would form pyrocatechin, the liberated oxygen at the same time oxidising other carbohydrates into acids. The following equation represents the possible transformation of grape-sugar into oxalic acid: $2C_6H_{12}O_6 + 9O_2 - 6H_2O = 6C_2H_2O_4$.

It is supposed that carbon dioxide and water may, under the influence of light, react upon each other in the following manner: $CO_2 + H_2O = CH_2O + O_2$, and the formaldshyde ($CH_2O$) thus produced giving rise to glucose ($C_6H_{12}O_6$). The formation of the carbohydrates, at any rate, is dependent on the presence of nitrogenous and mineral ingredients of plant food. These are,

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[1] Till recently it was supposed that all evolution of oxygen in vegetable physiology was dependent on the presence of light, and also intimately connected with chlorophyll, or the green colouring matter of plants. It would seem, however, that among the soil organisms these conditions are not necessary, and the evolution of oxygen may be carried on in the case of colourless organisms as well as in the absence of light.

however, only plausible conjectures as to the manner in which carbon dioxide and water are converted into organic compounds.

Assimilation of Oxygen and Hydrogen.—Plants do not possess the power of absorbing, or at least of assimilating, the free oxygen and hydrogen gases. Water supplies them with oxygen and hydrogen, whilst the latter element may also be obtained by them in small quantities from ammonia (NH_3). In the soil there are various kinds of organic bodies, containing oxygen and hydrogen, and soluble in water. It is a vexed question whether or not these soluble organic matters are taken up by plants, and used as food by them.

CHAPTER XXIV.

THE ASSIMILATION OF NITROGEN BY PLANTS.

The amount of nitrogen in plants is on an average not less than about 2 per cent, and this gas constitutes about four-fifths of the weight of the atmosphere.

Assimilation of Free Nitrogen.—The question, Can plants assimilate this free nitrogen? was therefore one very early discussed in the history of agricultural chemistry.

It is quite unnecessary to enter into a detailed account of the numerous experiments which have been carried out with a view of solving this important problem, which has only met with a solution—and that as yet incomplete—within the last few years. From 1771, when Priestley first raised the question, up till now, the problem has been discussed by all the leading agricultural chemists. Among those may be mentioned Ingenhuosz, Woodhouse, Sénébier, De Saussure, Boussingault, G. Ville, Lawes, Gilbert, Pugh, Berthelot, Hellriegel, Wilfarth, Dehérain, Atwater, Schloesing, Petermann, and others. So important was the subject considered, that in 1855 the French Academy appointed a commission to superintend a repetition of Ville's experiments, the results of which had been in opposition to those of Boussingault. But despite the elaborate care which characterised these earlier experiments, they did little to solve the problem, and it is only within the last few years that much progress has been made in throwing light on this most important question. The reason of this is to be found in the fact that the fixation of the free nitrogen is effected by means of micro-organic life. It is an established fact that free nitrogen is fixed by leguminous plants in symbiosis with microbes, as well as by mixtures of the lower organisms inhabiting soils, green algæ, and microbes. Hellriegel and Wilfarth were the first to prove this. The fixation of nitrogen in the case of the leguminosæ is connected with the formation of minute tubercles found in their roots. In these tubercles the micro-organism effecting the fixation of the nitrogen resides. The subject is still very obscure. It would seem that the fixation is the result of the joint action of certain micro-organisms in the soil and in the plant, and that these micro-organisms are not to be found in all soils. It would further seem from Nobbe's interesting experiments, that the fixation of the nitrogen may be effected by different organisms—in short, that it is the function of a class of organisms and not simply of one specific organism. Thus the organism in the tubercle of the pea differs from that in the tubercle of the lupin, and so on. The importance of this discovery can hardly be overrated. The property which members of the leguminous class of crops, such as clover, &c., possess in the way of accumulating nitrogen in the surface-soil has long been recognised in practical agriculture. Now, however, that the explanation of this action is forthcoming, much light has been shed on the principles underlying the practice of the rotation of crops.[1]

Nitric Acid a Source of Nitrogen.—The most abundant source of nitrogen to the plant is nitric acid absorbed as nitrates. This substance is found in the juices of plants, especially those of a fleshy, tuberous character. It exists in the soil, and is found largely, as we have shown in the chapter on drainage, in the water which flows through the soil. It is formed by the process of nitrification, which we have already described.

So far as we at present know, with the exception of that obtained from the atmosphere by leguminous crops, and certain other low forms of plant-life (green algæ), practically all the rest of the nitrogen absorbed by green-leaved plants is absorbed in the form of nitrates. That plants are capable of absorbing their nitrogen in other forms such as ammonia, urea, &c., has been proved by experiments. From what we know of the process of nitrification, it is highly improbable that in practice they exercise this power of drawing their nitrogen from sources other than nitrates.

CHAPTER XXV. 25

THE ASH CONSTITUENTS OF PLANTS.

That part of a plant which resists combustion is technically termed its "ash." It forms from 1 to 9 per

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[1] It must be pointed out that though leguminous crops do take doubtless a good deal, and can take all their nitrogen from the air, yet they nevertheless take up nitrates like other plants.

cent of the weight of plants, and it is absolutely essential to their existence. The ash is composed of various substances which vary in quantity and in kind in the different species of plants, and even in different individuals of the same vegetable. It is one of the problems of agricultural chemistry to discover what are the essential substances in the composition of every kind of useful plant. Another equally important question is, What is the exact quantity of each variety of mineral substance required for the healthy development of each kind of plant? It must be confessed that our knowledge in relation to these points—and especially with respect to the latter—is imperfect. There are, however, many earnest investigators, both at home and abroad, working zealously in this extensive and inviting field of research, and the results of their labours are yearly adding substantially to our stock of knowledge of the more intimate nature of the mineral or ash ingredients of plants, and their physiological functions in the vegetable economy.

Potassium (K) **in Plants.**—The metal potassium—chiefly as phosphate (K_3PO_4), chloride (KCl), and carbonate (K_2CO_3)—is invariably found in the ash of plants. In many varieties, for example in tobacco, potassium salts exist to the extent of from 60 to 80 per cent of their ash, and they rarely constitute less than 50 per cent of this portion of the plant. Various attempts have been made to substitute sodium entirely for potassium in plants, but they have all failed. According to Daubeny, Will, and Fresenius, wheat grown near the sea contains more potassium than when cultivated in inland situations; but Way's analyses yielded opposite results. In sea-water, sodium is thirty times more abundant than potassium, yet in sea-weeds the two metals exist in about the same relative proportions. In *Laminaria latifolia* Schwitzer found 16.91 per cent of potash, and 10.18 per cent of potassium chloride, as against 26.92 per cent of sodium chloride. Gödechaus found an average of 30 per cent of potash and potassium chloride in sea-weeds. In fourteen analyses of these plants made by Forchammer, sodium and potassium were equally abundant, whilst Anderson found more potash than soda in them. Cadet grew a soda-loving plant—namely, *Salsola kali*—in garden soil. The plants produced contained both potassium and sodium; but the seeds obtained from these plants when sown in the same soil developed into plants in which no sodium was present, but, on the contrary, a very large proportion of potassium. It has been found that many plants which usually grow at the sea-coast, and in which sodium compounds are abundant, contain little or none of that element when found in inland situations. Potassium, on the contrary, is always present in plants, no matter where they may be grown, and is necessary for the upbuilding of the plant's organic substance. According to Liebig, it plays an important part in the distribution of carbohydrates throughout the plant. Potassium is absorbed by the plant in the forms of sulphate, phosphate, and probably the silicate. According to Nobbe, the chloride is the most favourable form. Practical experience has demonstrated the inadvisability of applying potash to certain crops, such as potatoes, in the form of chloride. Potash is found in greatest abundance in the extremities of the plant, such as twigs and new leaves.

Sodium.—Sodium (Na) is found in great abundance in marine plants, chiefly as carbonate and chloride. It is largely present in the ash of the mangel-wurzel. There is no doubt that it is non-essential to any kind of vegetable, though it would appear as if it sometimes *partially* replaced potassium. The Rothamsted experiments have shown that up to a certain point—especially in their leaves and stems—plants can make shift with sodium in partial replacement of potassium. In the earlier analyses of the ash of plants, sodium appears always to have been found, and generally in large quantity. Thus, Sprengel estimated 38 per cent of soda in the ash of the bean, whilst Richon found only 19, and Levi 12 per cent in the same kind of seed. Boussingault, in comparatively modern times, detected no sodium at all in the pods of haricots (French beans); and Way and Ogston found only 2.8 per cent of soda in ordinary beans. Sprengel found 20 per cent of soda in peas, whilst Boussingault, Erdmann, and Rammelsberg found no soda in them. From the above it will be seen that the variation in the quantity of soda in plants is very great. The results of old analyses of plant-ash can hardly be relied on so far as soda is concerned. The extreme difficulty of estimating this ingredient accurately, especially when present in small quantities, is well known to every chemist. The variation in the amount of soda found in the oat plant at different stages of its growth is illustrated by Arendt's analyses as follows:—

	June 18.	June 30.	July 10.	July 21.	July 31.
Soda (Na_2O)	.86	1.28	1.47	1.12	.87

These results represent the average of 1000 analyses of the oat plant. Herapath analysed samples of light and heavy oats, with the result that he found soda in the former to the extent of 4.6 per cent, while in the latter it amounted to 7.2 per cent. In potatoes, soda has not been detected by two observers;[1] by others it has been found only in small quantities. This of course means in weighable quantities, for spectrum analysis has revealed the presence of soda in minute traces to be universal.

Sodium is indispensable to animal life. Perhaps the

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[1] Metzdorf and C. A. Cameron.

reason why animals instinctively desire and relish common salt (sodium chloride) is because it might not be always or generally supplied to them in vegetable food. Animals have not the same longing for potassium chloride, or calcium phosphate, substances equally indispensable to them as sodium chloride, but certain to be adequately supplied in vegetable food.

Calcium (Ca) **and Magnesium** (Mg) **in Plants.**—The metals calcium and magnesium are important and indispensable constituents of plant-ashes. The former is generally in by far the larger proportion in the succulent parts of plants. In the seeds of wheat, oats, and other plants, magnesia (MgO) usually preponderates over lime in the proportion of about 7 to 2. In the stems (straws) of the cereals, lime is nearly three times more abundant than magnesia. In root-crops lime exceeds magnesia in quantity. Very little is known as to the use of magnesium. Its distribution in plants appears to be tolerably uniform. In plants, calcium and magnesium exist as phosphates and carbonates, and also as constituents of such organic salts as calcium oxalate, &c. Magnesium and calcium phosphates, carbonates, and sulphates occur in soils, and occasionally magnesium and calcium chlorides. Plants, therefore, seldom fail to find adequate supplies of these metals.

Aluminium (Al).—In the ashes of certain *lycopods* or "club-mosses," aluminium has repeatedly been detected; and by one analyst, Professor Church, in considerable quantity. It is, however, not always to be met with in the lycopods, and it has very rarely been observed in any other plants. It is highly probable, therefore, that this metal is not essential to vegetable life, neither is it to animal existence.

Manganese (Mn) is very frequently found in minute quantity in plant-ashes. It is not essential to plant growth. Manganese is generally associated with iron, and one of its oxides (Mn_2O_3) resembles ferric oxide; Birner and Lucanus found that Mn_2O_3 could not replace Fe_2O_3 in vegetables. Kane detected 1 per cent of Mn_2O_3 in flax, and Ruling estimated 4 per cent of this oxide in the ash of the sweet flag, whilst it was detected to the enormous extent of 11.2 per cent in beech-ashes by Fresenius.

Silica, or Silicon Dioxide (SiO_2), constitutes no inconsiderable proportion of the external layers of the stems and leaves of the cereals; it makes up about 60 per cent of the weight of the ashes of straw, and 35 per cent of the inorganic portion of the grasses. It is chiefly found in the outer portion of plants. It is especially abundant in the joints of the bamboo. In other plants, and in seeds, it is a somewhat scarce substance. Grave doubts have been raised as to the essentialness of silica as a plant-food. Knop and Sachs grew artificially maize plants from which the silica was, save an almost inappreciable trace, rigorously excluded. The plants were healthy and produced seeds. Other experimenters of repute—Nobbe and Siegert, Stohman, Wolff, &c.—have produced oats, maize, and buckwheat containing no silica; and Pierre has demonstrated that the weakness sometimes observable in the stems of the cereals is not attributable to a deficiency of silica. It is not known in what form it is present in the plant.

Silica is generally regarded as an unessential ash ingredient. Perhaps the silica found in plants had been associated with potash, and taken up into the vegetable, not because the latter required silica, but because it stood in need of the potash. If the potash were appropriated, then the silica being insoluble would be mechanically retained in the tissues of the vegetable. It has been found that plants grown in solution of ammonium chloride have appropriated the ammonia of the salt, and set free the chlorine combined with hydrogen ($NH_4Cl = NH_3 + HCl$). A similar reaction is quite possible in the case of potassium silicate.

Chlorine (Cl) is taken up into plants chiefly in the form of common salt and chloride of potassium. It is not abundant in the cereals, is present in decided quantity in turnips, mangels, and similar plants, and is contained in large proportions in sea-coast and marine plants. In all probability chlorine is not essential to plant growth. It is certain that chlorine is always present in vegetables grown naturally.

Sulphuric Acid (H_2SO_4).—Calcium sulphate ($CaSO_4$) is probably the chief source of the sulphur trioxide found in plants, and which, without doubt, is absolutely essential to their growth. SO_3 (sulphuric anhydride) constitutes from 2 to 7 per cent of the ash of plants. Sulphurised ethereal oils occur in certain plants, such as the onion, garlic, horse-raddish, &c. Along with potash it is the most abundant ash ingredient. This is proved by the fact that it is found in the plant in greatest abundance where growth is most active. It is absorbed by plant-life in the form of sulphates.

Phosphorus Pentoxide (P_2O_5).—Phosphates of different bases exist largely in vegetable ashes. In some the amount of magnesium and calcium phosphates reaches 60 per cent. No one doubts the importance of the phosphates to vegetable life.

Fluorine (F) is found in the teeth and bones of animals, and is therefore in all probability derived from vegetables, which directly or indirectly exclusively furnish the nutriment for animals. It is certain that water does not, as a rule, contain fluorine. Fluorine is therefore probably essential to plants, but no doubt a very minute quantity of it is sufficient for their wants. Bran, it may be mentioned, is said to contain fluorine; and by some the alleged greater prevalence of decay in teeth in modern times has been attributed to the growing disuse of brown bread.

Iodine (I), **Bromine** (Br), **Copper** (Cu), **Lead** (Pb), **Lithium** (Li), **Cæsium** (Cæ), and **Rubidium** (Rb), although occasionally found in plants, are in all probability merely accidentally present. Some of them may be beneficial to certain plants.

CHAPTER XXVI.

THE COMPOSITION AND DISTRIBUTION OF THE ASH CONSTITUENTS OF PLANTS.

Percentage of Ash in Plants.—The percentage of ash in the dry matter of plants (that obtained by drying the plants at a temperature of 212° Fahr., until they cease to lose weight) is usually from about 3 to 6 per cent of the entire plant. In the seeds the amount of ash is generally very small. The percentage of ash in the seed is more constant than any other part of the plant; but in the leaves it often amounts to more than 20 per cent, and may be stated at from 2 to 5 per cent, old leaves being especially rich. In the process of growth all plants absorb a considerable amount of mineral food which is not necessary for their growth. The non-essential mineral matter which is thus absorbed is largely deposited in the older tissue of the plant. Such portions as the outer bark, the old leaves, and straw of cereals, chiefly receive this unnecessary mineral matter, which forms incrustations which may subserve a useful purpose in the way of protecting the tissue, or may be washed away by rain. The deposition of silica in straw and leaves is an example of this. The older belief, that the presence of silica in straw gave rigidity to the straw and was consequently a necessary ingredient, is now no longer held. In the following table the average percentage of ash in various vegetable products is shown :—

SEEDS.

Wheat grain	1.9	Indian corn	1.5
Oat "	2.9	Bean	3.6
Barley "	2.2	Peas	2.7
Rye "	2.6		

STEMS.

Wheat straw	5.0	Rye straw	5.2
Oat "	5.4	Bean "	8.0
Barley "	6.7	Pea "	6.2

ROOTS AND TUBERS.

Potato	4.3	Carrot	8.0
Mangel	8.5	Kohl rabi	8.0
Swede	11.0	White turnip	6.0
Turnip	10.0	Parsnip	6.2

WHOLE PLANTS.

Red clover	6.8	Wheat	4.6
White clover	7.3	Flax	4.3
Oats	5.2	Gorse or Furze	7.0
Hemp	4.5	Cabbage	8.0

WOODS.

	Wood.	Leaves.	Seed.
Willow	0.45	0.82	0.33
Beech	1.40	0.42	...
Birch	0.35	0.50	...
Pine	0.30	0.20	0.50
Elm	0.19	0.12	...

It appears, therefore, that by far the larger proportion of the inorganic matter which is withdrawn from the soil by a crop of corn is returned to it again, by the skilful husbandman, in the fermented straw. In the same way also nature, in causing the trees periodically to shed their leaves, returns with them to the soil a very large portion of the soluble inorganic substances which had been drawn from it by their roots during the season of growth.

Thus an annual top-dressing is naturally given to the land where forests grow; and that which the roots from spring to autumn are continually sucking up, and carefully collecting from considerable depths, winter strews again on the surface in the form of decaying leaves, so as, in the lapse of time, to form a rich and fertile soil. Such a soil must be propitious to vegetable growth, since it contains or is made up of those very materials of which the inorganic substance of former races of vegetables had been almost entirely composed.

Wolff states that the average amount of ash in cereal (fresh) grain is 2 per cent, and in their stems 5 per cent. In the leguminous crops the ash makes up 3 per cent of their seeds, and 4.5 per cent of their leaves.

A crop of 8 tons of potato-tubers per acre removes about 180 lb. of mineral matters, of which about one-half consists of potash, and one-ninth part of phosphoric acid. A mangel crop weighing 20 tons of roots per acre removes from the soil (excluding the amount taken up in foliage) from 300 to 380 lb. of mineral matter, including from 100 to 140 lb. of potash, and from 15 to 25 lb. of phosphoric acid. Cereal crops remove only about 85 lb. of mineral matter per acre, of which 10 or 12 lb. consist of potash, and 14 or 15 lb. of phosphoric acid.

Variability of Plant-ashes.—The ash of each of our cultivated plants has been, as a rule, repeatedly examined, and by different chemists. Their results have not generally been very close, and occasionally they have been almost discordant. In the case of particular kinds of plants, one chemist has found magnesium to preponderate in quantity over calcium; whilst in examining the same kinds of vegetables another analyst has found an excess of calcium over magnesium. Chlorine, silica, ferric oxide, and sulphur trioxide, have been detected by some chemists in certain ashes of plants in which other chemists failed to find one or more of these substances. We are not so well acquainted with the nature of the essential inorganic portion of plants as we are with that of animals. Many substances which are by no means likely to be useful to plants are found in their ashes; and even in the case of those elements which are really indispensable to vegetable life, they are occasionally and perhaps frequently present in greater quantity than is necessary. No doubt there is a physiological law governing the absorption of mineral matter by plants; each species requires in its normal state a certain amount of each of a limited number of substances. It is one of the objects of the agricultural chemist to discover what these substances are, and in what proportions they are actually required by the plant. It would seem to be an easier task to solve the first of the problems than the latter, but it has not yet been fully answered. There are some ash ingredients of the essential nature of which, in the vegetable mechanism, there is no longer any room to doubt; but there are several elements which, though they are often found in vegetables, yet chemists and vegetable physiologists disagree as to their essential or even useful character.

In the following table the composition of the ash of several of the more important of the agricultural plants is given. In each case, the composition of the ash has been calculated from the average results of analyses made by different chemists, and numbering from ten to seventy distinct investigations. The amount of carbonic acid has not been included in these analyses.

COMPOSITION PER 100 PARTS OF THE ASH OF PLANTS (EXCLUDING CARBON DIOXIDE).

	Wheat grain.	Barley grain with husk.	Oat grain with husk.	Rice grain.	Indian corn.	Peas (pods).	Beans (pods).	Flax seeds.	Potatoes (tubers).	Yellow globe mangels.	Long red mangels.
Potash (K_2O), . . .	31.54	21.28	37·48	23·70	37·95	45·40	42.50	30.55	61.60	35·09	25.18
Soda (Na_2O), . . .	2.66	4·00	2.40	4·00	3·00	2.00	3·34	2.61	1.00	28.90	32.10
Magnesia (MgO) . .	12.10	9.10	7·80	12.10	7·50	8.00	7·30	16.23	5.00	2.50	2.26
Lime (CaO) . . .	3.14	2.40	3·00	3.15	3·40	5·50	6.00	9·45	2.40	2.50	2.20
Ferric oxide (Fe_2O_3) .	trace	0.15	0.60	trace	0.40	0.85	0.40	0.38	0.85	0.66	0.50
Phosphoric anhydride (P_2O_5)	48.50	33·17	20.80	55.00	44.80	32.55	34.66	35·99	17.67	6.16	2.16
Sulphuric anhydride (SO_3) .	0.08	2.10	1.80	0.05	1.50	4·73	3·50	1.43	6.25	3·19	40.00
Silica (SiO_2) . . .	1.88	27.50	25.90	2.00	1.45	0.67	0.90	1.76	1.00	3·00	1.60
Chlorine (Cl) . .	0.10	0.30	0.22	trace	trace	0.30	1.40	1.70	2.23	18.00	30.00
	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.CO	100.00	100.00	100.00

COMPOSITION PER 100 PARTS OF THE ASH OF PLANTS (EXCLUDING CARBON DIOXIDE)—*continued.*

	Cow cabbage leaves.	Carrot root.	Wheat straw.	Oat straw.	Barley straw.	Pea straw.	Red clover hay.	Meadow hay.	GRASSES IN FLOWER.		
									Bromus erectus.	Solium perenne.	Annual rye-grass.
Potash (K_2O) . . .	34.85	41.46	12.16	20.60	19.32	22.00	31.86	26.80	25.92	30.79	27.07
Soda (Na_2O) . . .	4.60	17.60	1.00	6.00	4.50	6.00	2.16	5.80	0.50	9.90	2.87
Magnesia (MgO) . . .	4.40	5.36	4.00	3.66	2.70	7.34	12.16	4.32	4.80	8.25	2.59
Lime (CaO) . . .	19.60	8.86	6.82	8.10	7.00	39.00	31.09	12.86	10.20	3.00	6.82
Ferric oxide (Fe_2O_3) . .	0.17	0.32	1.02	0.83	0.26	1.08	0.66	0.76	0.23	trace	0.28
Phosphoric anhydride (P_2O_5)	16.63	12.68	3.20	4.16	4.83	6.84	9.00	6.95	8.00	9.00	10.07
Sulphuric anhydride (SO_3) .	17.31	6.93	5.78	13.32	3.78	6.30	3.03	4.45	5.42	5.20	3.45
Silica (SiO_2) . . .	2.44	2.00	65.34	50.08	56.85	6.18	6.71	31.04	38.10	21.56	41.79
Chlorine (Cl . . .	trace	4.79	0.60	3.25	0.76	5.26	3.33	7.02	6.83	17.30	3.06
	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

In the earlier analyses of vegetable ashes, the amount of soda is generally stated in higher figures than we find in the modern analyses of the same substances. In several of the statements of the analyses of beans and other plants used in preparing the table, no mention whatever is made of soda.

Causes of Variations in the Ash.—There are obvious reasons why analyses of any kind of plant must differ in their results. The composition of plants, like that of animals, but to a far greater extent, differs at different periods of their growth. A large excess of soluble mineral matters in the soil is probably the cause of a large amount of these substances being present in the plants grown upon it. Healthy plants have the power of absorbing a greater quantity of soluble inorganic matter than weakly ones. The eminent agricultural chemist, Arendt, found the following differences in the composition of healthy and weakly oat plants:—

	Potash and soda.	Lime.	Magnesia.	Ferric oxide.	Phosphoric acid.	Sulphuric acid.	Silica.	Chlorine.
Luxuriant oat plants .	45·3	6.1	2.9	0.4	8.2	4·8	27.0	6.7
Strong oat plants . .	34·3	5·4	2.3	0.5	8.5	4·1	39·9	5·8
Weakly oat plants . .	30.4	5·2	2.3	1.0	8.8	5·6	42.0	4·7

The Proportion and Nature of Ash vary during Growth.—The composition of the organic and mineral constituents of plants varies during their growth. Among the causes influencing variation in quantity of ash may be mentioned, in addition to stage of growth of the plant, the vigour of its development, relative development of its parts, the soil and the supply of food, and season and climate. In the clovers, the proportion of ash ingredients diminishes as the plants grow older. When the plants are young, their stems and leaf-stalks are very rich in inorganic matter; but at the period of flowering, the ash decreases in the stems and increases in the leaves. Potash abounds in the stems and lime in the leaves—increasing therein until the flowering of the plant is perfected. Phosphoric acid is at first abundant in the leaves, but ultimately it accumulates chiefly in the blossoms. Silica remains all through in the stems and leaves, whilst chlorine, which at first abounds in the stems and leaves, migrates subsequently in great part to the blossoms. The character of the soil as well as manuring affects the amount of ash ingredients in a plant. Some kinds of plants are more affected by these influences than others—succulent plants especially showing great variation.

Bretschneider analysed specimens from an oat crop at different periods of their development. 1st, 19th June, fifty-eight days after sowing; 2d, 29th June, when the ears had just left their sheaths; 3d, 8th July, when the crop was in full bloom; 4th, 28th July, when the plants were beginning to ripen; 5th, 6th August, when the crop was fully ripe. The composition of the ash at four of these stages is shown in the following table:—

COMPOSITION OF OAT-ASH AT DIFFERENT PERIODS OF THE PLANT'S DEVELOPMENT.

	1	2	3	4
Potash	28.96	25.60	25.90	19.14
Soda	6.40	8.67	4.16	5.29
Lime	5.66	6.46	5.19	5.43
Magnesia	5.34	5.25	4.98	5.02
Ferric oxide	1.22	0.39	0.31	0.39
Phosphoric acid	7.95	9.17	9.61	10.13
Sulphuric acid	5.57	2.46	1.99	3.89
Silica	36.28	40.00	45.57	49.17
Chlorine	3.38	2.58	2.94	2.00
	100.76	100.58	100.75	100.46

The oat assimilates little, if any, phosphoric acid, or magnesia, after blossoming. The leaves are rich in silica, which accumulates in the upper leaves after the plant has put forth its blossoms. It is worthy of note that the leaves of the oat are richer in silica than the stem. It may be that silica is taken up into plants in the form of potassium silicate, not because the plant wants silica, but because it requires potash. Silica thus introduced into plants would probably remain in their tissues owing to its insolubility. Phosphoric acid and magnesia attain to their maximum amounts in the ear.

Dr Anderson found that turnips, examined at four different periods from July 7th to October 6th, yielded the following percentages of ash in (dried quantities) root and leaves: Roots, 17.7, 8.7, 10.2, 20.97; leaves, 7.8, 20.6, 18.8, 16.2. Here we find the ash decreasing during nearly the first half of the growth of the root, and then increasing to more than the original amount. On the other hand, the leaves increased in ash constituents until the plants were about half-grown, when the amount of ash decreased by one-fourth during the rest of the growth of the crop.

In this chapter we have shown that the analyses of the ashes of plants do not always agree in the case of the same kind of plant; nevertheless these analyses have established certain broad facts—they have proved that the variation in the composition of each plant is confined within certain limits, and that there are well-marked differences between the composition of the ashes of many important classes of vegetables.

CHAPTER XXVII.

ON MANURING.

Why Manures are required.—In a state of nature, no impoverishment of the soil takes place—in fact a process of enrichment goes on, at any rate in the surface portions. The fertilising constituents removed by vegetation are restored in the dead vegetable matter, and the soil becomes gradually richer in organic matter. But in agriculture the conditions are different. There the crops produced upon a farm take out of its soils certain quantities of mineral matters and nitrogen. If the edible parts of the crops be consumed upon the farm, and the solid and liquid *excreta* of the animals fed upon them completely put into the soils, then the soils would increase in fertility up to a certain point. The instances, however, are very rare in which the produce of the land is consumed on the spot, and the products of its decomposition (after reorganisation in the bodies of animals) returned, with the exception of comparatively unimportant gaseous matter, to the soil. A feature of all the systems of agriculture prevalent in civilised countries is, that a large proportion of the animal or vegetable products of the farm is sent away to be consumed at a distance. The (effete) matters into which the products are converted, instead of being returned to the land from which they were obtained, are for the most part discharged into rivers, which convey them into the ocean. Furthermore, by the different tillage operations, such as ploughing, the oxidation of the organic part of the soil goes on at a very much greater rate. The problem then is, How may the farmer continue to send away the greater portion of the products of his land, and yet maintain the fertility of his soils?

The Mineral Theory of Manures.—Liebig offered a solution to this problem. He maintained that the fundamental principle of agriculture is the complete restoration to the soil of the mineral matters, or ash constituents, taken out of it by crops. With respect to the nitrogen, he believed that it is chiefly, if not altogether, derived from atmospheric sources—from nitric acid and ammonia. If crops be furnished with ash constituents, they will gather in their supplies of nitrogen from the air. According to Liebig, fallow increases the fertility of soils by allowing time for the decomposition of alkaline silicates, which would furnish supplies of potash in a soluble form. The rotation of crops is useful,—firstly, because certain of the crops in the rotation accumulate organic matter in the soil; secondly, because particular crops require only small proportions of ash ingredients, which other crops take up in considerable quantities. During the growth of a crop which, for example, requires but little magnesia, that substance accumulates (by decay of rock-materials) relatively to other ash ingredients. When, therefore, the time for sowing a magnesia-loving crop arrives, that substance will be present in larger quantity than would be the case if another magnesia-loving crop had been grown in the preceding year.

Liebig followed up his theory of manures by suggesting the employment of fertilisers, each of which should contain the mineral substances in such quantities and combinations as they are actually found in the crops to which they are to be applied. The nature of the ash of each crop being accurately ascertained, a manure of the same, or nearly identical, composition is to be manufactured and applied exclusively to that particular crop. "Mineral manures," prepared according to the suggestions of Liebig, were made patented articles in England and on the Continent, and were at first rather extensively employed. They failed, however, to realise the expectations of Liebig, and they soon fell into complete disuse.

Lawes and Gilbert *v.* Liebig.—Lawes and Gilbert were the first experimenters who proved that the "mineral theory" of Liebig did not agree either with actual practice or experimental results. They grew wheat with Liebig's "wheat manure," with a variety of other mineral compounds, with ammonium sulphate alone, with farmyard manure, and without any fertilisers. Liebig's manure (448 lb.) gave 20⅓ bushels of dressed corn, and 1676 lb. of straw; whilst "sulphate of ammonia" (224 lb.) alone produced 27⅓ bushels of dressed corn, and 2244 lb. of straw. The addition of 224 lb. of sulphate of ammonia to Liebig's manure increased the yield of dressed corn from 20⅓ bushels to 29¼ bushels, and the produce of straw from 1676 lb. to 2571 lb. Farmyard manure (14 tons) gave of dressed corn 27 bushels, and of straw 2454 lb.; whilst a portion of the land unmanured produced 18 bushels of dressed corn, and 1513 lb. of straw. These experiments show that an increase in the produce of wheat was produced by Liebig's mineral manure, but that it was very small as compared with the augmented yield caused by the application of ammonia salts.

This investigation (in 1845-46) led to a celebrated discussion between Baron Liebig and Lawes and Gilbert, which continued during many years, and which ended adversely to the "mineral theory" of the great German chemist. The long-continued experiments of Lawes and Gilbert certainly show that nitrogen is that constituent of soils which first fails when cropping is continued without the application of manures.

The Rothamsted experiments have conclusively shown that nitrogenous manures give a larger return of produce than mineral manures, and that mixed mineral and nitrogenous manures (including farmyard manure) produce much larger crops of grain and straw than ammoniacal salts, nitrate of soda, or mineral compounds produce when separately applied.

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CHAPTER XXVIII.

HOW SOILS LOSE AND GAIN DURING CROPPING.

Exports from the Farm.—A large—usually the larger—proportion of the nitrogen and the mineral matters extracted from the soil by crops is not taken away permanently, but is returned to the earth in the form of stubble, straw, the stems and foliage of certain plants (such as, for example, turnips), and in the *excreta* of the farm animals that have consumed on the spot a portion of the crops. The quantity of mineral matter taken away altogether in animal and vegetable products from the soils of a farm varies, but within moderate limits, according to the system of agriculture adopted on the farm. It sometimes happens that farmers, when their leases are expiring and are not to be renewed, adopt the plan of taking as much out of the land as they possibly can without giving it anything in return. Under such conditions a large quantity of nitrogen and mineral matters is extracted from the soil; but such a system of cropping cannot be long continued, and is, except perhaps for a year or two, thoroughly unsound. Sir J. B. Lawes has shown that in a short time land cropped, but unmanured, refuses to produce paying crops, but is by no means permanently injured. A small proportion of the food of plants contained in the soil is in a highly effective condition, and ready for assimilation. A few corn crops grown in succession take up a large proportion of this immediately available nourishment, and then the land goes *out of condition.* But being out of condition is very different from being reduced to barrenness. In the former case, tillage soon sets free a fresh portion of phosphates and potash, &c., from the rocky portion of the soil; and this operation, together with the application of manure, soon restores the soil to its former state of fertility.

The reason why it is practically impossible to exhaust a soil is simply because, in a very short time, the crops would become so poor as not to repay the cost of labour and the other expenses in connection with their cultivation. Lawes and Gilbert have shown the results of growing turnips three years in succession in the same field, and without manure. In the first year the yield of roots was 9388 lb.; in the second year, 4956 lb.; and in the third year, 1536 lb. It would be a vain attempt to render land barren by growing root crops therein. In the same field that Lawes and Gilbert could not grow turnips without manure, they raised three crops in succession by applying yearly farmyard manure, in the ratio of 12 tons per acre. The first year's crop amounted to 21,233 lb.; the second year's crop increased to 24,108 lb.; whilst in the third year a crop of 38,170 lb. of turnip roots was obtained. In these experiments the beneficial influence of the farmyard manure is clearly evident two years after its first application.

The amount of nitrogen and ash constituents removed from a farm is less if the products sent to market consist of meat, butter, cheese, and milk, than if they are composed wholly of vegetable products such as corn or potatoes. The proportions of nitrogen and ash constituents removed annually from an acre of land depend upon the system of farming adopted and the nature of the products exported from the farm. If an oat crop minus the straw be sold, it will take away about 50 to 60 lb. of mineral matter, including about 13 lb. of phosphoric acid, 9 lb. of potash, and 38 lb. of nitrogen. If the straw were removed from the farm, it would carry off per acre about 140 lb. of mineral matter, including about 37 lb. of potash, 6 lb. of phosphoric acid, and 17 lb. of nitrogen. A crop of 6 tons of potato-tubers extracts from an acre 120 lb. of mineral matter, including 22 lb. of phosphoric acid, 76 lb. of potash, 4 lb. of soda, 3½ lb. of lime, 7 lb. of magnesia, from 10 to 13 lb. of sulphuric acid, and about 45 lb. of nitrogen. The potato and turnip crops are among the most exhaustive to the farm, especially in potash.

The accompanying table (pp. 278, 279) shows the quantities of nitrogen and mineral matter per acre removed by average quantities of the ordinary farm crops.

The following table, based upon Lawes and Gilbert's experiments, shows the quantities of the more important matters removed from the soil by animal products :—

COMPOSITION OF THE ANIMAL EXPORTS FROM A FARM.

	Nitrogen.	Phosphoric acid.	Potash.	Lime.	Magnesia.
	lb.	lb.	lb.	lb.	lb.
Fat ox, per 1000 lb. fasted live weight .	23.18	16.52	1.84	19.20	0.63
Fat sheep, per 1000 lb. fasted live weight .	19.60	11.29	1.59	12.80	0.50
Fat pig, per 1000 lb. fasted live weight .	17.57	6.92	1.48	6.67	0.35
Milk, 1000 lb. . . .	5.25	2.03	1.80	1.56	0.16
Wool, unwashed, 1000 lb.	73.00	1.00	40.00	1.00	0.70

By "fasted" is meant that the digestive organs of the animals had been almost completely emptied of their contents before they were killed and analysed. These figures will enable the "meat manufacturer" to estimate, with a close approximation to the truth, the amount of nitrogen and mineral matters which, in the shape of beef, mutton, pork, milk, and wool, is annually extracted from the soils of his farm.

The Soil loses by Drainage.—In addition to the losses which the soil sustains by cropping, it loses no inconsiderable amount of valuable matters in the drainage-waters which flow through it. The amount of ammonia and phosphoric acid lost in this way is not serious—neither is there a sensible waste of potash; but a large quantity of nitrogen is carried off in the form of nitric acid. The results of experiments conducted at Rothamsted show that every inch of rain which passes so low down into the soil as to be beyond the reach of the roots of plants, entails a loss of nitrogen to the extent of 2¼ lb. per acre, if in every gallon of the drainage-water there are seven-tenths of a grain of nitrogen. Voelcker found (Journal of Royal Agricultural Society, vol. x., 1874) that the drainage from a plot of ground—which ground had received a short time previously a heavy dressing of nitrate of soda—contained 5.8 grains of nitrogen (in the form of nitrate of soda) per 100,000 parts. This was equal to a loss of 13 lb. of nitrogen per acre for every inch of rain that passed through the soil.

At Rothamsted, the loss taking place in the case of unmanured fallow has been found to amount to 54.2 lb. per acre a-year from soil 20 inches deep. This was the maximum loss. The minimum quantity was 20.9 lb. The average loss taking place on unmanured fallow land for 13 years to a depth of 20 inches, has been found to amount to 37.3 lb. Or to put it in a more striking way,

THE WEIGHT AND AVERAGE COMPOSITION OF

		Weight of Crop.		Total Produce.	Nitrogen.
		At Harvest.	Dry.		
		lb.	lb.	lb.	lb.
Wheat	Grain, 30 bushels	1,800	1,530	30	33
	Straw	3,158	2,653	142	15
	Total crop	4,958	4,183	172	48
Barley	Grain, 40 bushels	2,080	1,747	46	35
	Straw	2,447	2,080	111	13
	Total crop	4,527	3,827	157	48
Oats	Grain, 45 bushels	1,890	1,625	51	38
	Straw	2,835	2,353	140	17
	Total crop	4,725	3,978	191	55
Maize	Grain, 30 bushels	1,680	1,500	22	28
	Stalks, &c.	2,208	1,877	99	15
	Total crop	3,888	3,377	121	43
Meadow hay, 1½ ton		3,360	2,822	203	49
Red clover hay, 2 tons		4,480	3,763	258	102
Beans	Grain, 30 bushels	1,920	1,613	58	77
	Straw	2,240	1,848	99	29
	Total crop	4,160	3,461	157	106
Turnips	Root, 17 tons	38,080	3,126	218	63
	Leaf	11,424	1,531	146	49
	Total crop	49,504	4,657	364	112
Swedes	Root, 14 tons	31,360	3,349	163	70
	Leaf	4,704	706	75	28
	Total crop	36,064	4,055	238	98
Mangels	Root, 22 tons	49,280	5,914	426	87
	Leaf	18,233	1,654	254	51
	Total crop	67,513	7,568	680	138
Potatoes—tubers, 6 tons		13,440	3,360	127	47

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* Calculated from a

ORDINARY CROPS IN POUNDS PER ACRE.

Sulphur.	Potash.	Soda.	Lime.	Magnesia.	Phosphoric Acid.	Chlorine.	Silica.
lb.	lb.	lb.	lb.	lb.	lb.	lb.	lb.
2.7	9.3	0.6	1.0	3.6	14.2	0.1	0.6
5.1	19.5	2.0	8.2	3.5	6.9	2.4	96.3
7.8	28.8	2.6	9.2	7.1	21.1	2.5	96.9
2.9	9.8	1.1	1.2	4.0	16.0	0.5	11.8
3.2	25.9	3.9	8.0	2.9	4.7	3.6	56.8
6.1	35.7	5.0	9.2	6.9	20.7	4.1	68.6
3.2	9.1	0.8	1.8	3.6	13.0	0.5	19.9
4.8	37.0	4.6	9.8	5.1	6.4	6.1	65.4
8.0	46.1	5.4	11.6	8.7	19.4	6.6	85.3
1.8	6.5	0.2	0.5	3.4	10.0	0.2	0.5
...	29.8	...	...	...	8.0	...	...
...	36.3	...	...	...	18.0	...	...
5.7	50.9	9.2	32.1	14.4	12.3	14.6	56.9
9.4	83.4	5.1	90.1	28.2	24.9	9.8	7.0
4.4	24.3	0.6	2.9	4.2	22.8	1.1	0.4
4.9	42.8	1.7	26.3	5.7	6.3	4.3	6.9
9.3	67.1	2.3	29.2	9.9	29.1	5.4	7.3
15.2	108.6	17.0	25.5	5.7	22.4	10.9	2.6
5.7	40.2	7.5	48.5	3.8	10.7	11.2	5.1
20.9	148.8	24.5	74.0	9.5	33.1	22.1	7.7
14.6	63.3	22.8	19.7	6.8	16.9	6.8	3.1
3.2	16.4	9.2	22.7	2.4	4.8	8.3	3.6
17.8*	79.7	32.0	42.4	9.2	21.7	15.1	6.7
4.9	222.8	69.4	15.9	18.3	36.4	42.5	8.7
9.1	77.9	49.3	27.0	24.2	16.5	40.6	9.2
14.0	300.7	118.7	42.9	42.5	52.9	83.1	17.9
2.7	76.5	3.8	3.4	6.3	21.5	4.4	2.6

single analysis only.

an annual loss of nitrogen equal to that contained in two cwt. of nitrate of soda may take place on unmanured fallow land.

In the drainage from plots long unmanured with nitrogenous substances, 0.43 of nitrogen per 100,000 parts was found. As nitrogen is taken out of soils by crops to a greater extent than phosphoric acid or potash—since the loss in nitrogen by drainage is considerable—and finally, as the amount of nitrogen naturally present in the soil is small,—we can readily understand why it is that this is the first element which usually fails when crops are grown without manure.

Voelcker concludes from his experiments that nitrate of soda is best applied to crops when they are growing, or just immediately before the plants appear above ground. Lawes, however, has observed the beneficial effects of nitrate of soda long after its application. The proportion of rain which passes down into the soil beyond the reach of plants has been found by various experimenters to vary from 25 to 42½ per cent. Probably about one-third of the rain-water that falls is lost by drainage, and two-thirds evaporated or used by plants.

Gains to the Soil.—The losses which the soil sustains by part of its produce being exported and by drainage are compensated for, partly or fully, in three ways: 1st, By absorption of combined nitrogen from the atmosphere, and, according to the most recent results, by the fixation of free nitrogen from the air by leguminous plants; 2d, By artificial or natural manures imported into the farm; 3d, By the manure produced on the farm by the use of imported food.

Gain from the Atmosphere.—The soil gains from the atmosphere some of the most valuable of fertilising agents—nitrogen, sulphates, chlorides, water, and carbonic acid. The gain of nitrogen from the air is not equal to the loss of nitrogen in drainage, unless in the case of very poor soils, supplied with but little manure. There are different atmospheric sources of nitrogen—namely, nitric acid, ammonia, and in the case of leguminous crops, free nitrogen. Nitric acid and ammonia are both very soluble in water, and if carefully sought for, may always be found in rain. We have already considered in a previous chapter, when dealing with the composition of the air, the amount of combined nitrogen it contains—and it was there pointed out that the absolute and relative amounts of ammonia and nitric acid in rain vary in different countries, and in towns and rural districts.

CHAPTER XXIX.

THE VALUATION OF UNEXHAUSTED MANURES IN SOILS.

The potash and other substances required by plants exist for the most part in an inert condition in soils —that is, they require to be reduced to a gelatinous or finely pulverulent condition, or to be set free from certain chemical combinations, before they are in a suitable physical condition for absorption by plants. The amount of this immediately available plant-food is at any given time very small as compared with the quantity yet to be set free, or rendered assimilable. The addition of even very small quantities of certain manurial substances to a soil adds largely to the amount of the available plant-food, though it may not sensibly increase the total quantity of fertilising matter in the soil. In estimating the improvements made by an outgoing occupier of a farm, it has become the practice under certain conditions to place a value upon manures which had been applied to such a farm, but which had not subsequently been wholly removed by crops. It is very difficult to value correctly the unexhausted portion of manures applied from one to say five years previously. Some kinds of manure are very readily taken up by plants, others pass out of the soil very freely, and a portion may assume that temporarily inert condition in which the great mass of plant-food exists in the soil. Potash and phosphates do not, as we have seen, pass readily out of the soil—neither does ammonia;[1] but nitrates are soon carried out of soils by drainage-water. In determining the value of the residue of manures recently applied, there are two points to be considered: 1st, the original value of the manure; 2d, the tendency which it has to pass out of the soil. Sir J. B. Lawes has devoted considerable attention to the elucidation of this difficult matter, and to him and his distinguished colleague, Sir J. Henry Gilbert, we are indebted for many valuable data. When an animal consumes say a cwt. of molasses, the manure which is producible from it is worth next to nothing; but if the animal eats a cwt. of linseed-cake, then the disorganised constituents of the cake, which will pass out of its body, will possess considerable manurial value. Lawes and Gilbert have constructed a table which shows the value of the manure produced by the consumption of all the more commonly used feeding-stuffs.

The Rothamsted experiments have demonstrated that on an average animals remove from their food only about one-tenth of the nitrogen it contains. Probably the amount of phosphoric acid and potash similarly removed from the food by the animal to build up its tissue

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[1] That is, as long as it remains ammonia. It is, however, as we now know, so rapidly converted into nitric acid, that it cannot be regarded as a manure leaving any unexhausted residue behind.

is not a larger proportion of the total amount the food contains. Of course the amount will necessarily differ according to certain conditions, such as the age of the animal—*i.e.*, whether it is growing—and other conditions. It is possible, however, to obtain an approximation of the average amount, and this the Rothamsted experimenters have done (see Tables I. and II., pp. 285, 286).

Table I. gives the total quantities of the fertilising constituents of different foods. Table II. gives the proportion retained by the animal of the different fertilising constituents, and the proportion of the amount voided in the manure, and the manurial value of the food supposing it exercised its full theoretical effect. In point of fact, it is scarcely necessary to say that in practice the complete manurial value of the excreted portion of a food is never completely realised. There are a variety of reasons for this. As we shall have occasion to point out in a future chapter, loss of valuable fertilising ingredients is apt to take place in the fermentation and keeping of farmyard manure. The case when the manurial value of food is most effectively realised will be when stock consume cake in the field. The excreta go in this case directly on to the land. It is impossible to say what the actual manurial value of a food really is, therefore, as so much will depend on different circumstances. For the purpose of estimating the amount of compensation due to the unexhausted manurial value of consumed food, Sir J. B. Lawes has suggested that the original manurial value of each ton of food should be discounted to the extent of 50 per cent for the food consumed within the last year. In the case of food consumed in the last year but one, he suggests a deduction of one-third of the allowance for last year, while for food consumed three years a deduction of one-third from this sum should be made, and so on for whatever number of years down to eight may be taken. It is not desirable to lay down any hard-and-fast rules for estimating the amount of compensation due to the unexhausted manurial value of foods consumed on a farm. As Lawes and Gilbert have remarked, "It is pretty certain indeed that every claim for compensation will have to be settled on its own merits; that the character of the soil, the cropping, the state of the land as to cleanliness, and many other points, will be taken into consideration both for and against any claim." The fact that the money value of different foods is constantly changing renders the revision from time to time of such tables as the following necessary.

With regard to the unexhausted value of different artificial manures, a word or two may be said. In their case consideration must also be paid to the conditions under which they are applied. As a rule it will be safe not to look for much action from such quickly available soluble manures as nitrate of soda and sulphate of ammonia after the first year. Such manures, if not utilised by the crop the first year, are very likely to be entirely washed away in drainage-water. The effect of dissolved phosphates will similarly be chiefly derived the first year, although they may undoubtedly have a slight effect in succeeding years. Guano, bones, slag, and other less quickly available artificial manures, on the other hand, may exercise a beneficial influence for several years after their application. The residual value of artificial manures is very variously assessed in different parts of the country. In the majority of cases, in all probability the tendency is to overrate rather than underrate the durability of manure. As an example of the way in which unexhausted manures are calculated, we may subjoin Table III., p. 288, to which, however, we do not commit ourselves. It may be taken as an example of how tables are drawn up.

TABLE I.—AVERAGE COMPOSITION, PER CENT AND PER TON, OF CATTLE FOODS.

No.	FOODS.	PER CENT.					PER TON.		
		Dry Matter.	Nitrogen.	Mineral Matter (Ash).	Phosphoric Acid.	Potash.	Nitrogen.	Phosphoric Acid.	Potash.
		per cent.	per cent.	per cent.	per cent.	per cent.	lb.	lb.	lb.
1	Linseed	90.00	3.60	4.00	1.54	1.37	80.64	34.50	30.69
2	Linseed-cake	88.50	4.75	6.50	2.00	1.40	106.40	44.80	31.36
3	Decorticated cotton-cake	90.00	6.60	7.00	3.10	2.00	147.84	69.44	44.80
4	Palm-nut-cake	91.00	2.50	3.60	1.20	0.50	56.00	26.88	11.20
5	Undecorticated cotton-cake	87.00	3.75	6.00	2.00	2.00	84.00	44.80	44.80
6	Cocoa-nut-cake	90.00	3.40	6.00	1.40	2.00	76.16	31.36	44.80
7	Rape-cake	89.00	4.90	7.50	2.50	1.50	109.76	56.00	33.60
8	Peas	85.00	3.60	2.50	0.85	0.96	80.64	19.04	21.50
9	Beans	85.00	4.00	3.00	1.10	1.30	89.60	24.64	29.12
10	Lentils	88.00	4.20	4.00	0.75	0.70	94.08	16.80	15.68
11	Tares (seed)	84.00	4.20	2.50	0.80	0.80	94.08	17.92	17.92
12	Indian corn	88.00	1.70	1.40	0.60	0.37	38.08	13.44	8.29
13	Wheat	85.00	1.80	1.70	0.85	0.53	40.32	19.04	11.87
14	Malt	94.00	1.70	2.50	0.80	0.50	38.08	17.92	11.20
15	Barley	84.00	1.65	2.20	0.75	0.55	36.96	16.80	12.32
16	Oats	86.00	2.00	2.80	0.60	0.50	44.80	13.44	11.20
17	Rice-meal[1]	90.00	1.90	7.50	(0.60)	(0.37)	42.56	(13.44)	(8.29)
18	Locust-beans[1]	85.00	1.20	2.50	..	..	26.88	..	..
19	Malt-combs	90.00	3.90	8.00	2.00	2.00	87.36	44.80	44.80
20	Fine pollard	86.00	2.45	5.50	2.90	1.46	54.88	64.96	32.70
21	Coarse pollard	86.00	2.50	6.40	3.50	1.50	56.00	78.40	33.60
22	Bran	86.00	2.50	6.50	3.60	1.45	56.00	80.64	32.48
23	Clover-hay	83.00	2.40	7.00	0.57	1.50	53.76	12.77	33.60
24	Meadow-hay	84.00	1.50	6.50	0.40	1.60	33.60	8.96	35.84
25	Pea-straw	82.50	1.00	5.50	0.35	1.00	22.40	7.84	22.40
26	Oat-straw	83.00	0.50	5.50	0.24	1.00	11.20	5.38	22.40
27	Wheat-straw	84.00	0.45	5.00	0.24	0.80	10.08	5.38	17.92
28	Barley-straw	85.00	0.40	4.50	0.18	1.00	8.96	4.03	22.40
29	Bean-straw	82.50	0.90	5.00	0.30	1.00	20.16	6.72	22.40
30	Potatoes	25.00	0.25	1.00	0.15	0.55	5.60	3.36	12.32
31	Carrots	14.00	0.20	0.90	0.09	0.28	4.48	2.02	6.27
32	Parsnips	16.00	0.22	1.00	0.19	0.36	4.93	4.26	8.06
33	Swedish turnips	11.00	0.25	0.60	0.06	0.22	5.60	1.34	4.93
34	Mangel-wurzels	12.50	0.22	1.00	0.07	0.40	4.93	1.57	8.96
35	Yellow turnips[1]	9.00	0.20	0.65	(0.06)	(0.22)	4.48	(1.34)	(4.93)
36	White turnips	8.00	0.18	0.68	0.05	0.30	4.03	1.12	6.72

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[1] In the case of neither rice-meal, locust-beans, nor yellow turnips have records of ash analyses been found. For rice-meal the same percentages of phosphoric acid and potash as in Indian corn, and for yellow turnips the same as in swedes, are provisionally adopted; but in all the Tables the assumed results are given in parentheses. For locust-beans no figure has been assumed, and the columns are left blank.

Estimate of the Original Manure Value

TABLE II.—SHOWING THE DATA, THE METHOD, AND THE RE-
OF CATTLE FOODS

DESCRIPTION OF FOOD.	Fattening Increase in Live Weight (Oxen or Sheep).		NITROGEN.								
			In Food.		In Fattening Increase (at 1.27 per cent).		In Manure.				
	Food to 1 Increase.	Increase per ton of Food.	Per cent.	Per ton.	From 1 ton of Food.	Per cent of total consumed.	Total remaining for Manure.	Nitrogen equal Ammonia.	Value of Ammonia at 6d. per lb.		
		lb.	%	lb.	lb.	%	lb.	lb.	£	s.	d.
Linseed	5.0	448.0	3.60	80.64	5.69	7.06	74.95	91.0	2	5	6
Linseed-cake	6.0	373.3	4.75	106.40	4.74	4.45	101.66	123.4	3	1	8
Decorticated cotton-cake	6.5	344.6	6.60	147.84	4.38	2.96	143.46	174.2	4	7	1
Palm-nut-cake	7.0	320.0	2.50	56.00	4.06	7.25	51.94	63.1	1	11	7
Undecorticated cotton-cake	8.0	280.0	3.75	84.00	3.56	4.24	80.44	97.7	2	8	10
Cocoa-nut-cake	8.0	280.0	3.40	76.16	3.56	4.67	72.60	88.2	2	4	1
Rape-cake	(10)	(224)	4.90	109.76	2.84	2.59	106.92	129.8	3	4	11
Peas	7.0	320.0	3.60	80.64	4.06	5.03	76.58	93.0	2	6	6
Beans	7.0	320.0	4.00	89.60	4.06	4.53	85.54	103.9	2	11	11
Lentils	7.0	320.0	4.20	94.08	4.06	4.32	90.02	109.3	2	14	8
Tares (seed)	7.0	320.0	4.20	94.08	4.06	4.32	90.02	109.3	2	14	8
Indian corn	7.2	311.1	1.70	38.08	3.95	10.37	34.13	41.4	1	0	9
Wheat	7.2	311.1	1.80	40.32	3.95	9.80	36.37	44.2	1	2	1
Malt	7.0	320.0	1.70	38.08	4.06	10.66	34.02	41.3	1	0	8
Barley	7.2	311.1	1.65	36.96	3.95	10.69	33.01	40.1	1	0	1
Oats	7.5	298.7	2.00	44.80	3.79	8.46	41.01	49.8	1	4	11
Rice-meal	7.5	298.7	1.90	42.56	3.79	8.91	38.77	47.1	1	3	6
Locust-beans	9.0	248.9	1.20	26.88	3.16	11.76	23.72	28.8	0	14	5
Malt-combs	8.0	280.0	3.90	87.36	3.56	4.08	83.80	101.8	2	10	11
Fine pollard	7.5	298.7	2.45	54.88	3.79	6.91	51.09	62.0	1	11	0
Coarse pollard	8.0	280.0	2.50	56.00	3.56	6.35	52.44	63.7	1	11	10
Bran	9.0	248.9	2.50	56.00	3.16	5.64	52.84	64.2	1	12	1
Clover-hay	14.0	160.0	2.40	53.76	2.03	3.78	51.73	62.8	1	11	5
Meadow-hay	15.0	149.3	1.50	33.60	1.90	5.65	31.70	38.5	0	19	3
Pea-straw	16.0	140.0	1.00	22.40	1.78	7.95	20.62	25.0	0	12	6
Oat-straw	18.0	124.4	0.50	11.20	1.58	14.11	9.62	11.7	0	5	10
Wheat-straw	21.0	106.7	0.45	10.08	1.36	13.49	8.72	10.6	0	5	4
Barley-straw	23.0	97.4	0.40	8.96	1.24	13.84	7.72	9.4	0	4	8
Bean-straw	22.0	101.8	0.90	20.16	1.29	6.39	18.87	22.9	0	11	6
Potatoes	60.0	37.3	0.25	5.60	0.47	8.39	5.13	6.2	0	3	1
Carrots	85.7	26.1	0.20	4.48	0.33	7.37	4.15	5.0	0	2	6
Parsnips	75.0	29.9	0.22	4.93	0.38	7.71	4.55	5.5	0	2	9
Swedish turnips	109.1	20.5	0.25	5.60	0.26	4.64	5.34	6.5	0	3	3
Mangel-wurzels	96.0	23.3	0.22	4.93	0.30	6.09	4.63	5.6	0	2	10
Yellow turnips	133.3	16.8	0.20	4.48	0.21	4.69	4.27	5.2	0	2	7
White turnips	150.0	14.9	0.18	4.03	0.19	4.71	3.84	4.7	0	2	4

SULTS OF THE ESTIMATION OF THE ORIGINAL MANURE VALUE AFTER CONSUMPTION.

PHOSPHORIC ACID.						POTASH.						
In Food.		In Fattening Increase at (0.86 per cent).		In Manure.		In Food.		In Fattening Increase at (0.11 per cent).		In Manure.		Total original Manure value per ton of Food consumed
Per cent.	Per ton.	From 1 ton of Food.	Per cent of total consumed.	Total remaining for Manure.	Value at 3d. per lb.	Per cent.	Per ton.	From 1 ton of Food.	Per cent of total consumed.	Total remaining for Manure.	Value at 2½d. per lb.	
°/°	lb.	lb.	°/°	lb.	s d.	°/°	lb.	lb.	°/°	lb.	s. d.	£ s. d.
1.54	34.50	3.85	11.16	30.65	7 8	1.37	30.69	0.49	1.60	30.20	6 3	2 19 5
2.00	44.80	3.21	7.17	41.59	10 5	1.40	31.36	0.41	1.31	30.95	6 5	3 18 6
3.10	69.44	2.96	4.26	66.48	16 8	2.00	44.80	0.38	0.85	44.42	9 3	5 13 0
1.20	26.88	2.75	10.23	24.13	6 0	0.50	11.20	0.35	3.13	10.85	2 3	1 19 10
2.00	44.80	2.41	5.38	42.39	10 7	2.00	44.80	0.31	0.69	44.49	5 11	3 5 4
1.40	31.36	2.41	7.68	28.95	7 3	2.00	44.80	0.31	0.69	44.49	9 3	3 0 7
2.50	56.00	1.93	3.45	54.07	13 6	1.50	33.60	0.25	0.74	33.35	6 11	4 5 4
0.85	19.04	2.75	14.44	16.29	4 1	0.96	21.50	0.35	1.63	21.15	4 5	2 15 0
1.10	24.64	2.75	11.16	21.89	5 6	1.30	29.12	0.35	1.20	28.77	6 0	3 3 5
0.75	16.80	2.75	16.37	14.05	3 6	0.70	15.68	0.35	2.23	15.33	3 2	3 1 4
0.80	17.92	2.75	15.35	15.17	3 9	0.80	17.92	0.35	1.95	17.57	3 8	3 2 1
0.60	13.44	2.68	19.94	10.76	2 8	0.37	8.29	0.34	4.10	7.95	1 8	1 5 1
9.85	19.04	2.68	14.08	16.36	4 1	0.53	11.87	0.34	2.86	11.53	2 5	1 8 7
0.80	17.92	2.75	15.35	15.17	3 9	0.50	11.20	0.35	3.13	10.85	2 3	1 6 8
0.75	16.80	2.68	15.95	14.12	3 6	0.55	12.32	0.34	2.76	11.98	2 6	1 6 1
0.60	13.44	2.57	(19.12)	10.87	2 8	0.50	11.20	0.33	2.94	10.87	2 3	1 9 10
(0.60)	(13.44)	2.57	(19.12)	(10.87)	(2 8)	(0.37)	(8.29)	0.33	(4.00)	(7.96)	(1 8)	(1 7 10)
..	..	2.14	..	..	..	..	..	0.27	..	..	..	..
2.00	44.80	2.41	5.38	42.39	10 7	2.00	44.80	0.31	0.69	44.49	9 3	3 10 9
2.90	64.96	2.57	3.96	62.39	15 7	1.46	32.70	0.33	1.01	32.37	6 9	2 13 4
3.50	78.40	2.41	3.07	75.99	19 0	1.50	33.60	0.31	0.92	33.29	6 11	2 17 9
3.60	80.64	2.14	2.65	78.50	19 8	1.45	32.48	0.27	0.83	32.21	6 8	2 18 5
0.57	12.77	1.38	10.81	11.39	2 10	1.50	33.60	0.18	0.54	33.42	7 0	2 1 3
0.40	8.96	1.28	14.28	7.68	1 11	1.60	35.84	0.16	0.45	35.68	7 5	1 8 7
0.35	7.84	1.20	15.31	6.64	1 8	1.00	22.40	0.15	0.67	22.25	4 8	0 18 10
0.24	5.38	1.07	19.89	4.31	1 1	1.00	22.40	0.14	0.63	22.26	4 8	0 11 7
0.24	5.38	0.92	17.10	4.46	1 1	0.80	17.92	0.12	0.67	17.80	3 8	0 10 1
0.18	4.03	0.84	20.84	3.19	0 9	1.00	22.40	0.11	0.49	22.29	4 8	0 10 1
0.30	6.72	0.88	13.10	5.84	1 5	1.00	22.40	0.11	0.49	22.29	4 8	0 17 7
0.15	3.36	0.32	9.52	3.04	0 9	0.55	12.32	0.04	0.32	12.28	2 7	0 6 5
0.09	2.02	0.22	10.89	1.80	0 5	0.28	6.27	0.03	0.48	6.24	1 4	0 4 3
0.19	4.26	0.26	6.10	4.00	1 0	0.36	8.06	0.03	0.37	8.03	1 8	0 5 5
0.06	1.34	0.18	13.43	1.16	0 4	0.22	4.93	0.02	0.41	4.91	1 0	0 4 7
0.07	1.57	0.20	12.74	1.37	0 4	0.40	8.96	0.03	0.34	8.93	1 10	0 5 0
(0.06)	(1.34)	0.14	(10.78)	(1.20)	(0 4)	(0.22)	(4.93)	0.02	(0.34)	(4.91)	(1 0)	(0 3 11)
0.05	1.12	0.13	11.61	0.99	0 3	0.30	6.72	0.02	0.30	6.70	1 5	0 4 0

TABLE III.—ESTIMATED MONEY VALUE of the UNEXHAUSTED RESIDUE of MANURES remaining after the Growth of different Crops, expressed in Shillings for every Twenty Shillings original *Manure Value* of the Purchased Feeding-Stuff or Manure employed.

AFTER.		Purchased or saleable food.	Farmyard or town-stable manure.	Rape-cake, or other cake used as manure.	Bones.	Nitrate of soda.	Sulphate of ammonia.	Guano, in natural state or manufactured.	Compound artificial or refuse manures.	Superphosphate, made from mineral phosphates.
		Shillings allowable for every 20 shillings original *manure value.*								
	Purchased (or saleable) feeding-stuff consumed with roots, or manure applied for roots.									
1st year	Food consumed with roots on land . .	17	...	...	...	...	...	...	...	...
	Food consumed with roots in yards . .	16	...	...	...	...	...	...	...	...
	Manure applied to roots consumed on land	...	17	16	17	15	15	15	12	9
	Manure applied to roots consumed in yards	...	16	15	16	14	14	14	10	8
2d year	Corn crop; grain sold, straw left . .	7	9	7	8	4	4	4	2	2
3d year	Corn crop; grain sold, straw left	1	3	1	2	1	2	1	...	...
3d year	Grass or hay consumed	2	5	3	4	2	1	2	...	...
4th year	Grass or hay consumed . . .	...	2	...	1	...	...	...	...	...
3d year	Hay sold	...	2	...	1	...	...	...	...	...

	Manure applied for a corn-crop.									
1st year	Corn crop; grain sold, straw left	...	12	7	...	6	6	6	6	5
2d year	Corn crop; grain sold, straw left	...	6	1	...	...	...	...	...	...
2d year	Grass or hay consumed	...	8	3	...	1	1	1	1	...
3d year	Grass or hay consumed	...	4	1	...	...	...	...	...	...
2d year	Hay sold	...	4	...	...	...	...	...	...	...
	Feeding-stuff consumed on, or manure applied to, grass-land—grazed.									
1st year	Grazed	18	18	...	18	16	16	16	14	12
2d year	Grazed	12	14	...	13	10	10	10	6	4
3d year	Grazed	4	8	...	6	2	2	2	...	...
4th year	Grazed	...	2	...	1	...	...	...	...	...
	Feeding-stuff consumed on, or manure applied to, grass-land—hay consumed.									
	No crop	18	...	...	...	...	...	...	...	...
1st year	Hay consumed	11	16	...	16	14	14	14	13	10
2d year	Hay consumed	2	12	...	10	8	8	8	4	2
3d year	Hay consumed	...	6	...	3	1	1	1	...	...
4th year	Hay consumed	...	...	...	...	...	...	...	...	...
	Feeding-stuff consumed on, or manure applied to, grass-land—hay sold.									
	No crop	18	...	...	...	...	...	...	...	...
1st year	Hay sold	2	10	...	10	2	2	2	2	...
2d year	Hay sold	...	4	...	4	...	...	...	...	...
3d year	Hay sold	...	...	...	...	...	...	...	...	...

CHAPTER XXX.

FARMYARD MANURE AND ANIMAL EXCREMENTS.

Farmyard Manure is a complex fertiliser of variable composition and value. It consists essentially of straw-litter and the *excreta* of oxen and horses, but it also often contains the excrements of the pig and sheep, house-offal, turnip and mangel tops, and various other refuse matters. The composition of the manure will depend on the animals contributing it, the nature of their food, and the nature and amount of litter added. The excrements of fattening animals being almost altogether retained by their litter, a rich manure is the result. The nature of the litter has also some—but less—influence on the quality of the manure; straw contributing most, and sawdust least, fertilising materials to the compost.

The small amount of ash in the (calculated) composition of the manure by Lawes and Gilbert is accounted for by the fact that in the ordinary manure there is always some earthy matter mixed up. The fresh manure analysed by Voelcker was fourteen days old; it was composed of litter and the *excreta* of horses, cows, and pigs: the rotten manure was six months old. Anderson's analysis refers to the average composition of eight specimens of farmyard manure produced upon Scotch farms, and which appear on the whole to be poor fertilisers. No. 8 analysis is that of farmyard manure exposed for months to rain, by which much of its soluble matters had been washed out.

PERCENTAGE COMPOSITION OF FARMYARD MANURE.

	1. Lawes & Gilbert (calculated).	2. Anderson.	3. Boussingault.	4. Voelcker.		5. E. Wolff.	6. Cameron.	
				Fresh.	Rotten.		Fresh.	Long exposed to rain.
Water	70.00	72.48	79.30	66.17	75.42	75.00	69.14	73.22
1 Organic matter	27.23	13.94	14.03	28.24	16.53	18.09	24.21	21.17
2 Ash	2.77	13.58	6.67	5.59	8.05	6.91	6.65	5.61
	100.00	100.00	100.00	100.00	100.00	100.00.	100.00	100.00
1 Containing nitrogen	0.64	0.38	0.41	0.64	0.71	0.53	0.50	0.12
2 Containing potash	0.53	0.32	not	0.67	0.49	0.68	not	not
and Phosphoric acid . .	0.23	0.31	stated.	0.31	0.45	0.32	stated.	stated.

The following is a complete analysis of farmyard manure fourteen days old, and composed of horse, cow, and pig dung :—

100 parts contain—

Water		66.17
[1] Soluble organic matter		2.48
Soluble inorganic matter (ash) :—		
Soluble silica	.237	
Tricalcic-phosphate	.299	
Lime	.066	
Magnesia	.011	
Potash	.573	
Soda	.051	
Sodium chloride	.030	
Sulphuric acid	.055	
Carbonic acid and loss	.218	
		1.54
[2] Insoluble organic matter		25.76
Insoluble inorganic matter (ash) :—		
Soluble silica	.967	
Insoluble silica	.561	
Oxide of iron, alumina, with phosphates	.596	
(Containing phosphoric acid	.178)	
(Equal to tricalcic phosphate	.386)	
Lime	1.120	
Magnesia	0.143	
Potash	.099	
Soda	.019	
Sulphuric acid	.061	
Carbonic acid and loss	.484	
		4.05
		100.00
[1] Containing nitrogen		.149
[2] Containing nitrogen		.409
Whole manure contains free ammonia		.034
" " " in form of salts		.088

Animal Excreta. — The urine of animals is far more valuable as a manure than their solid excrements, yet greater care is taken to preserve the latter, the former being in great part too often allowed to run into the drains. The following is the approximate composition of the solid and liquid excrements of the animals of the farm.

Cattle-dung is the most abundant, and least valuable in composition, of the animal manures. It decomposes slowly, giving out but little heat; hence it is said to be a *cold* manure. This is quite correct, for manures, such as horse-dung, which decompose rapidly in the soil, warm the latter. Decomposition in such cases is really a slow combustion. The urine of oxen is richer in fertilising matters than their solid excrements; yet we often find that farmers who take good care of the dung of their oxen permit the urine to be wasted.

Horse-dung is more valuable than cattle-dung. It contains less water, is not so coherent, and does not form during its decomposition an unctuous mass such as cattle-dung does. Horse-dung decomposes rapidly, and is therefore a *hot* manure. It is a useful addition to cattle-dung, as it renders the latter more friable, whereby it can be more equably distributed throughout the soil.

Sheep-dung decomposes more rapidly than cattle-dung, and not so quickly as horse-dung. It is richer in solid matters than the former.

Pig-dung. — The pig being almost an omnivorous animal, its excrements vary in composition according to the nature of its food. Its dung is soft and compact, and it decomposes slowly. It may be either one of the poorest or one of the richest kinds of animal manure, according to feeding; but it is alleged that when used alone as a manure, it gives a disagreeable flavour to roots. On the Continent, pig-dung is largely applied to the hemp crop.

The analyses of the animal excrements which have been made in the past show how extremely variable their composition is. It is impossible to give in such a case an average analysis, as so much depends on the conditions under which the excrements are produced. In *Gorup-Besanez's Lehrbuch der Physiologischen Chemie*, the following analyses are given:—

Composition of Animal Fæces.

100 parts of each contain—

	Pig.	Cow.	Sheep.	Horse.
Water	77.13	82.45	56.47	77.25
Solid matters	22.87	17.55	43.53	22.75
	100.00	100.00	100.00	100.00
	Pig.	Cow.	Sheep.	Horse.
Ash	8.50	2.67	5.87	3.04
The ash includes, per 100 parts—				
Potash	3.60	2.91	8.32	11.30
Phosphoric acid	5.39	8.47	9.40	10.22

In Stöckhardt's 'Agricultural Chemistry,' the composition and money value (in Germany) of animal excrements are given as follows:—

Composition of Dung of Animals.

	Cows fed during winter.	Horses fed during winter.	Sheep fed upon nearly 2 lb. hay daily.	Horses fed upon strong food during winter.
Water	840	760	580	800
[1]Solid matters	160	240	420	200
	1000	1000	1000	1000
[1] Including—				
Nitrogen	3	5	7.5	6
Potash and soda	1	3	3.0	5
Money value, per 1000 lb.	3s.	5s.	7s. 8d.	5s. 8d.

According to Stöckhardt, cow's urine contains 8 per cent of solid matters (including 0.8 per cent nitrogen, and 1.4 per cent potash and soda); horse's urine, 11 per cent of solids (including 1.2 per cent nitrogen, and 2 per cent potash and soda); sheep's urine, 13 per cent of solids (including 1.4 per cent nitrogen, 2 per cent potash and soda, and 0.05 per cent phosphoric acid); and pig's urine, 25 per cent of solids (including 3 per cent nitrogen, 2 per cent potash and soda, and 0.125 per cent phosphoric acid).

In Cameron's 'Chemistry of Agriculture,' the following analyses are given:—

1000 PARTS OF ANIMAL EXCREMENTS CONTAIN—

	COW.		HORSE.		SHEEP.		PIG.	
	Dung.	Urine.	Dung.	Urine.	Dung.	Urine.	Dung.	Urine.
Water . . .	860	915	750	900	640	950	760	976
[1]Solid matters .	140	85	250	100	360	50	240	24
	1000	1000	1000	1000	1000	1000	1000	1000
[1]Containing—								
Nitrogen . . .	3.6	9	6.0	11	6	8	7.0	3.0
Phosphoric acid .	3.0	...	4.0	...	5	...	5.0	1.2
Potash and soda .	2.2	16	3.5	14	3	8	6.5	2.0

Voelcker analysed the fresh dung of sheep fed upon roots placed on old pasture, and obtained the following results :—

100 parts contained—

Water	73.13
[1]Organic matter	20.28
Ash	6.59
	100.00
[1]Containing nitrogen	0.95
Equal to ammonia	1.15

The urine of horses, cows, and sheep is very alkaline, and contains a large amount of *hippuric acid*, which is highly nitrogenous. Pig's urine is also alkaline: it contains urea, but not hippuric acid.

The amounts of urine and dung voided by the farm animals are variously estimated. Stöckhardt's estimates are as follows :—

Average Quantities of Excrements voided yearly by the

	Cow.	Horse.	Sheep.	Pig.
	lb.	lb.	lb.	lb.
Dung	20,000	12,000	760	1800
Urine	8,000	3,000	380	1200
Total	28,000	15,000	1140	3000
Money value (in Germany)	£5, 14s.	£4, 10s.	10s. 6d.	13s.

Stöckhardt's estimates in the case of the cow are evidently too high; whilst Dr Thomson appears to be under the correct figures in giving the average annual amount of the dung of the cow at 3100 lb. Boussingault states that the average annual yield of urine from the cow is 6510 lb. Mr T. Baldwin of Glasnevin states that, from observations which he caused to be made, he found that horses gave 12 lb. of urine daily—and cows, well fed, 70 lb.

In a trial made with different kinds of dung as a manure for barley, the following results were obtained, equal quantities of the manures being used :—

	Barley.		Barley.
Cow-dung	167 lb.	Pig-dung	233 lb.
Horse-dung	226 "	Sheep-dung	244 "

Bird's dung.—The bird voids but one excrement, which partakes more of the nature of urine than of fæces. It is a good manure, but it is not usually obtained in these countries in large quantities. The manure from the poultry-yard, such as it is, should be carefully gathered up and added to the compost-heap. The same observation applies to the dung of pigeons, which in some farmsteads is occasionally produced in large quantities. A specimen of pigeon's dung, collected fresh, and as free as possible from admixture with earthy matters, was found by Professor Anderson to contain—

Water	58.32
[1] Organic matter	28.25
Phosphates	2.69
Sulphate of lime	1.75
[2] Alkaline salts	1.99
Sand	7.00
	100.00
[1] Yielding ammonia	1.75
[2] Containing phosphoric acid, equal to phosphate of lime	0.10

COMPOSITION OF DUNG OF BIRDS (ANDERSON).

100 parts contain—

	Hen.	Duck.	Goose.
Water	60.88	46.65	77.08
[1] Organic matter, &c.	19.22	36.12	13.44
Phosphates	4.47	3.15	0.89
Calcium carbonate	7.85	3.01	...
[2] Alkaline salts	1.09	0.32	2.94
Sand	6.69	10.75	5.65
	100.00	100.00	100.00
[1] Yielding ammonia	0.74	0.85	0.67
[2] Containing phosphoric acid, equal to tricalcic phosphate	0.07	trace	0.12

Boussingault has described pigeons' dung to be of extremely high value; but he analysed the article as imported in a dried condition from Egypt, and therefore more of the nature of guano than of dung.

In Flanders, the manure of 100 pigeons is considered to be worth 20s. a-year for agricultural purposes. In Catalonia, Aragon, and some other parts of Spain, pigeons' dung is sold as high as 4d. a pound, for applying, when mixed with water, to flower-roots, melons, tomatoes, and other plants. The estimation in which it was held in ancient Palestine may be inferred from the statement that, during a siege of Samaria, the fourth part of a cab of doves' dung was sold for five pieces of silver—2 Kings vi. 25. That which is here translated *doves' dung* was, however, considered by Linnæus to mean the bulbous root of the *Ornithogallum umbellatum*, still eaten in Palestine, and forming part of the food of some of the tribes of Hottentots at the Cape of Good Hope.

Straw.—The straw (oat, wheat, and barley) which forms the bedding of cattle enters into the composition of most kinds of farmyard manure. It contains on an average about 5 parts of nitrogen, 10 of potash, and 3 of phosphoric acid, per 1000 parts. As from 2000 to 3000 lb. of straw are produced from an acre of a corn crop, this substance restores to the soil a considerable proportion of the fertilising matters extracted from it. In addition to straw, bracken fern, peat-moss, sawdust, and other substances may be used as litter. Of these, peat-moss has been found to make an admirable litter, and is now increasingly used.

CHAPTER XXXI.

THE STORAGE AND APPLICATION OF FARMYARD MANURE.

Changes which Farm Manure undergoes in Storage.—Fresh farmyard manure generally contains about 65 to 80 per cent of water, and 35 to 20 per cent of (dry) organic and earthy matters. Only a very small proportion of the dry matters consists of substances soluble in water. In a short time, however, the organic matters—straw, &c.—begin to ferment, one result of which process is the production of soluble compounds. Fresh manure produces but little effect when applied to crops; but when it is far advanced in decomposition (*i.e.*, well rotted), it then contains so much soluble matter absorbable by plants that it acts as a powerful fertiliser (if used in sufficient quantity).

In fresh manure, the most important constituent of its soluble portion is potash; of phosphoric acid and ammonia it contains but very small proportions. Rotten manure, on the contrary, yields to the solvent action of water larger amounts of nitrogen and phosphoric acid. If good fresh farmyard manure be dried at 212° F., the soluble organic matters of the residue will be found to amount to from 7 to 8 per cent, and its soluble mineral matters to from 4 to 5 per cent. On the other hand, dry rotten farmyard manure contains from 13 to 16 per cent of soluble organic matters, and 5 to 6 per cent of soluble mineral substances.

Fermentation depends on the condition of the heap. The more open that is and the more loosely the manure is compressed, the quicker it goes on. On the other hand, when compressed and when air is excluded it goes on least rapidly.

The total percentage of nitrogen in farmyard manure may be stated at from .4 to .657, the total potash .4 to .7, and phosphoric acid .2 to .4. Thus one ton may contain from 9 to 15 lb. of nitrogen and potash, 4 to 9 lb. of phosphoric acid.

Dr Voelcker has shown that there is very little *free* ammonia in either fresh or old farmyard manure, and that the peculiar odour of the latter is not due, as popularly supposed, to the escape of ammonia from the manure. In the hot centre of a fermenting dung-heap some free ammonia is formed, but this is prevented from escaping by the cold outer layers of the manure, which act like a chemical filter.

Dr Voelcker, in a paper of great value, published in the 17th volume of the Royal Agricultural Society, gives the following summary of the changes which farmyard manure undergoes in storage:—

1. That during the fermentation of dung, the proportion of both soluble organic and soluble mineral matters rapidly increases.

2. That peculiar organic acids, not existing—at least, not in considerable quantities—are generated during the ripening of dung from the litter and other non-nitrogenised organic constituents of manure.

3. That these acids (humic, ulmic, and similar acids) form, with potash, soda, and ammonia, dark-coloured, very soluble compounds. Hence the dark colour of the drainings of dung-heaps.

4. That ammonia is produced from the nitrogenous constituents of dung, and that this ammonia is fixed for the greater part by the humus substances produced at the same time.

5. That a portion of the sulphur and phosphorus of

the excrementitious matters of dung is dissipated in the form of sulphuretted and phosphoretted[1] hydrogen.

6. That volatile ammoniacal compounds, apparently in inconsiderable quantities, escape into the air.

7. That the proportion of organic substances in fresh dung rapidly decreases during the fermentation of dung, whilst the mineral substances increase in a corresponding degree.

8. That this loss of organic substances is accounted for by the formation of carbonic acid, carbon monoxide, and light carburetted hydrogen, or marsh gas.

9. That the proportion of nitrogen is larger in rotten than in fresh dung (dry weights).

Loss of Fertilising Matters from Manure.—The experiments of Voelcker show that farmyard manure does not lose much of its valuable fertilising constituents by exposure to air, heat, and light. The deterioration which ill-kept manure-heaps undergo is therefore due to losses by drainage. The dark-coloured liquid which we too often observe trickling away from badly kept dung-heaps is rich in nitrogen, phosphoric acid, and potash.

Koerte found that 100 loads of dung kept in the usual wasteful manner were reduced at the end of—

	Loads.		Loads.
81 days to	73.3,	sustaining a loss of	26.7
285 "	64.4,	" "	35.6
384 "	62.5,	" "	37.5
499 "	47.2,	" "	52.8

Thus in sixteen months more than one-half—and that the most valuable portion—of the manure had disap-

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[1] It is not probable that phosphoretted hydrogen is given off during the decay of any kind of ordinary organic matter. Plösz and Hoppe-Seyler found that decomposing fish emitted sulphuretted hydrogen, but not phosphoretted hydrogen.—C. A. C.

peared, leaving a highly carbonaceous matter, poor in all the elements of fertility.

Voelcker analysed a specimen of pig-dung which a farmer had kept for three years, in the expectation of converting it into an excellent turnip-manure. It was greasy, black, and had an earthy rather than an animal odour. 100 parts contained—

Water	73.66
[1]Soluble organic matter	2.70
[2]Insoluble organic matter	9.95
[3]Soluble inorganic matter	2.68
Insoluble inorganic matter	11.03
	100.00
[1]Containing nitrogen	0.157
[2]Containing nitrogen	0.470
	0.627
[3]Containing calcium phosphate	0.577
And potash	0.376
Containing phosphoric acid (equal to calcium phosphate, 1.176)	0.543
And potash	0.317
Total nitrogen (equal to ammonia, 0.770)	0.627
Total calcium phosphate	1.753
Total potash	0.693

It seems certain that at least half the amount of fertilising matter contained originally in this dung was lost by keeping the manure too long

Application of Farmyard Manure.—Instead of keeping farmyard manure for months or years in heaps, exposed to rain, as is too often the case, Voelcker recommends its immediate application to the soil—that is, whenever the conditions of labour, &c., on the farm admit of it, the manure should be carted out to the field, and either put into the soil at once or spread over it. In the latter case, no loss of any consequence would be sustained by evaporation; whilst the soluble matters would, if rain fell, be merely washed into the soil, in which they would be securely retained until required by the crop. Voelcker appears to consider that it is better to let the rain wash the soluble matters into the soil in a uniform manner than to plough in the fresh manure at once. The objection to allowing manure to be washed by the rain after being applied to the field is, that fermentation of the manure will not take place so rapidly after the manure is incorporated with the soil, owing to its having lost its soluble nitrogenous compounds. He believes that on clay soils manure may be safely spread for six months before it is ploughed in; but of course on very porous sandy soils it is preferable to apply the manure, previously well fermented, shortly before the time it is required for the crop.

Manure made under Cover.—Manure produced by cattle in boxes, and afterwards kept under cover, is much superior to ordinary farmyard manure. Lord Kinnaird experimented with the manure produced from a certain number of animals under cover—and from a like number of animals of the same kind and age, and fed similarly, kept in an open yard—and obtained the following results:—

Manure produced under cover.	Manure not produced under cover.
1st year, potatoes = 11¼ tons per acre.	1st year, potatoes = 7 tons 12 cwt. per acre.
2d year, wheat=corn, 54 bush.; straw, 215 stones.	2d year, wheat=corn, 42 bush.; straw, 156 stones.

Manure made under cover owes its richness to the circumstance that less straw is required to bed the cattle, and also that the urine of the animals, which in open yards is chiefly wasted, is almost altogether preserved in the box-made manure. Mr Way analysed manure made in boxes on Mr Charles Laurence's well-known farm near Cirencester, and found its composition to be as follows:—

100 parts contained—

	Box manure.	Ordinary Farmyard manure.
Water	71.40	71.00
[1] Dry matter	28.60	29.00
	100.00	100.00
[1] Containing nitrogen, equal to ammonia	2.37	1.70
Phosphoric acid	0.30	0.26
Potash and soda	2.00	0.80

Manure-Drainings.—The dark-coloured liquid which trickles out of manure-heaps has been analysed by Voelcker. He found one imperial gallon (70,000 grains) to contain 1357.74 grains of solid matters; including nitrogen, 31.08 grains—phosphates of calcium and iron, 72.65 grains—and carbonate and chloride of potassium, 358.02 grains. In other instances Voelcker found from 353.36 grains of solids to 764.64 grains per gallon.

The older farmyard manure is, the more soluble will it be, and consequently the more liable to deterioration by exposure to rain. Perfectly fresh manure does not lose much by the action of rain upon it, especially if it be stored in large quantity.

The drainings from manure-heaps, and animal manures generally, should not, when stale, be mixed with quicklime, because that substance would cause them to lose, though not largely, ammonia. If they have to be kept for a considerable time, the addition of a little gypsum will be found useful. Liquid manure, especially when diluted, loses, however, but little valuable matter by evaporation.

Liquid-manure Tank.—Every farmstead should be provided with at least one tank for the storage of liquid manure. Into this all the sewers or drains from stables, privies, laundries, &c., should empty their contents. If this were always done, there would be fewer cases of foul water being drunk by the dwellers in houses near farmsteads. The shafts of the pumps near the houses of farmers too often collect the sewage, which, if proper provision had been made, should have gone into the liquid-manure tank. Water contaminated with decomposing animal matter is a common cause of disease, and this polluted water is very often that which is alone used by the farmer and his family.

Deep tanks for the storage of liquid manure are not, as a rule, desirable, as it is difficult to prevent their contents from leaking out. From 6 to 7 feet will be sufficient depth, or even less, when the land is unfavourably circumstanced with regard to drainage. To save expense in arching, the width need not exceed from 6 to 8 feet; but the capacity of the tank may be secured by extending the length of it so far as may be found necessary. Two or more tanks may also be built side by side.

When the soil underlying the site of the tank is so stiff as not readily to allow of the passage of water, the expense of flagging the bottom of the tank and of building its walls will not be great; but when the excavations necessary for the construction of the tank are made in wet ground, or one abounding in springs, the following precautions should be adopted in order to prevent leakage from the tanks. In the case of springs, intercept and discharge them into the nearest drains. In the other case, puddle the bottom of the tank with stiff, tenacious clay, behind and under the stone and brick work. This is best done as follows: A coating of welltempered clay, but only slightly moist, is spread over the bottom of the excavation and well rammed down, so as to form a layer about one foot in depth, and one foot in every direction beyond the site of the intended foundations of the walls. This done, the bottom, including the space necessary for the foundations of the walls, is to be paved with flags, well jointed, or with bricks set edgeways. As the walls are being carried up, a layer of puddle a foot thick should be rammed in between them and the surrounding earth. Rubble masonry or bricks may be used in the construction of the arches. Each tank, in addition to an opening to admit of a pump, should have a man-hole at each end to permit free admission to the interior. The tanks are best placed so that when full they will be under the level of the discharging-pipe. The best conduits from the sources of the manure to the tanks are glazed earthen pipes, jointed with cement.

CHAPTER XXXII.

GUANO.

Peruvian Guano.—The term *guano* is a corruption of the Peruvian word *huano*, signifying dung. Guano was used for manurial purposes by the aboriginal inhabitants of Peru; and it is stated that it was held in such high estimation by the Peruvians, that the penalty of death was inflicted on those convicted of the offence of killing the sea-fowl whose excrements constituted this valuable manure. The crops to which it was chiefly applied were maize and capsicums.

There are large numbers of rocks and small islands on the coast of Peru which are resorted to by vast numbers of birds. The droppings of these denizens of the air, and in some cases their bodies, constitute, when dried, the substance termed guano. In cold and rainy climates, extensive guano-deposits are not formed; this substance is only found on islands or rocks elevated above the reach of the waves, and on which rain seldom or rarely descends. The excrements of the birds are rapidly dried by the heat of the sun, and, after desiccation, undergo but little further changes of any importance.

Deposits of guano are found in many dry and hot parts of the world, but up to the present Peru has yielded the chief supplies; in some years the imports of Peruvian guano into the United Kingdom have exceeded 200,000 tons.

For a great number of years Peruvian guano was obtained almost exclusively from the three "Chinchas," islets in latitude 13° 44′ S., longitude 76° 13′ W. The deposits on these islets have now been entirely exhausted; and recent importations have been chiefly from Punta de Lobos, Huanillos, Pabillon de Pica, and Lobos de Afuera. Quite recently a very high-class guano has been discovered in Corcovado. In these localities the deposits are in many parts more than 100 feet in depth; and in 1874 Mr Spring estimated the amount of guano at Pabillon de Pica alone to be 5,000,000 tons.

Peruvian guano varies in colour from a very light yellow or grey to a dark brown hue. It occurs in the form of a powder mixed with lumps mostly of a crystalline nature, and somewhat difficult to reduce to powder. Guano is rather light, a bushel weighing about 70 lb.; adulterated guano is generally much heavier.

Guano is a very complex substance. Amongst the compounds which have been found in it may be enumerated ammonium carbonate, oxalate, phosphate, urate, ulmate, humate, and chloride; potassium sulphate, chloride, and phosphate; calcium phosphate, carbonate, and oxalate; microcosmic salt ($HNa(NH_4)PO_4$, $4H_2O$), ammonium magnesium phosphate; sodium sulphate and chloride, a peculiar substance termed *avic acid*, united with bases; guanine, organic matter of undetermined nature, waxy matter, sand, water, &c. Guanine ($C_5H_5N_5O$) is a nitrogenous basic substance found in several kinds of guano, but especially in Peruvian. It is a white powder, insoluble in water; but, combined with acids and alkalies, it forms compounds soluble in water. There is not much free ammonia in guano; but it often contains a large amount of ammonium carbonate, which is rather volatile. The free ammonia varies from a trace to 1 per cent, and gives to guano its pungent odour, but it is not the cause of its peculiar strong odour.

Guanos may be divided into two great classes—viz., (*a*) those containing nitrogen, and (*b*) those of a purely phosphatic nature. Nitrogenous guanos can only be formed in rainless districts. Where rain falls, the nitrogenous portion becomes washed away.

The guano at present sold contains about 4 to 8 per cent of nitrogen, 14 to 23 per cent of phosphoric acid, and 2 to 4 per cent of potash. The nitrogen is chiefly present in the form of uric acid and ammonium salts; while the phosphoric acid is chiefly as insoluble phosphate of lime: a varying proportion is present in some guanos as alkaline phosphates. Many guanos, therefore, contain a certain amount of soluble phosphate.

The following is an analysis of a sample of recently imported Corcovado guano by C. M. Aikman:—

COMPOSITION OF PERUVIAN GUANO.

Moisture		19.30
[1]Organic matter		41.10
[2]Phosphoric acid		14.53
Lime		11.60
[3]Magnesia, alkaline salts, &c.		9.20
Insoluble matter		4.27
		100.00
[1]Containing nitrogen	10.57	
Equal to ammonia	12.83	
[2]Equal to tricalcic phosphate	31.73	
[3]Containing potash	3.61	

Dissolved Peruvian Guano.—Messrs Ohlendorff & Co., of London and Hamburg, introduced a manure, prepared by treating Peruvian guano with sulphuric acid. By this process the calcium phosphate and nitrogen are rendered soluble, and the organic matter is so much altered in composition that it decomposes more readily in the soil. The manure is made by treating the guano with 25 to 30 per cent of sulphuric acid (sp. gr. 1.73). This is of special value for treating damp guanos.

We have found the composition of a specimen of this manure to be as follows:—

COMPOSITION PER 100 PARTS OF DISSOLVED PERUVIAN GUANO.

Moisture	17.06
Organic and volatile matters	51.50
(Including nitrogen equal to ammonia	12.06)
Monocalcic phosphate	14.52
(Equal to tricalcic phosphate made soluble	22.65)
Tricalcic (bone) phosphate	3.40
Alkaline salts	4.60
Calcium sulphate	7.82
Insoluble matters	1.10
	100.00

Dissolved Peruvian guano is a fine powder, is of uniform composition, and its constituents appear to be in a somewhat higher degree of effectiveness than are the ingredients of the unmanufactured guano.

African Guano, &c.—Cargoes of guano are occasionally imported into the United Kingdom from Africa and various parts of America.

The following table gives the percentage composition of the guanos at present in use :—

NITROGENOUS GUANOS.

	Nitrogen =	Ammonia.	Phosphoric acid.	Tricalcic phosphate.
	per cent.	per cent.	per cent.	per cent.
Corcovado	11	13	15	33
Saldanha Bay	9	11	9	20
Ichaboe	8	10	9	20
Pabellon de Pica	7	9	14	31
Punta de Lobos	4	5	15	33
Huanillos	6	7	13	28

PHOSPHATIC GUANOS.

	Phosphoric acid. =	Tricalcic phosphate.
	per cent.	per cent.
Baker Island	39	85
Enderbury	37	81
Aves	34	74
Sidney Island	34	74
Malden Island	32	70
Browse Island	31	68
Huon Island	28	61

Value of Guano as a Fertiliser.—Sir J. B. Lawes says of Peruvian guano, that it is one of the best artificial manures for wheat; for which purpose 2 or 3 cwt. per acre, sown broadcast before the seed, and harrowed into the soil, will be found a sufficient quantity. Voelcker found that 2½ cwt. of Peruvian guano gave an increase of 12$\frac{1}{10}$ bushels of grain, and of 8 cwt. of straw, when used with a wheat crop. Mixed with superphosphate, it has been found a most valuable top-dressing for permanent pasture; and, with or without superphosphate, it constitutes an excellent manure for green crops and potatoes. Peruvian guano is without doubt the most valuable auxiliary manure which the farmer possesses, and it resembles in the complexity of its composition farmyard manure, more than any other purchased manure does.

CHAPTER XXXIII.

BONES AND OTHER PHOSPHATIC MANURES.

Bones.—If a fresh bone be placed in a hot oven for some hours, it will be found to lose a considerable amount of its weight: the loss is occasioned by the evaporation of water. If the dried bone be next burnt in such a way that anything it may leave can be collected, it will be found that it loses a still larger proportion of its weight. This further loss is caused by the destruction of the organic portion of the bone. The organic portion consists chiefly of *bone cartilage*, or *ossein*, a substance closely resembling gelatin. This is exclusive of a small quantity of sulphur. Ossein is insoluble in water, but by continuous boiling it is converted into gelatin, which dissolves readily in water. Ossein and gelatin are valuable fertilisers, and to their action the manurial effect of bone is in part due. Good bones, when dried, yield about 4½ per cent of ammonia. The commercial article has about 3½ per cent nitrogen, and about 23 per cent phosphoric acid.

Von Bibra states that bone varies somewhat in composition according to the nature and sex of the animal; but this is denied by Fremy. Zaleski asserts that the relative proportions of organic and inorganic matter vary very slightly in the case of man and of the inferior animals. The results of numerous experiments gave the following results:—

	Man.	Ox.	Guinea-pig.
Organic matter	34.56	32.02	34.70
[1] Inorganic matter (ash)	65.44	67.98	65.30
	100.00	100.00	100.00
[1] Containing per cent—			
Carbonic dioxide	5.734	6.197	...
Phosphoric acid	39.019	40.034	40.381
Chlorine	0.183	0.200	0.133
Fluorine	0.229	0.300	...
Lime	52.965	53.887	54.025
Magnesia	0.521	0.468	0.485

The bones of birds contain from 68 to 76 per cent of ash, and those of fishes from 50 to 60 per cent. The bones of herbivorous animals and birds contain a larger proportion of lime than is found in the bones of reptiles and of flesh-eating animals. In cartilaginous fishes—such, for example, as the lamprey—the amount of earthy matters is very small. The manurial values of the bones of horses, oxen, and sheep do not differ in any important degree.

The use of bones as a manure is a very old one, and dates back to the beginning of the present century. They were first used in large pieces. Gradually, however, their action was found to be more speedy when they were reduced to smaller pieces; and now bones are largely used in the form of fine powder—bone-meal and bone-dust. When added to the soils bones decompose, this decomposition taking place in proportion to the fineness of their condition.

Bones are now largely prepared as a manure by extracting their oil by steaming. The extracted bones show a higher percentage of phosphoric acid (29 per cent), but a considerable loss of nitrogen takes place, there being only about 1½ per cent left. Benzene has also been used for extracting the oil. This is a more economical method, as less nitrogen is removed than in steaming. Bones bereft of their fat are also obtained in treating them for gelatin by boiling them under pressure. Commercially, bones are sold under the forms of half-inch bones, quarter-inch bones, bone-meal, bone-dust, and bone-flour, and are generally guaranteed to contain from 45 to 50 per cent of calcium phosphate; the nitrogen being equal to from 4 to 4½ per cent of ammonia. As they are slow in their action, they are usually employed for pasture and turnips. Among farmers they are a most popular manure.

Fermented Bones.—As it requires powerful machinery to grind bones, it may be found expedient to try some other process for hastening their manurial action. A good plan is to ferment them. This may be effected by mixing them with one-third of their weight of clay, saturating the compost with urine, and covering the mass with damp clay to the depth of 2 or 3 inches.

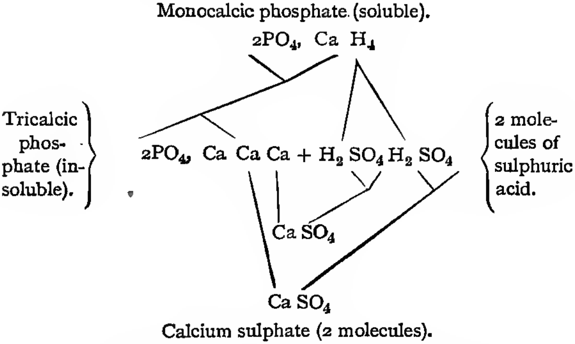
In an experiment made by the late Mr Pusey with 8½ bushels of fermented bones (costing £1, 0s. 9d.) and 17 bushels of ordinary bones (costing £2, 6s. 9d.) as manure for turnips, equal amounts of produce—13¼ tons per acre—were obtained. In a second experiment, £1, 11s. worth of fermented bones produced 17 tons 1 cwt. of turnips per acre; whilst £3, 10s. worth of unfermented bones yielded only 14¼ tons of produce.

On the farm of Sir Charles Coote, in Queen's County, on that of Mr Glascott, Priesthaggard, county of Wexford, and on many others, experiments with fermented bones as a turnip manure have given highly satisfactory results. Large bones, no doubt, are *lasting* manures, their effects being felt during many years; but it is not economical to apply a manure a portion of which will produce no effect for perhaps a dozen of years.

Dissolved Bones.—The desire to render bones more quickly available as a manure led to the discovery by Baron Liebig of the manufacture of superphosphate. He found that when bones were treated with sulphuric acid their phosphoric acid was converted into a soluble form which was speedily available for the plants' uses. This discovery led to the manufacture of superphosphate from different mineral phosphates, a trade which has now assumed gigantic proportions. Dissolved bones form a most valuable manure. It is to be doubted, however, whether it is not more economical to use only mineral phosphates for the manufacture of superphosphate, and apply the bones in their natural condition.

Bone-ash, &c.—Bones are also used as a manure in the forms of bone-ash and bone-black. Bone-ash is formed when bones are burnt, and is a very rich phosphatic substance, containing between 70 and 80 per cent of calcium phosphate. It is largely imported into this country from South America, and is used for the manufacture of high-class superphosphates. Bone-black is formed when bones are charred by heat in close ovens. It is used for filtering sugar through in sugar refineries, and is sold by them for manurial purposes as spent char. It is slightly poorer in phosphoric acid than bone-ash.

Superphosphate of Lime.—Enormous quantities of this valuable manure are now used in this country. The manure termed "superphosphate of lime" was at first made, as we have already pointed out, by acting upon bones with oil of vitriol; but it is now almost altogether prepared by mixing sulphuric acid with bone-ash, bone-black, and various mineral or native phosphates. In all these phosphates there exists tricalcic phosphate to the extent of from 45 to 80 per cent. This substance is very insoluble in water, and in the case of the mineral phosphates, its action as a manure is very slow. By acting upon a molecule of tricalcic phosphate by means of two molecules of sulphuric acid, the former loses two atoms of calcium, which are replaced by four atoms of hydrogen. The new phosphate is very soluble in water, and hence its value, as we shall see further on. The changes which take place in converting insoluble into soluble phosphate are as follows:[1]—



$$\text{or } Ca_3 2PO_4 + 2H2SO_4 = CaH_4 2PO_4 + 2CaSO_4$$

According to Armsby ('American Journal of Science,' July 1876), *one* molecule of sulphuric acid acting upon

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[1] The nature of the reactions taking place has been recently (Ruffle, 'Soc. Chem. Ind. Jour.,' 1887, p. 327) shown to be somewhat different from what was formerly believed. The soluble phosphate produced was formerly regarded as made up of monocalcic phosphate. It has now been shown that a part, and often a large part, of the soluble phosphate consists of free phosphoric acid. In the first stage in all probability free phosphoric acid is alone produced. This reacting on the remaining undecomposed phosphate, forms monocalcic phosphate. When strong sulphuric acid is used, free phosphoric acid is chiefly formed, the total soluble phosphoric acid being at the same time diminished.

one molecule of tricalcic phosphate, produces, with one-half of the phosphate, tetrahydric calcic phosphate, which, slowly acting upon the other moiety of phosphate, produces dihydric dicalcic phosphate — $H_4Ca2PO_4 + Ca_32PO_4 = 2H_2Ca_22PO_4$.

There are three kinds of sulphuric acid met with in commerce — namely, *white* (specific gravity, 1.845°), *brown* (specific gravity, 1.700°), and *chamber* (specific gravity, 1.570°). It requires 64 lb. of white, 82 lb. of brown, and 114 lb. of chamber acid to convert 100 lb. of insoluble phosphate into soluble phosphate. If, therefore, bones or a native phosphate containing say 50 per cent of tricalcic phosphate be perfectly converted into soluble phosphate, it will use up 41 per cent of its weight of brown acid, or 32 per cent of white acid. As, however, the bones or other phosphatic materials invariably contain calcium carbonate, this compound will use up a portion of the acid—thus $CaCO_3 + H_2SO_4 = CaSO_4 + CO_2 + H_2O$. Every pound of calcium carbonate in the raw material will use up, or rather almost waste, its own weight (strictly, 0.9816 per cent) of white, 1¼ lb. of brown, and 1¾ lb. of chamber acid. The mineral phosphatic materials invariably include small quantities of alumina and oxide of iron, which unite with sulphuric acid, and produce sulphates of aluminium and iron; 100 lb. of raw phosphate may in this way waste from 4 to 2 lb. of sulphuric acid. Knowing, then, the composition of his raw material and the strength of his acid, the manufacturer can determine the exact quantity of the latter to add to the former.

Manufacture of Superphosphate.—The manufacture of superphosphate is naturally too complicated a process to describe here. It may be mentioned that considerable improvements have of recent years been introduced, more especially in the apparatus for pulverising the mineral phosphate. It is of the greatest importance that the phosphate should be ground to an extremely fine powder, if the sulphuric acid is to have its full effect. In artificial manure works, the raw phosphate (reduced to powder between millstones, or by a centrifugal disintegrator) is placed in a close vessel called a *mixer*, and the necessary quantity of acid is let down upon it from a tank, through a kind of hopper. The acid used is ordinary chamber acid (sp. gr. 1.57). This acid is used for economical reasons. The acid must contain water, as the dryness of the resulting superphosphate depends on the formation of gypsum ($CaSO_4 2H_2O$). The gases evolved from the mixture are chiefly carbon dioxide, hydrofluoric acid (HF), and fluoride of silicon (SiF_4). It is alleged that arsenical vapours are also given off; but of this there is some doubt. It is, however, desirable that the vapours and gases from the mixer should not be directly discharged into the atmosphere; they should be carried through a long flue, provided with numerous fine jets of water, which would condense the dangerous portion of the volatile matters.

When the acid is let down upon the phosphate, the solid and liquid are intimately mixed by means of a strong spindle provided with four blades, placed at right angles. In a short time the bottom of the mixer is opened by means of a lever, and the contents—usually from 10 to 20 cwt.—fall on the ground of a close chamber called a *den*. The different batches of superphosphate thus made are afterwards put through a Carr's disintegrator, and stored for some time, and finally put into bags for sale.

Superphosphate is occasionally made by the farmer; but there is no economy to be effected in this way, as he is obliged to buy sulphuric acid[1] from the vitriol-maker, and to use bones, which are a very expensive material. If the farmer has bones available, his best plan is to ferment or grind them, and to add them to a purely mineral superphosphate, which he can purchase very cheaply. If, however, the farmer decides to become his own artificial-manure maker, he should proceed as follows: Provide a wooden trough, 12 feet long, 4 feet wide, and 1½ foot deep. Protect its interior from the action of the acid by a coat of pitch. Spread over the bottom of this vessel the bones, &c., to be vitriolised, and add about one-third of their weight of water; next pour uniformly over them half their weight of brown acid, or one-third of their weight of white acid; mix quickly with a wooden spade, and let the mixture stand for an hour or so. The manure may then be removed to a covered shed and kept until required, which should not be for a month or two at least.

As the cost of the carriage of oil of vitriol from one place to another is sometimes considerable, it may under certain circumstances be found more economical to use the white acid, though it is the dearest. One pound of white sulphuric acid is equal to 1¼ lb. of brown acid, and 1¾ lb. of chamber acid.

It is regrettable that in the manufacture of ordinary mineral superphosphates, all the insoluble phosphate is not converted into soluble phosphate; in general from one-sixth to one-third remains unaltered. The proper plan would be to thoroughly "dissolve" the mineral phosphate and to "dry" the damp superphosphate thereby produced with fine bone-meal, or that failing, with

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[1] It is well known in the manure trade that most of the profit made by the manufacturer of superphosphate is in the production of sulphuric acid. In selling his superphosphate, he is in reality making a profit almost solely upon his acid.

gypsum. The following is the composition of a mineral superphosphate :—

100 parts contain—

Water	15.00
Organic and volatile matters	12.00
[1] Monocalcic phosphate	18.00
Insoluble phosphate	6.00
Calcium sulphate	41.95
Alkaline salts	0.55
Insoluble matters	6.50
	100.00
[1] Equal to calcium phosphate made soluble by acid	28.28

"Biphosphate of lime" is very often the term used for "monocalcic phosphate," in the statement of the analysis of a superphosphate. Formerly this substance was regarded as a compound of one molecule of lime with one of phosphoric acid; it was termed "biphosphate of lime," and assigned the formula—$CaO + P_2O_5$. Now, 100 parts of this compound corresponded to 156 parts of insoluble phosphate (by old notation, $3CaO + P_2O_5$). Chemists still state that 1 per cent of monocalcic phosphate equals 1.56 per cent of "phosphate made soluble," meaning thereby that 1.56 parts of the insoluble are required to produce 1 part of the soluble. When a manure is said to contain 20 per cent of soluble phosphate, it implies, not that it contains that amount of monocalcic phosphate ("biphosphate of lime"), but that the soluble phosphate present had been produced from 20 per cent of insoluble, or "bone," phosphate. In reality, one part of soluble phosphate is equal to only 1.33 parts of insoluble phosphate, or to 0.85 per cent of "biphosphate."

Reduced Phosphates.—In many superphosphates the amount of soluble phosphate decreases from 1 to 5 per cent, when the manure is kept for some months. This circumstance often leads to disputes and litigation between the sellers and buyers of artificial manure. There are differences of opinion as to the cause or causes of this "going back" of the soluble phosphate. Some chemists believe that the insoluble phosphate is produced by a molecule of insoluble phosphate reacting upon one of soluble, and producing therewith two molecules of dihydric dicalcic phosphate ($Ca_3 2PO_4 + CaH_4 2PO_4 = 2H_2Ca_2 2PO_4$). The phosphate of calcium thus formed, though not so insoluble as bone-earth, is still comparatively insoluble. Other chemists contend that it is the oxide of iron and alumina in the manure which gradually combine with a portion of the phosphoric acid of the soluble phosphate, and produce insoluble calcium, iron, and aluminium phosphates. This is the more probable conjecture; though it appears strange that in superphosphates the oxide of iron and alumina should escape being dissolved, whilst the phosphate and fluoride of calcium are decomposed by the oil of vitriol. In some minerals, however, alumina and iron oxide are not readily dissolved by acids. When superphosphate is put into the soil, its soluble phosphate is immediately converted into insoluble phosphate, by the action of the lime which is sure to be present. If we suppose that this effect is produced by calcium carbonate the change would be as follows: $CaH_4 2PO_4 + 2CaCO_3 = Ca_3 2PO_4 + 2CO_2 + 2H_2O$. The alumina, oxide of iron, and magnesia of soils may also, especially in the absence of lime, produce precipitates.

The precipitated phosphate assumes the form of a jelly, and if there be sufficient moisture in the soil (*i.e.*, if the weather be wet at the time), it is surprising how large a quantity of gelatinous matter is produced from a cwt. of good superphosphate. This soft mass of phosphate dissolves readily in the water containing carbonic acid, salts of ammonia, &c., present in the soil, and in these menstrua it is carried up into the organs of the plants.

The amount of "reduced" or "reverted" phosphate present in a manure can be estimated by its solubility in a solution of ammonium citrate. In value it comes next to superphosphate, being very much more soluble than the tricalcic or common phosphate.

While Liebig was the first to recommend the treatment of bones with sulphuric acid, Lawes first applied the process to mineral phosphates, and took out a process for the patent in 1842. The superphosphate trade thus dates from 1842; and some idea of the rate at which its development has gone on may be inferred by the statement that nearly three-quarters of a million tons of superphosphate are now annually made in the United Kingdom, a larger quantity in Germany and Austria, and over a million tons in America, while large quantities are also annually manufactured in France and other countries. The different mineral phosphates from which these enormous quantities of superphosphate are manufactured are numerous and varied in composition.

Mineral Phosphates.—Phosphoric acid in combination with calcium, magnesium, aluminium, and iron, is widely diffused throughout the crust of the globe, and in some localities is found in large quantities, constituting an article of commercial importance. The following are some of the more important mineral phosphates which are used in the artificial manure industry.

Coprolites are grey, hard, nodular masses found in the upper greensand of Cambridgeshire and in some other localities. They are believed to be fossilised bones of extinct races of animals. They contain in general about from 52 to 60 per cent of earthy phosphates, 12 to 18 per cent of calcium carbonate, 4 or 5 per cent of alumina and oxide of iron, 2 to 3½ per cent of fluoride of calcium, and 6 to 9 per cent of sand. The Cambridgeshire phosphates are the richest of all the mineral phosphates found in England. A brown variety, termed *pseudo*, or *false* coprolites, is found in Suffolk, Bedfordshire, and Buckinghamshire; they consist of a mixture of fossilised bones and dung of extinct animals, and are somewhat inferior to the Cambridge coprolites, on account of their larger percentage of alumina and iron oxide, and smaller proportion of phosphoric acid. They contain from 45 to 55 per cent of calcium phosphate, from 10 to 18 per cent of calcium carbonate, and from 7 to 12 per cent of alumina and iron oxide. "Boulogne coprolites" resemble Suffolk coprolites; but another phosphatic mineral obtained from France, under the name of "Lot" phosphate, is nearly white, includes from 65 to 80 per cent of calcium phosphate, and produces a very concentrated superphosphate.

In 1887 about 20,000 tons of these coprolites were used. They are now less extensively used than formerly, as there is an abundance of richer and cheaper mineral phosphates available.

Navassa guano obtained from Hayti occurs in brown lumps and reddish powder. Its calcium phosphate varies from 60 to 70 per cent, its calcium fluoride from 1 to 2 per cent, its calcium carbonate from 4 to 7 per cent, and its iron oxide and alumina from 10 to 12 per cent. It also includes rather large amounts of aluminium phosphate. It is very abundant, but it does not appear to be a good raw material for the manufacturer, on account of its large proportion of iron and aluminium compounds.

Charleston or S. Carolina phosphate is now largely imported from the United States. It is highly fossiliferous, varies in colour from grey to fawn in the case of the variety termed "land phosphate"; whilst the "river phosphate" is almost black. It contains from 50 to 60 per cent calcium phosphate, 12 to 14 per cent calcium carbonate, 3 to 4 per cent iron and aluminium oxides, 12 to 16 per cent sand, and 1 to 3 per cent calcium fluoride. There are three classes, the lowest containing from 50 to 52 per cent, the second 55 to 56, and the third 58 to 60 per cent. It is at present the most largely used mineral phosphate, and produces the ordinary quality of superphosphate—viz., that containing 25 to 28 per cent "soluble" phosphate. It is not easy to grind this mineral, but it is readily dissolved by acid.

Florida Phosphate.—Quite recently large deposits of phosphates have been discovered in Florida. These are of different qualities—the land-rocks now imported containing from 70 to 80 per cent phosphate of lime, and the river phosphate about 60 per cent. The latter are very similar in composition to the best South Carolina river phosphate, which they much resemble.

Belgium and Somme Phosphate.—This phosphate occurs in enormous deposits in the north of France and in Belgium. The deposits extend over 7,000,000 acres. They occur in ordinary white chalk, and consist of yellowish grains embedded in chalky matrix. On an average the phosphate of lime in this rock is from 20 to 30 per cent, but pockets are found in certain portions very much richer, containing from 50 to 80 per cent. This latter quality is known as Somme phosphate. In 1888 no less than 150,000 tons of this Somme phosphate were raised. There are four grades in the market—viz., (i.) containing 55 to 60 per cent; (ii.) 60 to 65; (iii.) 70 to 75; and (iv.) 75 to 80. This phosphate—at any rate the higher grades—forms the chief source of high-class superphosphate. The Belgian phosphate imported into this country in 1886 amounted to over 45,000 tons.

Sombrero phosphate is not now imported in quantity. It contains about 70 to 78 per cent of phosphates.

Orchilla guano contains about 45 per cent of calcium phosphate and nearly 20 per cent of calcium carbonate; it is not, therefore, suited for making superphosphate.

Estremadura phosphate is obtained from Spain and Portugal. An immense deposit of this phosphate occurs at Caceres. It occurs of different qualities — some containing as high as 70 per cent phosphate, while other qualities show only 50 to 60 per cent. The calcium carbonate varies from 6 to 16 per cent. Larger quantities of this phosphate were formerly imported into this country than is the case at present.

Of a similar character to Estremadura phosphate is *apatite*, the mineral which constitutes the *Canadian* and *Norwegian phosphates.* This phosphate is much richer than the Estremadura phosphate. The former contains from 70 to 80 per cent of calcium phosphate. The latter contains from 70 to 90 per cent of calcium phosphate, from 1 to 4 per cent of calcium chloride, and from 3 to 10 per cent of sand, iron oxide, &c. For manure-making, the Norwegian phosphate is best, owing to its freedom from calcium fluoride.

There are large quantities of phosphatic minerals, but of poor quality, in Wales.

Aruba phosphate.—This is one of the Caribbean phosphates from the West Indies, the others being Curaçao, Sombrero, Monk, and St Martin's Islands, the last two of which are exhausted. They are often classed as phosphatic guanos. Of Aruba phosphate about 20,000 tons are annually raised, one-half of which is imported into the United Kingdom. It contains 75 to 80 per cent of calcium phosphate.

Curaçao phosphate.—This is one of the richest phosphates, containing as much as 88 per cent of calcium phosphate, and is extremely valuable for the manufacture of high-class superphosphate.

Redonda and Alta Vela phosphates.—These phosphates are made up of aluminium and iron phosphates, and are hence unsuited for the manufacture of superphosphate.

Bordeaux phosphate.—This is also an impure phosphate, containing a considerable quantity of iron and alumina.

Nassau or Lahn phosphate is not now imported into this country, as it is also very impure, especially the lower qualities. It contains iodine.

Tricalcic phosphate ($Ca_3 2PO_4$) is the substance which, as we have stated, occurs in bones, and in the various mineral phosphates above described. It is never found in nature in a state of absolute purity, but is nearly in a pure form in the mineral termed *osteolite.* The precipitated phosphate is a white powder, soluble according to its mechanical state in from 35,000 to 110,000 of water (Warington), easily soluble in acids, and slightly in various saline solutions.

Hydric calcium phosphate ($HCaPO_4$) has been found to the extent of 18.03 per cent in Rossa guano, from the Gulf of California. It has also been found in other phosphates. It is obtained sometimes crystalline, but generally as a white amorphous powder, soluble in acid; it is more soluble in solution of carbonic acid, &c., than tricalcic diphosphate.

Tetrahydric calcium diphosphate (H_4Ca2PO_4) is formed, as we have already seen (page 315), by separating two atoms of calcium from tricalcic phosphate, and replacing them by four atoms of hydrogen. It is a very acid salt, becomes moist and oil-like by exposure to air, and dissolves in a very small quantity of water. It can be obtained in small crystals united with one molecule of water. It is decomposed by heat.

According to Erlenmeyer, crystals of monocalcic phosphate are decomposed by cold water into dicalcic phosphate (which is insoluble), and a super-acid salt, which is soluble.

Solubility of Calcium Phosphate.—According to C. P. Williams, phosphates suspended in water, through which carbon dioxide was transmitted for several hours, dissolved in the following proportions:—

	Parts of water.
Calcium phosphate in apatite is soluble in	222.222
Do. in finely ground apatite	140.840
Do. in bone-ash	5.678
Do. in burnt bones	8.020
Do. in South Carolina phosphate	4.122
Do. in same, finely powdered	6.554
Do. in phosphatic guano from Orchilla	8.009

The mean result of several experiments made by R. Warington showed that 1 part of pure tricalcic diphosphate dissolved in 6788 parts of water saturated with carbonic acid.

Application of Superphosphate.—This manure is chiefly used with green crops—which, indeed, appear to be most benefited by it. It, however, enters largely into the composition of nearly all the "special manures" for cereal, leguminous, and grass crops, which are now manufactured in large quantities. In these manures it is mixed with sulphate of ammonia, potash salts, shoddy, &c. The most concentrated superphosphates are made from such purely phosphatic guanos as Malden Island, &c. Bone-ash and spent char also yield on treatment with sulphuric acid high-class superphosphates. The soluble phosphates in such superphosphate may amount to as much as 45 per cent: ordinary superphosphate contains only about 25 to 28 per cent. Of insoluble phosphates ordinary superphosphate contains 2 to 3 per cent. It is useful to the turnip at every stage of its development, and is specially so at an early period of its growth in hastening the brairding of the young plant, and getting it above the reach of the fly. From 5 to 7 cwt. of superphosphate are applied per acre of roots; but if there be abundance of dung available, from 3 to 4 cwt. will be sufficient. If no farmyard dung be used with the root crop, then the following crop should be specially manured, and, if possible, with a fertiliser rich in organic matter. It is desirable to mix superphosphate with two or three times its bulk of ashes, mould, or fine clay, before applying it. When this manure (or any other into the composition of which it enters) is applied as a top-dressing to grass or clover, showery weather should be selected, as the rain will wash the soluble part equably into the soil.

When applied to the soil the "soluble" phosphate undergoes a process of reversion — it is converted into dibasic phosphate. In this state it is insoluble, and is thus not liable to be washed out of the soil. Ultimately it is probable that the iron present in the soil converts it into iron phosphate, a less available form for plant uses. This change would account for the fact that the action of fresh superphosphate is always better than that obtained from the residue in the soil of superphosphate applied a previous year.

Insoluble phosphates have of recent years been used. Their state of division must be very fine, otherwise they exercise practically no effect. Among these, *Thomas slag* is the most important. This substance, which is a by-product in the manufacture of steel by the basic process, is now used in enormous quantities. It is reduced by powerful machinery to a very fine state of division, and when bought ought to be submitted to a mechanical test to ascertain its fineness as well as a chemical one. A point of considerable interest with regard to slag is the fact that its lime and phosphoric acid are in a state of combination peculiarly characteristic, and unknown in other compounds. The phosphate it contains is tetrabasic phosphate of lime. This phosphate in solubility stands next to the reverted phosphate, and is more soluble than the ordinary tricalcic phosphate. The value of slag has been estimated, according to a number of experiments by P. Wagner and others, at one half of superphosphate. It is best suited for land containing a large quantity of organic matter, and has been used with especial benefit on peaty and moorland soils. Its action on such soils is twofold. Not merely does it supply phosphoric acid, but it acts in virtue of the free lime it contains. The humic and carbonic acids of the soil act upon its phosphate and dissolve it. Thomas slag contains 15 to 20 per cent of phosphoric acid.

CHAPTER XXXIV.

HUMAN EGESTA AND TOWN SEWAGE.

Human Egesta.—The average amount of dry solid excrement voided by a human being, averaging both sexes and all ages, is about 3 oz. per day = nearly 31 lb. yearly; and of urine, 2 lb. = 730 lb. yearly. The solid excrement consists of woody fibre, undigested food, fatty, waxy, and resinous substances, together with phosphates of calcium and magnesium, and various earthy and saline matters. Wehsarg found fæces to consist of 73.3 parts of water, and 26.7 parts of solid matters; whilst Berzelius states that they are composed of 75.5 parts of water, and 24.5 parts of solid matter. About 5 or 6 per cent of fæces consist of mineral matters, or ash. According to Porter, this ash contains 6.1 per cent of potash, 5.07 per cent of soda, 26.46 per cent of lime, 10.54 per cent of magnesia, 36.03 per cent of phosphoric acid, 1.33 per cent of common salt, and 11.47 per cent of oxide of iron, sulphuric acid, &c. = 100.

Urine varies considerably in composition, some specimens containing 3 per cent of solid matters, whilst others yield from 4 to 6 per cent. It contains a large amount of urea, and a small proportion of other nitrogenous bodies. It also includes phosphoric acid, potash, and soda.

There are great discrepancies in the statements published in reference to the value of human excrements as a manure. It is wellnigh impossible to put a value on human excrements, as so much of their value as a manure depends on their mode of application.

Human excrements are highly valued in China, where they are preserved, and applied with great economy. In Belgium, too, not only do the farmers use up the nightsoil, &c., produced on their farms, but they contract with persons to have the contents of the cesspools of the nearest town brought regularly to them. To retain these matters until required for use, they construct very substantial and expensive liquid-manure tanks. When required, the liquid manure is pumped up from its underground receptacle, and distributed uniformly—so many gallons to so many square yards—over the land.

Poudrette.—In many Continental towns the nightsoil is collected, dried, and converted into a manure termed *poudrette*. Sometimes it is mixed with gypsum or other substances, for the purpose of disguising its odour. Poudrette is in general manufactured in a very unscientific manner, and is seldom worth the price at which it is sold. It rarely contains more than 2 per cent of nitrogen, and frequently only 1 per cent, together with 3 per cent of calcium phosphate, and 1.5 per cent of potash.

The attempts to evaporate urine nearly to dryness, so as to produce from it a portable manure, have proved failures. The cost of evaporation was considerable, and there were difficulties in the way of collecting and conveying the liquid.

Where earth-closets are used, the mixture of excrements and earth produces a good fertiliser, but one which is not sufficiently valuable to bear the cost of carriage to a greater distance than five or ten miles. If charcoal were used as a substitute for the earth, the manure produced would be more valuable.

Voelcker's and Gilbert's analyses of earth-closet manure have shown that it possesses but little value.

Town Sewage.—By far the greater portion of the *excreta* of the inhabitants of towns passes into sewers, from which it is discharged into rivers or the sea. The urine of the immense number of horses, cows, and other animals in towns is chiefly disposed of in a similar manner. The loss of fertilising matter in this way is enormous, and is constantly on the increase, owing to the extension of water-closets and main sewers. Not only is there a waste of valuable manure in this way; but the removal of fæces, urine, and waste-matters of various kinds by water-carriage, has resulted in the pollution of the rivers of a large portion of the United Kingdom. These rivers are no longer fit sources of potable water, and many of them evolve noxious exhalations, which no doubt must have a prejudicial effect upon the public health.

QUANTITY AND VALUE OF TOWN MANURE.

Name of Town.	Population using privies.	Tons of manure annually.	Money received.	Value per head.
			£	*d.*
Liverpool	350,000	138,777	8,000	5.5
Widnes	12,000	1,800	150	3.0
Salford	120,000	38,600	4,000	8.0
Manchester . . .	300,000	73,594	6,740	5.4
Bolton	75,000	22,465	1,567	5.0
Bury	29,000	7,000	100	0.8
Oldham	77,000	50,000	2,000	6.2
Ashton-under-Lyne .	37,000	6,637	95	3.2
Southport . . .	15,000	9,000	740	8.8
Total . .	1,015,000	347,873	23,392	5.5

Composition and Money Value of Sewage.—Town sewage varies considerably in composition, the variation chiefly resulting from the local conditions under which the towns are placed. The rainfall, the supply of pipe-water, the number of water-closets, the nature of the manufactories, and many other factors, determine the composition of the sewage.

100 TONS OF THE SEWAGE OF DUBLIN CONTAIN THE FOLLOWING FERTILISING INGREDIENTS :—

1. In complete solution—					
Nitrogen . .	16.50 lb.	at £70 per ton	£0	10	3.75
Phosphoric acid .	3.85 „	40 „	0	1	4.50
Salts of potassium .	5.12 „	20 „	0	0	10.97
Salts of sodium .	16.63 „	1 „	0	0	1.78
	Total		£0	12	9.00
2. Mechanically suspended—					
Nitrogen . .	2.48 lb.	at £70 per ton	£0	1	6.60
Insoluble calcic phosphate . . .	1.84 „	8 „	0	0	1.57
Organic matter .	14.00 „	0 10 „	0	0	0.75
	Total		£0	1	8.92
	Grand total . .		£0	14	5.92

The money value here placed upon sewage is, however, based upon the supposition that its ammonia, phosphoric acid, &c., are as useful as if they were in the form of guano. So they would be, if the sewage in limited quantity and at the proper time were applied to the soil; but town sewage is in most instances collected in a very expensive manner, is distributed over the land during the whole year, and is usually applied in quantities far greater than is necessary for the wants of at least most crops. In fact, it is extremely doubtful whether sewage as a manure is worth applying, except in very few exceptional cases.

Application of Sewage. — This manure has been applied to every kind of field crop, and has been employed by market-gardeners; meadows, however, have up to the present been most benefited by its use. A portion of the sewage of the Old Town of Edinburgh has for many years been used as an irrigant, especially on the meadows at Craigentinny. The extreme difficulty in the successful application of the sewage of a large town lies in the fact that the amount to be disposed of is so enormous. Experiments carried out to test the value of sewage, when applied for irrigating land, have undoubtedly shown that it is of considerable value. But an experiment on a small scale is very different from utilising the sewage of a large town. The chief fact to be recognised in dealing with the sewage question is, that it does not admit of any general solution, so much depending on the condition under which sewage is produced as well as the quantity to be dealt with. This cannot be too strongly emphasised, for it is due to ignoring it that much of the confusion prevailing in the minds of the general public with regard to the value of sewage arises. Statements on the part of certain writers, with regard to its enormous manurial value, have engendered false notions as to its real value. These statements are due to overlooking the fact that the manurial ingredients in sewage are so minute in quantity, and are so diluted with worthless material, that their value is very trifling. The treatment of it so as to purify it, and at the same time to obtain a valuable manure, is simply an impossibility, as many experiments have shown.

In 1861 a Royal Commission was appointed to experiment on the sewage at Rugby. The object was to determine the quantity and composition of grass produced on land, a portion of which was to be manured with sewage, and another portion to remain unmanured. Fifteen acres were divided into three equal parts—one for grass on which cows were to be fed, another for grass on which oxen were to be fed, and the third was to be meadowed. Each of these five-acre divisions was further subdivided into four plots, one of which was left unmanured, and the others received respectively different quantities of sewage. Some of the results obtained are tabulated in the following table:—

PRODUCE GIVEN TO OXEN.

Plot.	Sewage required per annum.	Actually applied to end of October.	Total grass per acre.				Increase of grass per 1000 tons of sewage.			
			tons.	cwt.	qr.	lb.	tons.	cwt.	qr.	lb.
1	...	...	9	5	3	5	...	...	...	...
2	3,000	1,872	14	16	3	8	2	19	1	7
3	6,000	4,423	27	1	0	10	4	0	1	9
4	9,000	6,153	32	16	3	8	3	16	2	9

On the grass given to the milch-cows the effects of the sewage were still more favourable, as will be seen in the following table:—

PRODUCE GIVEN TO MILCH-COWS.

Sewage applied.	No. of weeks the produce kept a cow.	Gallons of milk per acre.	Value of milk at 8d. per gallon.	Value of milk from increased produce of 1000 tons sewage.
			£ s. d.	£ s. d.
...	19.0	321.0	10 14 3	5 0 0
1,387	40.9	570.7	19 0 6	5 19 10
2,804	58.8	820.4	27 6 11	5 16 8
4,226	68.9	961.3	32 0 10	5 0 11

In these trials it is shown that the application of sewage was attended by a very great increase in the produce of grass.

The great difficulty in the way of a successful application of sewage irrigation consists in the great amount of land required for the purpose. A certain quantity of land is only able to filter properly a certain quantity of sewage. It has been found also that land so treated becomes after a time what is termed "sewage sick," and no longer possesses the power of absorbing from the sewage its fertilising ingredients. Land, therefore, requires a rest from time to time. Hence, what is called intermittent filtration seems to be the only successful way of carrying out sewage irrigation. The difficulty of disposing of it during winter-time, when the soil may be frost-bound, is another great difficulty. Our knowledge of the process of nitrification has thrown much light on the conditions regulating the successful application of sewage irrigation.

Soils suitable for Sewage.—All soils have the power of filtering sewage, but light or medium soils resting on a sandy subsoil will be found the best absorbents of it, although their power of retaining the fertilising ingredients is not so great as that of heavy clays. On stiff clay lands, the chief fault of which is their impertransible nature, large dressings of town sewage would not be beneficial—nay, would be the reverse: the fluid would rest on the surface, and render the soil so cold and wet as to be decidedly injurious to most plants. Land of any kind under cereals cannot constantly be the scene of sewage irrigation; for during the long period of the year devoted to the preparation of the ground, a dry and easily pulverulent condition of the staple is desirable—and during the ripening of the crop, heat and a very moderate degree of humidity are necessary. It is clear, then, that cereal crops could only be benefited by very moderate doses of sewage applied at only certain periods of the year. Still, where sewage is available, we believe that both white and green crops would be largely served by its use; and if it were in a more concentrated condition than that derived from large towns is, it might be applied during by far the greater part of the year.

Chemical Treatment of Sewage. — A very large number of patents have been taken out in reference to the preparation of portable manures from sewage. The general method adopted was to add to the manure such substances as "superphosphate of lime," crude aluminium sulphate, mineral phosphates, &c. The A B C process (which got an extensive trial) consisted in adding alum, blood, clay, and charcoal to the manure. The resulting precipitate, collected and dried, constituted the "native guano" of which we have heard so much. Although it was shown that the money value of the native guano was less than that of the materials from which it was produced, there are chemists who still consider this process as one likely yet to produce good results financially.

The difficulties in the way of precipitating a really good manure out of town sewage are,—first, the small quantity of fertilising matter in it; second, the fact that by far the most valuable portion of the sewage, namely, its urea, cannot be precipitated; and third, the high cost of the precipitants. The value of sludge obtained by allowing sewage to settle after precipitating it with lime or other precipitant has been the subject of much debate and experiment. Experiments with sewage sludge carried out in 1884 by Dr J. M. H. Munro gave the following results:—

	Swedes per acre.	
	tons.	cwt.
No manure	5	18
5 tons Coventry sludge per acre	9	6½
5 " West Ham " "	9	8½
5 " Leyton " "	10	4
5 " Farmyard manure	10	1½
10 " " "	13	11½

So far as our present knowledge permits us to judge of the vexed subject of sewage utilisation, filtration through soils is the process which appears the simplest and most practicable. A combined system of precipitation and filtration is not admissible, for ordinary sewage is already too dilute as a manure without making it still poorer by removing a portion of its fertilising ingredients. In some cases it may be found desirable to discharge town sewage into deep sea-water, simply because land for irrigation cannot be got, and the sea is close at hand. Under such circumstances a precipitation process might be found useful if a precipitant sufficiently inexpensive could be discovered. Where, however, land of suitable quality can be got, and its situation is favourable, the sewage should be directly applied to it without any previous chemical treatment.

CHAPTER XXXV.

ANIMAL MANURES.

Flesh and Blood.—The *flesh* of warm-blooded animals is a valuable manure—not, however, much used for manurial purposes. In some manure-manufactories the carcasses of horses are subjected to the action of steam, sulphuric acid, &c., reduced to pulp, and mixed with superphosphate of lime. The carcasses of animals that perish from disease should be cut up into pieces, and mixed with 4 times their bulk of a mixture of 3 parts of clay and 1 of quicklime. The compost so formed will not prove a nuisance, but within a year, if kept under cover, will be converted into a valuable fertiliser. A carcass weighing 500 lb. yields about 12 lb. of ammonia, 24 lb. of bone phosphate, and 1 lb. of potash, besides a large amount of organic matter.

Blood.—It is a curious fact that there is nearly as large an amount of *dry* matters in blood as in very lean flesh. The latter contains about 74 per cent, the former from 78 to 72 per cent, of water. 100 parts of blood contain about 2½ parts of nitrogen, together with very small quantities of phosphoric acid and potash. Where pigs or other animals are killed upon a large scale (to make bacon, for example), large quantities of blood are available for manurial purposes. The blood is in these places often dried with or without the addition of sulphuric acid, gypsum, &c. The process is an offensive one, unless great care is taken to prevent the escape of the noxious vapours, &c., evolved from the blood into the atmosphere. Dried blood is an excellent manure, and contains from 9 to 12 per cent of nitrogen.

A rich compost is made by mixing blood with its own weight of wood or peat ashes, to which a little charcoal is a useful addition. This compost requires about a year to become matured.

Blood is about equal to flesh as a manure, the larger proportion of water which it contains being compensated for by its greater facility for mixing with other substances, and with the soil, and its tendency to decompose more rapidly. Its effects are, it is said, more marked in light lands than in stiff clays.

Hides, Horns, Hoofs, Hair, and Feathers are similar in composition. When dry they contain from 15 to 17 per cent of nitrogen, but nothing else of any manurial importance. Whalebone resembles horns. The large amount of nitrogen in these substances renders them valuable to the manure-manufacturer, who often finds it difficult to procure cheap ammonia-producing materials. It is, however, only the hoofs of cattle, the refuse part of hides in the process of tanning, the parings of leather, dust, &c., from the comb-maker, and similar refuse matters, which the manufacturer purchases. In these there is always a large admixture of sand, lime, and other useless matters, and the amount of nitrogen in them varies from 4 to 8 per cent.

Horns and similar substances remain for years undecomposed in the soil, and therefore they are of little value if means be not adopted to hasten their decomposition. Made into composts, it requires several years before they are converted into soluble manures. In the chemical manure works, they are covered with sulphuric acid, which in the course of some months renders them in great part soluble. The stronger the acid is, the more readily does it act upon the texture of the horns, &c.; and if the acid be hot, so much the better. Instead of mixing dissolved leather-clippings,

&c., with superphosphate of lime, it is better to put them together with the raw phosphate into the mixer (page 317), and pour the acid down upon both. The free acid in the mixture of leather-clippings, &c., will then prove serviceable in *vitriolising* a portion of the phosphate.

Tallow-greaves (the nitrogenous residue after melting tallow) are chiefly used in making prussiate of potash, but occasionally they are used as manure. They resemble hair in composition, but decompose more readily.

Animal guano or meat-meal is the term applied to a manure now largely manufactured in South America, Queensland, and New Zealand, from the refuse parts of animals. It is very variable in composition, some specimens being rich in phosphates, others in nitrogen: the former are for obvious reasons to be preferred. The nitrogenous kinds contain as much as 11 to 13 per cent of nitrogen, and at most 2 or 3 per cent of phosphoric acid. The phosphatic kinds, on the other hand, contain only about half as much nitrogen, and 14 to 17 per cent of phosphoric acid.

Wool, when dried and deprived of its fatty ingredients, contains as much nitrogen as hair, feathers, &c. (about 17 per cent). Some varieties contain, however, very large proportions of a peculiar fatty matter termed *suint*, which is rich in potash. Raw merino wool contains from one-fourth to one-third of its weight of suint. In France the removal of potash from wool constitutes a small industry. 1000 lb. of raw merino wool yield from 70 to 90 lb. of potassium carbonate, and from 5 to 6 lb. of potassium chloride and sulphate. In the wool of British sheep there is about 10 per cent of potash-salts, so that these animals withdraw a considerable amount of potash from the lands which maintain them.

Woollen rags and *shoddy* (the latter a waste material from the cloth-mills) are largely used as manures. In Kent, woollen rags are applied in a compost form to the hop-plants, and are so much esteemed for that purpose that £5 per ton has been paid for them by the hop-growers. The nitrogen in shoddy ranges from 4 to 8 per cent. Woollen rags and shoddy can be rendered more immediately available as a manure by digesting them for some months with oil of vitriol.

Fish.—The refuse of the pilchard and herring fisheries, and the whole fishes, together with mackerel, sprats, &c., when captured in numbers too great to find a market, are used as manure. They should be applied in the form of a compost, which may consist of 5 barrels of fish (or fish-refuse), and 3 times as much clay, peat-mould, &c., per acre. In Norfolk, sprats are sometimes used as a manure for turnips; 30 cwt. (in compost form) are applied per acre.

Fish-guano (dried fish) has lately been imported from the United States, and is now increasingly used. It is also manufactured in Norway, in this country, and elsewhere. It contains 7 to 10 per cent of nitrogen, 6 to 9 per cent phosphoric acid.

Shell-fish, when abundant, might with advantage be collected, crushed, and made into a compost. They would make a good manure for root-crops, but a small proportion of superphosphate might advantageously be employed along with them.

CHAPTER XXXVI.

VEGETABLE MANURES.

There are three purposes which vegetable manure serves. First, it loosens the land, opens its pores, and makes it lighter; second, it supplies nitrogenous food to the roots of the growing plant; third, it yields to the roots those saline and earthy matters which exist in decaying plants in a state more peculiarly fitted to enter readily into the circulating system of fresh races of plants.

Decayed vegetable matters, therefore, are in reality *mixed manures*, and their value in enriching the land must vary considerably with the *kind* of plants, and with the *parts* of those plants, of which they are chiefly made up. This depends upon the remarkable difference which exists in the *quantity* and *kind* of the inorganic matter contained in different vegetable substances, as indicated by the ash they leave. Thus, if 1000 lb. of the *sawdust* of the willow be fermented and added to the soil, they will enrich it by the addition of only 4½ lb. of saline and earthy matter; while 1000 lb. of the *dry leaves* of the same tree, fermented and laid on, will add 82 lb. of inorganic matter. Thus, independent of the effect of the organic matter in each, the one will produce a very much greater effect upon the soil than the other. It is owing, in part, to this large quantity of saline and other inorganic matters which they contain, that fermented leaves alone form too strong a dressing for flower-borders, and that gardeners therefore generally mix them up into a compost.

There are several states in which vegetable matter is collected by the husbandman for the purpose of being applied to the land—such as the *green* state, the *dry* state, that state of imperfect natural decay in which it forms *peat*, and the decomposed state of *charcoal*, &c., to which it has been reduced by art.

Green Manure.—When grass is mown in the field and laid in heaps, it speedily heats, ferments, and rots. But, if turned over frequently and dried into hay, it may be kept for a great length of time without undergoing any material alteration. The same is true of all other vegetable substances—they all rot more readily in the green state. The reason of this is, that the sap or juice of the green plant begins very soon to ferment in the interior of the stem and leaves, and speedily communicates the same condition to the moist fibre of the plant itself. When once it has been dried, the vegetable matter of the sap loses this easy tendency to decay, and thus admits of longer preservation.

The same rapid decay of green vegetable matter takes place when it is buried in the soil. Hence the cleanings and scourings of the ditches and hedge-sides form a compost of mixed earth and fresh vegetable matter, which soon becomes capable of enriching the ground. When a green crop is ploughed into a field, the whole of its surface is converted into such a compost—the vegetable matter in a short time decays into a light, black mould, and enriches in a remarkable degree the soil. This is one reason why the success of wheat after clover, or of oats after lea, depends so much on the ground being well covered when first ploughed up.

The practice of green manuring has been in use from very early periods. The second or third crop of *lucerne* was ploughed in by the ancient Romans, and it still is by the modern Italians. In Tuscany, the *white lupin* is ploughed in; in parts of France, the bean and the vetch;

in Germany, *borage;* and upon sandy soils in Holstein, *spurry*. In parts of Northern France, two crops of *clover* are cut, and the third is ploughed in. In some parts of the United States the clover is never cut, but is ploughed in as the only manure; in other districts the first crop is cut and the second ploughed in. In some of the northern States, Indian corn is sown upon poor lands, at the rate of 4 to 6 bushels an acre; and two or sometimes three such crops are put into the soil during the summer.

In Sussex, and in parts of Scotland, *turnip*-seed has been sown at the end of harvest, and after two months again ploughed in, with great benefit to the land. *Wild mustard*, also, which grows so abundantly as a weed on many of our corn-fields, is not unfrequently raised for ploughing in green. White mustard is sown in Norfolk, and ploughed in as a preparation for wheat; sometimes, also, on the stubble, as a preparation for turnips. It is said to destroy the wire-worm. *Turnip-leaves* and *potato-tops* decay more readily and more perfectly, and are more enriching, when buried in the green state. It is a prudent economy, therefore, where circumstances admit of it, to bury the potato-tops on the spot from which the potatoes are raised. Since the time of the Romans, it has been the custom to bury the cuttings of the vine-stocks at the roots of the vines themselves; and many vineyards flourish for a succession of years without any other manuring. In the Weald of Kent the prunings of the hop-vine, chopped and dug in, or made into a compost and applied to the roots of the hop, give a larger crop, and with half the manure, than when they are burned or thrown away, as is usually done.

Buckwheat, rye, winter tares, clover, and rape, are all occasionally sown in this country for the purpose of being ploughed in. This should be done *when the flower* *has just begun to open*, and, if possible, at a season when the warmth of the air and the dryness of the soil are such as to facilitate decomposition.

That the soil should be richer in vegetable matter after this burial of a crop than it was before the seed of that crop was sown, and should also be otherwise benefited, will be understood by recollecting that perhaps three-fourths of the whole organic matter we bury has been derived from the air — that by this process of ploughing in, the vegetable matter is more equably diffused through the whole soil than it could ever be by any merely mechanical means—and that by the natural decay of this vegetable matter, ammonia and nitric acid are, to a greater extent, produced in the soil, and its agricultural capabilities in consequence materially increased. The conservation of the soil nitrogen by the agency of crops is now one of the most generally recognised of the benefits conferred on the soil by the practice of green manuring. The liability of a soil to lose its nitrates through drainage is, as has been repeatedly pointed out in these pages, very great. By absorbing the nitrogen in the soluble form of nitrates and converting it into the insoluble organic form, where it is safe against immediate loss, the green crops effectually prevent this loss. The value of green manuring with leguminous crops is of the very highest kind. By growing them and then ploughing them in, the nitrogen of the soil is largely increased by the nitrogen drawn from the air in the growth of these crops. Indeed, it is conceivable that by a skilful adoption of certain rotations of crops in which leguminous crops were largely grown, the necessity for the addition of nitrogenous manures might be largely obviated. (See Aikman's 'Manures and the Principles of Manuring,' where the question is dealt with more fully.)

These considerations, while they explain the effect and illustrate the value of green manuring, show that he overlooks an important natural means of wealth who neglects to utilise the green sods and the crops of weeds that flourish by his hedgerows and ditches. Left to themselves, they will ripen their seeds, and sow them annually in his field; collected in compost-heaps, they will materially add to the weight of his crops.

Sea-weed.—Among green manures, the use of fresh sea-ware deserves especial mention, from the remarkable fertilising properties it is known to possess, as well as from the great extent to which it is employed on all our coasts. The agricultural produce of the Isle of Thanet, in Kent, is said to have been doubled or tripled by the use of this manure; the farms on the Lothians at one time let for 20s. or 30s. more rent per acre when they had a right of way to the sea, where the weed is thrown ashore; and in the Western Isles, sea-weed, shell-marl, and peat-ash are the three great natural fertilisers upon which the agriculture of this remote region depends. In Ireland, sea-weeds are a favourite manure for potatoes.

The common red tangle, which grows farther out at sea, is in some districts preferred as a manure to the other varieties of sea-weed, when applied green or made into compost. Used alone for potatoes, it gives a good return, but generally of inferior quality. The potatoes are said to be of better quality when the sea-weed is put into the soil and covered with a layer of earth, upon which the potatoes are to be planted. On the south-east coast of Fife, where the sea-weed is laid on the stubble at the rate of 20 carts an imperial acre, ploughed in, and the turnips afterwards raised with half dung, the *clover is said never to fail.*

Sea-weeds decompose with great ease when collected in heaps or spread upon the land. During their decay they yield ammonia and saline matters—the latter in large quantities.

Especially to this saline matter may be ascribed the beneficial influence of sea-weed on garden asparagus, originally a seaside plant, and upon fruits like raspberries, which contain much alkaline matter.

The value of sea-weed as a manure differs according to the proportion in which it is made up of the different classes of weed—some of which possess greater manurial value than others—and the state of its dryness. When fresh it contains about 80 per cent of water. Of nitrogen it contains, when in a dry condition, from 1 to 3 per cent, and about 3 per cent of potash, and half a per cent of phosphoric acid. Its manurial value is generally reckoned as equal to that of farmyard manure, and its action, when applied, may be described as similar, with the exception that it is as a rule deficient in potash.

Straw.—Almost every one knows that the sawdust of most common woods decays very slowly—so slowly, that it is rare to meet with a practical farmer who considers it worth the trouble to mix sawdust with his composts. This property of slow decay is possessed in a certain degree by all *dry* vegetable matter. Heaps of dry straw when alone, or even when mixed with earth, will ferment with comparative difficulty, and with great slowness. It is necessary, therefore, to mix it, as is usually done, with some substance that ferments more readily, and which will impart its own fermenting state to the straw. Animal matters of any kind, such as the urine and droppings of cattle, are of this character; and it is by admixture with these that the straw which is trodden down in the farmyard is made to undergo a more or less rapid fermentation.

The object of this fermentation is twofold: first, to reduce the particles of the straw to such a minute state of division that they may admit of being diffused throughout the soil; and second, that the dry vegetable matter may be so changed by exposure to the air and other agencies as to be fitted to yield without difficulty food to the roots of the plants it is intended to nourish.

Straw is undoubtedly more valuable as a food than as a manure, as we shall see when we come to treat of the feeding of the animals of the farm. Indeed its manurial value is very slight, and unless it is well rotted it is of little use. The riper the straw is, the less valuable is it either as a manure or a food.

The following table gives the relative proportion of fertilising ingredients in different kinds of straw:—

1000 lb. contain—	Nitrogen.	Potash.	Phosphoric acid.
Wheat straw . .	4.8	6.3	2.2
Barley " . .	5.6	10.7	1.9
Oat " . . .	6.4	16.3	2.8
Bean " . .	13.0	19.9	2.9

Sawdust applied largely to the land has been found to improve it,—little at first, more during the second year after it was applied, still more during the third, and most of all in the fourth season after it was mixed with the soil. That any dry vegetable matter, therefore, does not produce an immediate effect ought not to induce the practical farmer to despise the application to his land—either alone or in the form of a compost—of everything of the kind he can readily obtain. If his fields are not already very rich in vegetable matter, both he and they will be ultimately benefited by such additions to the soil.

Saturated with ammoniacal liquor, or with liquid manure, sawdust has been profitably used, and without further addition, in the raising of turnips. It may also be charred, either by burning or by alternate layers of quicklime, and thus beneficially applied. It cannot, however, be regarded as other than a very poor manure.

Bran.—The bran and pollard of wheat are useful manures, as they generally contain about half a per cent of nitrogen, about the same quantity of phosphoric acid, and slightly more potash. If moistened with urine and slightly fermented, the action of bran would no doubt be hastened and rendered more powerful; but it seems foolish to use so good a food as bran is for manurial purposes.

The husk of the oat, hitherto wasted at many of the oatmeal-mills, ought to be fermented and employed as a manure.

Brewers' Grains, though now used as a food for fattening cattle or milch-cows, were formerly employed by farmers as a manure. They are supposed to pay best when mixed with farmyard manure. They are extremely poor in nitrogen, potash, and phosphates.

Malt-dust or Combings.—This substance forms an extremely useful food, and is now almost exclusively used as such. If used as a manure, however, it decomposes slowly, although it is comparatively rich in fertilising ingredients, containing between 3 and 4 per cent of nitrogen, and about 2 per cent of phosphoric acid, and slightly more of potash.

Peat.—In many parts of the world, vegetable matter continually accumulates in the form of peat. This peat ought to supply an inexhaustible store of organic matter for the amelioration of the adjacent soils. We know that by draining off the sour and unwholesome water, and afterwards applying lime and clay, the surface of peat-bogs may be gradually converted into rich corn-bearing lands. It must therefore be possible to convert peat itself by a similar process into a compost fitted to improve the condition of other soils. Partially dried, it may be very beneficially employed in absorbing the liquid manure of the farmyard, or in mixing with the contents of the tanks.

Peat-compost.—Many other ways of working up peat have been suggested, such as adding lime, salt, and other substances, to aid the fermentation. The composition of peat varies considerably. Professor S. W. Johnson found in a number of samples which he examined that the amount of nitrogen varied from .4 to 2.9, giving an average of 1.5 per cent. Peat is now being largely used, as has been already pointed out in the chapter on farmyard manure, in lieu of straw as a litter.

Tanners' Bark is a form of vegetable matter which, like sawdust and peat, is difficult to work up, and is therefore often permitted largely to go to waste. Like peat, it may be dried and burned for the ash, which is light, portable, and forms a tolerably good top-dressing. It is best used in compost form. The hard thick fragments of bark, however, cannot be so soon decomposed as the already finely divided peat, and must be expected, therefore, to demand more time. With lime it may, like sawdust or peat, be decomposed.

Charcoal and Soot.—When wood and other vegetable substances are heated in close vessels they are converted into charcoal. Coal (which is of vegetable origin), deposits in our chimneys, when burned, large quantities of soot; and when distilled in gas-retorts it yields, besides gas, a quantity of coal-tar and other products. All these substances have been tried and recommended as manures.

Charcoal-powder possesses the remarkable properties of absorbing noxious vapours from the air and from the soil, and of extracting unpleasant impurities as well as saline substances from water, and of decomposing many saline compounds. It also absorbs into its pores much oxygen and other gases from the air. Owing to these and other properties, it forms a valuable mixture with liquid manure, nightsoil, farmyard manure, ammoniacal liquor, or other rich applications to the soil. It is even capable itself of yielding *slow* supplies of nourishment to living plants; and it is said to be used with advantage as a top-dressing. In moist charcoal the seeds sprout with remarkable quickness and certainty; but after they have sprouted, they do not continue to grow well in charcoal alone. Drilled in with the seed, charcoal-powder is said greatly to promote the growth of wheat. Placed round the roots of the dahlia, it darkens and enriches the colour of the flowers. It acts in the same way upon roses, petunias, &c., when spread over the soil.

Charcoal prepared from sea-weeds is recommended by Mr Stanford as a valuable vehicle for applying animal manures to the soil.

Soot, whether from the burning of wood or of coal, consists chiefly of a finely divided charcoal, possessing the properties above mentioned. It contains, however, ammonia, gypsum, nitric acid, and certain other substances, to which its well-known effects upon vegetation are chiefly to be ascribed. In many localities it increases the growth of the grass in a remarkable degree; and as a top-dressing to wheat and oats, it sometimes produces effects equal to those which follow the use of nitrate of soda.

Thus wheat and oats dressed with soot, in comparison with undressed, gave the following return of grain :—

	Wheat.	Oats.
Undressed . . .	44 bushels.	49 bushels.
Dressed	54 "	55 "
Increase . .	10 "	6 "

It acts also upon root-crops—56 bushels of soot mixed with 6 of common salt having produced larger crops of carrots than 24 tons of farmyard manure, with 24 bushels of bones.

Soot contains from 16 to 40 per cent of mineral matter, consisting of earthy substances from the coal carried up into the chimney by the draught, and of gypsum and magnesic sulphate derived from the lime of the flue and the sulphur of the coal. It contains, besides, from 2 to 5 per cent of ammonia, chiefly in the state of sulphate. Average quality contains about 3½ per cent of nitrogen.

When applied to grass in spring, it is said to give a peculiar bitterness to the pasture, and even to impart a disagreeable flavour to the milk. Hence, in large towns, the cow-feeders of the milk-dairies are sometimes unwilling to purchase early grass which has been manured with soot.

Coal-dust.—In the county of Durham the dust of common coal, such as is sifted out at the mines as too small for burning, has been spread upon poor, cold, arable land, and as a top-dressing upon old pastures, with, it is said, advantage. Something will, no doubt, depend both upon the quality of the coal and upon the kind of land to which it is applied, but it seems a very poor manure.

Leaves of trees, if abundant, should be collected and used as litter. Leaves are apt on certain soils to produce too great sourness. This is due to the fact that in their decomposition considerable quantities of organic acids, such as humic and ulmic acids, are formed. They may also be ploughed in, fermented or not according as the soil is light or stiff. They vary considerably in composition, but generally contain from 6 to 10 lb. of nitrogen, 1 to 3 lb. of potash, and 1 to 4 lb. of phosphoric acid per 1000 lb.

Wild Plants.—Some weeds and other wild plants contain large quantities of nitrogen and ash, whilst others are poor in these constituents. Thus Anderson found in nettles, 0.34 per cent of nitrogen in the stems, and 0.92 per cent in the leaves. The ash of the former amounted to 1.66, and of the latter to 4.34; the ash was rich in potash-salts, but not in phosphoric acid. The buttercup and coltsfoot contained 0.21 and 0.31 per cent of nitrogen respectively, and each yielded a little over 2 per cent of ash, rich in potash, but poor in phosphoric acid.

CHAPTER XXXVII.

SALINE AND EARTHY MANURES.

The general nature and mode of operation of such saline and mineral substances as are capable of acting as manures, will be understood from what has already been stated as to the necessity of nitrogen and of inorganic food to plants, and as to the kind of inorganic food which they especially require. It will be necessary, however, to explain here more fully the composition of some of the substances which supply crops with these substances.

Ammonia-salts.—The value of ammonia as a manure has been already referred to. It exists in all fermenting animal manures, and thus is constantly applied to the land even in districts where least attention is bestowed upon the cultivation of the land.

Ammonia, or Gas-liquor.—Coal contains from 1 to 2 per cent of nitrogen. In the process of making coal-gas, this nitrogen combines in great part with a portion of the hydrogen of the coal, and forms ammonia-gas (HN_3). In purifying the coal-gas a large proportion of the ammonia which it contains is condensed, and, together with carbonic, acetic, and other acids, sulphuretted hydrogen, tarry matters, &c., constitutes what is termed *gas*, or *ammonia-liquor*. One ton of coal generally yields about 10 gallons of ammonia-liquor, containing from 3½ to 6 oz. of ammonia per gallon. From one ton of gas-liquor ½ cwt. of ammonia (equal to 2 cwt. of sulphate of ammonia) may at least be expected.

To grass-land this ammoniacal liquor may be applied with advantage by means of a water-cart—being previously diluted with from three to five times its bulk of water. If too strong, it will burn up the grass at first, especially if the weather be dry; but, on the return of rain, the herbage will again spring up with increased luxuriance.

On arable land it may be applied to the young wheat or other corn by the water-cart, or it may be dried up by peat, charcoal, sawdust, or any other suitable porous material, and thus put into the turnip or potato drills. Added to liquid manure or to composts of any kind (under cover) it greatly enhances their value. Manuring with gas-liquor is not now, however, practised to any extent, the ammonia being converted into sulphate of ammonia.

Sulphate of Ammonia (*Ammonium Sulphate* = $(NH_4)_2SO_4$).—This substance, which, along with nitrate of soda, has largely taken the place of guano as a source of nitrogen, is now one of the most important of artificial manures. Formerly obtained almost exclusively from the gas-works, it is now produced as a by-product in several different kinds of manufacture. Among these may be mentioned paraffin-shale and iron works, which both supply large quantities. It is also obtained from bone-distilleries and coke-ovens. At present the annual total production of sulphate of ammonia amounts to about 200,000 tons, of which nearly three-fourths is produced in the United Kingdom. When pure it contains 25.75 per cent of ammonia (NH_3), but the commercial article is generally sold on a basis of 24.5 per cent. At a red-heat it should be almost entirely dissipated, anything beyond a very slight residue being an impurity.

It may be applied to all soils and all crops, but is especially valuable for cereals. It may be applied to the soil shortly before sowing, and is not liable to be washed out of the soil by rain, in the same way as nitrate of soda is. The comparative value of sulphate of ammonia and nitrate of soda as nitrogenous manures, has formed the subject of an innumerable number of experiments in recent years. Much seems to depend on the nature of the season. In a wet year sulphate of ammonia seems to have an advantage over nitrate of soda; whereas in dry seasons the reverse seems to be the case. As it is an extremely concentrated manure—indeed the most concentrated of all common nitrogenous manures—it should not be applied in large quantities, 1 cwt. per acre being as a rule quite sufficient. It may be mentioned that sulphate of ammonia is the most commonly used nitrogenous ingredient in the so-called "special" manures. It is the most stable condition of ammonia, and is thus the safest compound to use. Other compounds of ammonia have been tried as manures, but none other is used to any extent. It may be useful to know that ¾ cwt. of sulphate of ammonia contains as much nitrogen as 1 cwt. of nitrate of soda.

Steeping of seeds in the salts of ammonia.—The salts of ammonia, especially sal-ammoniac and the sulphate of ammonia, have been strongly recommended as steeps for seed-corn. They have in many cases been found very advantageous in hastening germination: thus, in one experiment, seeds of wheat, steeped in solution of sulphate of ammonia on the 5th of July, had by the 10th of August tillered into nine, ten, and eleven stems of nearly equal vigour; while unprepared seed had not tillered into more than two, three, or four stems.

Lime from Gas-works.—This substance essentially consists of a mixture of calcium hydrate and carbonate (CaH_2O_2 and $CaCO_3$), together with 6 to 9 per cent of gypsum, and smaller quantities of other and unimportant matters. When fresh it contains sulphide of calcium, which is injurious to plants, but which by exposure to air becomes calcium sulphate. Gas-lime must not therefore be used until after some months' exposure to the air.

Nitrate of Soda (*Sodium Nitrate* = $NaNO_3$).—Potassium nitrate (saltpetre) is found in large quantities in India, but it is too dear to be used very widely as a manure. Crude sodium nitrate (or cubic nitre) occurs in deposits of great extent on the south-west coast of South America. These deposits are chiefly situated in Chili, and have been the source of enormous wealth to the Government of that country. The *caliche*, as the raw material is called, occurs in huge deposits at a depth of 10 inches to 16 feet from the surface of the soil. The layers are 6 inches to 3 feet in depth. While sometimes found near the surface, it is generally covered with a layer of rock of the nature of conglomerate or pudding-stone, called *costra*. The *caliche* contains a varying percentage of impurities, chiefly common salt, of which it may contain from 20 to 60 per cent. The other chief impurities are sodium and magnesium sulphates, and earthy matter. No beds exist nearer than fifteen miles from the sea, those farthest away being about ninety miles. When purified from earthy matters, &c., it is exported—chiefly to Europe and the United States—to be employed as a manure, and in the manufacture of oil of vitriol. It is essentially valuable as a source of nitrogen. The nitrate of soda of commerce contains from 15 to 16 per cent of nitrogen, so that 3 parts of sulphate of ammonia contain about the same quantity of nitrogen as 4 parts of nitrate of soda. As nitric acid is the form in which plants absorb their nitrogen, and as all forms of nitrogen in the soil are slowly converted into nitrates by the process of nitrification, nitrate of soda is, of all artificial nitrogenous manures, the most speedily available.

Nitrate of soda may be applied to every kind of crop which requires nitrogen, especially corn crops. It is best applied along with superphosphate, but not at the same time. It should always be applied as a "top-dressing"—that is, after the crop is above ground. The reason for this is, that unless the crop is present in the ground, ready to receive it, it is apt to be lost by drainage. If added to mixtures, care should be taken not to mix it with damp superphosphate of lime, otherwise loss of nitrogen in the form of nitric acid is apt to take place. Nitrate of soda is now exported yearly from South America to the extent of nearly *one million tons* annually, of which over one-tenth finds its way into this country.

Gypsum (*Calcium Sulphate* = $CaSO_4 + 2H_2O$) is applied to tracts of grass-land in Germany, and it is said with decided success. It is also used with great success in France. In the United States it is used for every kind of crop, and is alleged to produce very striking effects on Indian corn. It is specially adapted to the pea, the bean, and the clover crops. It is more sensibly efficacious when applied in the natural state than after it has been burned.

Although it contains two necessary plant constituents —viz., *lime* and *sulphuric acid*—its action as a manure can scarcely be attributed to this fact, as most soils are abundantly supplied with these ingredients. Probably its chief value lies in the fact that it acts on the potash present in the soil, and renders that available for plants' needs. This is in all probability the reason of its especially favourable action on such potash-loving crops as clovers, which are so much benefited by the application of gypsum. It also promotes the process of nitrification. In all probability, therefore, the addition of gypsum to most soils is tantamount to the addition of a potash manure. This fact is gradually becoming more recognised, and gypsum is no longer used to the same extent in this country as formerly.

Those who largely use mineral superphosphates should recollect that nearly one-half of the weight of those manures consists of gypsum.

Magnesium Sulphate ($MgSO_4 + 7H_2O$) was formerly occasionally introduced into "special" manures, prepared by manufacturers for corn crops. As magnesium is an abundant constituent of the seeds of the cereals, its salts may occasionally be found of use; but they are rarely purchased directly by the agriculturist. In most manures magnesium phosphate or carbonate occurs in small quantities, and there are few limestones from which magnesium carbonate is absent.

Potash-salts.—Formerly potash was obtained from kelp, the ashes of sea-weed, the ashes of plants, &c. Since, however, the discovery of the Stassfurt potash deposits, it is almost entirely obtained from them. Potash has therefore become very much cheaper than was formerly the case. We have seen that potassium salts are indispensable to plants, and that they constitute a large, sometimes the larger, proportion of the weight of their ashes. In some soils potash exists even to the extent of 2 per cent; but in general it is present in the proportion of 0.1 to 0.4 per cent. In light sandy and in calcareous soils it is sparsely diffused. We have seen that the crops imported from the farm carry off a large quantity from the soil. Now the artificial manures already described furnish but trifling quantities—Peruvian guano, 1 to 3 per cent; superphosphates, a mere trace—to the soil, which therefore depends upon farmyard manure to make good the losses in potash which it sustains. As farmyard manure restores only a portion of the abstracted potash, it would seem reasonable that artificial manures should make up the deficit. Potash, as a rule, especially in such a country as Scotland, is not so generally lacking in the soil as phosphoric acid or nitrogen. Especially in the case of heavy soil is an application of potash not likely to be beneficial. Of all crops potash seems most to benefit pasture and leguminous crops, such as clover, peas, beans, &c. It may also be applied to potatoes and root-crops. On light soils it seems to exercise its most striking effect.

Potassium Nitrate (KNO_3), *Saltpetre.*—This salt of potassium constitutes the most concentrated manure we have, for it contains the two fertilising ingredients nitrogen and potash. It is got in large quantities in India from the *nitre soils*, to which reference has already been made when discussing nitric acid. It is too expensive a salt to be used for manurial purposes, and is chiefly employed in the manufacture of gunpowder.

Potassium Chloride (KCl) has, under the name of muriate of potash, been used as a manure for many years, but not extensively. It contains 52.35 per cent of potassium, which is equal to 63.1 per cent of dry potash (K_2O). It is obtained as a by-product in the manufacture of potassium chlorate, in the purification of nitre, in the manufacture of iodine from kelp, and sugar from beetroot, and in other manufactures. It is also obtained from molasses, from sea-water from which common salt has been separated, and from crude potash-salts, and is generally sold for manurial purposes on a basis of 80 per cent purity. The potassium chloride sold as a manure is often very impure. Potassium chloride is now chiefly obtained from Stassfurt.

Kainite.—This is the principal form in which potash is found at Stassfurt. It is chiefly composed of potassium sulphate, and magnesium sulphate and chloride. It contains about 13 per cent of potash.

Potassium Sulphate (K_2SO_4) is, as we have just seen, the chief potash-salt in kainit. It is obtained as a by-product in a number of manufactures. It is not used to a great extent as a potash manure.

Soda-salts.—The results of very many experiments prove conclusively that soda-salts (unless, perhaps, in inappreciable quantities) are not essential to any kind of plants. One of the sodium salts is, however, used as a manure—viz., sodium chloride, or common salt.

The nature of its action has been much discussed in the past, and offers a problem surrounded with many difficulties. Opinions as to its action vary very much. In all probability the true action of salt is to be found in the mechanical effect which it exercises on the soil, and which in many respects resembles that of lime. Thus, when applied to soils it causes coagulation of the fine clay particles, and lessens the tendency to puddle. It further acts as a solvent for the different fertilising ingredients in the soil. Its action on double silicates is similar to that of gypsum. It thus helps to set free potash and phosphoric acid. Its action as an antiseptic must also be noted, which probably serves to explain its well-known action in preventing rankness of growth.

The best kind of common salt is that which is procured from the fish or bacon curer, as it contains some animal matter, and is sold cheaply. Sometimes this waste salt is very wet, which detracts from its value.

Kelp.—Sea-weeds reduced to ashes constitute *kelp.* This substance is now chiefly used as a source of iodine; but it is still occasionally employed as a manure, especially for potatoes. In Ireland it has been used for that purpose probably for a couple of centuries, and on the western and northern coasts of Scotland it has also been largely applied as a general manure. It is, however, bad economy to burn the weeds for the mere purpose of converting them into manure; by so doing, the large amount of nitrogen which they contain is lost. In the Channel Islands the sea-weeds (termed there *varec*) are burned as fuel, and their ashes carefully collected and used as manure.

Kelp is variable in composition, containing from 20 to 40 per cent of potassium salts, from 20 to 50 per cent of sodium compounds (chiefly as common salt and sodium carbonate), 3 to 8 per cent of calcium phosphate, and 15 to 40 per cent of earthy salts. "Drift-weed" contains less potash than "cut-weed."

Iron-salts—common copperas—ferrous sulphate ($FeSO_4 + 7H_2O$)—applied in the form of a weak solution to sickly, blanched plants, has been observed to change their colour to green, and to improve their appearance generally. It has been applied to diseased trees. The value of this substance as a manure has been much discussed of recent years, and considerable difference of opinion has been expressed. It is commonly regarded as a plant poison, and probably acts as such except in minute quantities and under exceptional circumstances. The interesting question is as to its action. According to experiments by Dr Griffiths, when applied at the rate of ½ cwt. per acre, a remarkable increase in the crop has been obtained in the case of beans, turnips, potatoes, hay, and mangels. The effect, according to this investigator, on the composition of the ash of the crop of the sulphate, is to increase the iron and phosphoric acid, and diminish the potash—conclusions, we may add, at variance with the results of other investigators. Sir Humphry Davy was of the opinion that the benefit of ferrous sulphate was to be found in its indirect action in giving rise to the formation of gypsum, and that consequently its action would only be beneficial where there was an abundance of lime. That this old explanation is really the true one, some recent experiments carried out in France seem to prove,—the amount it is safe to apply depending entirely on the quantity of lime present in the soil.

The table (p. 362) shows the percentage of nitrogen, phosphoric acid, and potash in some of the more commonly used manures, and may be useful for reference. As the quality of different samples varies, the figures must be taken as only approximate.

Waste Lime Compounds.—The lime used by tanners and soap-makers, and the calcium sulphate from mineral-water manufactories, can generally be procured at nominal prices, and sometimes for the mere cost of carting. The first and last named are the most useful to the farmer; but they cannot be profitably conveyed to any but a short distance from where they are produced.

PERCENTAGES OF NITROGEN, PHOSPHORIC ACID, AND POTASH IN SOME PHOSPHATES AND MANURES.

Manures.	Nitrogen.	Phosphoric acid.	Potash.
	Per cent.	Per cent.	Per cent.
South Carolina phosphate	...	25	...
Belgian "	...	18	...
Somme "	...	33	...
Estremadura "	...	23	...
Canadian "	...	33 to 39	...
Aruba "	...	39	...
Curaçao "	...	40	...
Navassa "	...	32	...
Cambridge coprolites	...	26	...
Bedfordshire "	...	24	...
Pas de Calais "	...	20	...
Sea-weed (in dry matter)	1 to 3	.5	3
Fish manure	7 to 10	8 to 10	.3
Peruvian guano	2.5 to 9	14 to 21	3 to 4
Ichaboe "	12	9	1.5
Baker Island "	.5	34	.1
Malden Island "	.4	35	.2
Oilcakes	2.5 to 7	1.5 to 3	1 to 2
Sodium nitrate	15 to 16	...	...
Sulphate of ammonia	20	...	...
Dried hoofs and horns	15	...	...
Dried blood	9 to 12	...	...
Meat-meal guano—			
Nitrogenous	11 to 13	.6 to 3	...
Phosphatic	6 to 7	14 to 17	...
Shoddy and wool waste	3 to 8	...	...
Soot	3.5	...	...
Fresh bones	3.5	19	...
Steamed bones	1.4	29	...
Bone-ash	...	34	...
Basic slag	...	17	...
Superphosphate (ordinary)	...	11 to 12	...
Superphosphate (high class)	...	17	...
Muriate of potash	...	...	50
Nitrate of potash	14	...	46
Kainit	...	...	13
Wood-ashes	...	4 to 6	6 to 10
Coal-ashes	...	...	2.5
Bats' guano	5	7	...
Pure dissolved bones	2.2 to 2.5	13 to 16	...
Dissolved bone compound	...	13 to 16	...
Steamed bone-flour	2	25 to 27	...
Dissolved Peruvian guano	5	11	3

CHAPTER XXXVIII.

APPLICATION AND VALUATION OF ARTIFICIAL MANURES.

Application of Manures.—In the application of artificial manures, one or two considerations must be borne in mind. Among these may be mentioned evenness of distribution. This is sometimes difficult to carry out, owing to the fact that the quantity of manure applied per acre is so small. It is precisely in such cases that the necessity of equable distribution is greatest, since the manures applied in small quantities are the expensive concentrated manures. In order to ensure an even distribution, manures may be mixed with soils, ashes, sand, &c. The manure is thus diluted in its strength, and a much larger bulk of substance is obtained to work upon. Circumstances must decide which of these substances it is most advisable to use. If the soil be a heavy clay, the addition of sand or ashes may have an important mechanical effect; while, on the other hand, if it be a light soil, the addition of peat may similarly improve its mechanical condition. It must be noted, however, that manures containing ammonia must not be mixed with ashes or lime, or any substance containing free lime or caustic alkali, otherwise a loss of the valuable ammonia is sure to ensue.

Time of application.—With regard to the time of application, manures may be drilled in with the seed, as is done in the case of turnips, or may be sown broadcast or ploughed in before seedtime. In the case of certain soluble quickly available manures, such as nitrate of soda, top-dressing is the favourite mode of application. Of course, in the case of pastures, top-dressing is the only available method of manuring. It may be pointed out that too late application of manures in the form of a top-dressing, especially in the case of nitrate of soda, is apt to increase the tendency of a crop to "shoot." Another condition which ought to be borne in mind is the nature of the soil. This is, of course, obvious. Manures with an abundance of organic matter will have a better effect on light sandy soils. Heavier soils, whose retentive power is greater, are best able to retain soluble manures. The climate will also have an important effect on determining the efficacy of different manures: in a wet climate an insoluble manure will act more speedily than in a dry climate.

Manurial requirements of crops.—One must also discriminate between the different requirements of various crops, for true economy in the application of manures depends largely on this consideration. Generally speaking, it may be said that when the three ingredients, nitrogen, phosphoric acid, and potash, are applied alone, the most favourable results in the case of *nitrogen* will be on *cereal crops*, that of *phosphoric acid* on *root-crops*, and that of *potash* on *leguminous crops.*

Rate of application.—A point which we have not adverted to is the rate at which manures ought to be applied. It is impossible, however, to lay down any general rules on this point, as it depends on various conditions, such as the previous treatment of the soil. This question can best be decided by experiments carried out with different crops themselves, and on different soils.

Valuation of Manures.—A word or two on the principle of valuing manures may be of use, as it is to be feared considerable ignorance still prevails with regard to what alone constitutes the value of a manure. It must be pointed out, of course, that the value of a manure depends to a certain extent on supply and demand, and is bound to vary very considerably from time to time. Apart, however, from the commercial value of the manure, farmers would do well to constantly seek for the cheapest source of the different fertilising constituents. There are only three ingredients which give to a manure its commercial value. These are nitrogen, phosphoric acid, and potash. In the first place, the value of a manure will depend on the percentage of these ingredients it contains. Another consideration—and this is a most important one—is the form in which these ingredients are present. Nitrogen may be present in the shape of some insoluble organic form, as in bones, shoddy, &c., or it may be present in some soluble form, as ammonia or nitric acid. The value of nitrogen in these forms is, as every farmer knows, very different. Similarly, phosphoric acid may be present in a soluble or insoluble form. What the relative manurial values of these different forms of fertilising ingredients are, can only be determined by experiments. These values, together with the question of supply and demand, fix the commercial value of manures. What is known as "unit value" is obtained by dividing the price per ton of the manure by the percentage of nitrogen, phosphoric acid, and potash it contains. To take an example. Sulphate of ammonia of 97 per cent purity contains 24 per cent of ammonia, and at present (1893) is valued at £11, 10s. per ton. In order to obtain the unit value of ammonia in sulphate of ammonia, we have to divide £11, 10s. by 24. This gives us 9s. 7d. as the unit value. The following table, taken from the 'Transactions' of the Highland and Agricultural Society of Scotland, gives the units used for determining the commercial value of manures:—

UNITS TO BE USED IN DETERMINING THE COMMERCIAL VALUE OF MANURES.

For Season 1893.

Items to be valued.	Guanos.		Scrap manures.			Bone-meal.		Steamed bone-flour.	Dissolved or vitriolated bones.	Superphosphates.	Dissolved compounds.		
	Ichaboe.	Peruvian (riddled).	Fish-guano.	Frey-Bentos guano.									
Classes	Genuine.	Genuine.		*a.*	*b.*	*a.*	*b.*	*a.*			From	To	Average.
Phosphates—													
Dissolved	...	...	...	...	...	...	...	...	2/6	...	2/-	2/6	2/3
Undissolved	2/-	2/-	1/5	1/6	1/4	1/4	1/3	1/5	1/6	1/11	1/3	1/9	1/6
Ammonia	16/-	17/6	10/-	11/6	10/-	10/-	9/6	10/-	11/6	...	10/-	12/-	11/-
Potash	...	3/6	...	...	...	...	...	...	...	...	3/4	3/8	3/6
Prices per ton, March 1893—													
From	250/-	230/-	130/-	150/-	120/-	105/-	100/-	95/-	95/-	45/-	...	...	...
To	270/-	290/-	150/-	180/-	140/-	115/-	110/-	110/-	110/-	60/-	...	...	...

In order, therefore, to obtain an approximation as to the value of the manure, we have first to ascertain its analysis, and then multiply the percentage of nitrogen, phosphoric acid, and potash it contains by the unit value stated in the above table. It must be remembered, however, that such tables require constant revision, as the commercial value of manures is a fluctuating one.

Having discussed the question of soils and manures, we may next consider the very important question of animal nutrition.

CHAPTER XXXIX.

ANIMAL NUTRITION.

Composition of Animal Body.—The composition of the animal body is a matter of considerable importance, if we are to clearly understand the functions performed by the different foods. Broadly speaking, it may be divided into the fluid and the solid portions. The percentage of fluids, which consist chiefly of blood, varies somewhat. It may be stated at from 4 to 9 per cent. In old and fat animals it is less than in young and lean animals. The solid tissue is made up of bones, which form 6 to 12 per cent; muscles and tendons, which form 35 to 48 per cent; and the fat, which is extremely variable, and may range from 4 to 40 per cent.

Organic and Mineral Portion.—The animal body, like plant tissue, consists of an organic or combustible portion, and an inorganic or incombustible portion. As in the plant, the organic portion forms by far the larger percentage. The inorganic portion varies in amount from 2 to 5 per cent, and is greatest in lean and least in fat animals. While occurring most abundantly in certain parts, such as the bones, it is found in nearly all parts of the body, and is essential for life. We have already seen in a previous chapter that the constituent elements which form animal tissue are the same as those found in the plant. But while neither sodium nor chlorine can be considered necessary for plant life, these elements are absolutely necessary for animal life. Indeed salt (which is a compound of sodium and chlorine) is a most important mineral food.

The most abundant mineral constituent of the animal body is *calcium phosphate*, which forms, on an average, about four-fifths of its entire amount of mineral matter. The other chief ash constituents are potash and soda salts. These saline constituents, although only found in small quantities in the various fluids and tissues, are constantly being excreted from the body, and hence the necessity for their presence in food. In building up the animal frame, especially in the formation of bones, considerable quantities of lime and phosphoric acid are required.

Composition of Bones.—If we submit a piece of bone to the action of heat, the structure of the bone is destroyed, and we have left a whitish ash. On the other hand, if we submit a bone to the action of an acid, the bone remains unchanged, but it loses considerably in weight. In the first experiment the organic or combustible portion of the bone is burnt and the mineral portion left, while in the second experiment the mineral portion is dissolved and the organic portion, which forms the framework of the bone, is left. The relative amounts of the mineral and organic portions vary according to the age of the animal. In dried bones from a very young animal the mineral portion amounts to 50 per cent; while in older animals it forms

75 per cent. The organic portion is chiefly made up of a nitrogenous substance called *ossein* (from which gelatine is formed). Phosphate and carbonate of lime are the chief ingredients in the mineral portion, the former amounting to about seven-eighths of the whole bone-ash. In a fat animal about 80 per cent of the total mineral matter of the body is found in the bones. The weight of the bones (skeleton), it may be added, of man is to that of the whole body as 10.5 to 100, and as 8.5 to 100 in woman. The bones give strength to the softer portions of the body, protect the vital parts of it—such as, for example, the brain and lungs—and together with the muscles form the levers by which locomotion and other movements are effected.

Blood is a very complex substance. Examined through a powerful microscope, it presents the appearance of a colourless liquid containing immense numbers of small flat red discs. Shortly after blood has been withdrawn from the body, the small amount of *fibrin* which is in it solidifies, or clots, and entangling with it the red discs, leaves a nearly colourless liquid. There are in 1000 parts of blood about 780 parts of water, and 220 parts of solid matters, of which more than one-half consists of blood-discs, more than one-fourth of albumin, and about one-seventh of extractive matter and salts. In the blood of the carnivora the phosphates, and in that of the herbivora the carbonates, of metals abound; whilst in both, common salt exists in about the same proportions.

Flesh owes its red colour to the presence of blood; washed with water for some time, the blood and soluble albuminoids are removed, and a nearly white substance, chiefly composed of fibrin (p. 88) and fat, is left. If very lean flesh be kept for some hours at a temperature of 212°, it loses nearly three-fourths of its weight, the loss being due to evaporation of water. The small proportion of flesh which dissolves in water consists of salts of the blood (chiefly magnesium, calcium, and potassium phosphates and common salt), albumin, peculiar nitrogenous crystallisable substances termed *kreatin* and *kreatinin; inosite*, or "muscle-sugar," and a few other substances.

Brain contains about 80 per cent of water, 7 of albumin, 5 of peculiar substances termed *lecithin* and *cerebrin*, and various fatty substances. In the brain phosphorus is rather abundant, and appears to exist in a very low form of oxidation.

Organic Portion of Animal Body.—Water is the most abundant ingredient of the animal body. Its amount is greatest in young animals, and gradually lessens with age or in fattening. The organic portion of the animal may be divided into two classes of substances—(1) those containing nitrogen, and (2) the non-nitrogenous group.

Nitrogenous Substances.—Those in turn may be subdivided into (1) *albuminoids* or *proteids*, (2) *gelatinous bodies*, and (3) *horny matter*. The albuminoids, which consist of *albumin*, *casein*, *fibrin*, &c., have already been described. They are, of all constituents of the animal body, the most important, and constitute the chief portion of the flesh, and an important part of the blood and other fluids. The gelatinous substances are very similar in composition to the albuminoids. They are found in such portions of the body as the bones (the ossein), the tendons, and cartilage. When boiled for a long time the gelatinous substances are converted into *glue*. The horny substances are chiefly found in the outer portions of the body, such as the hair, wool, horns, skins, hoofs, feathers, nails, claws, &c. In composition all the nitrogenous bodies resemble one another closely.

On an average they contain about 16 per cent of nitrogen. The amount of ash they contain tends to increase with age. During fattening, however, it decreases.

Non-nitrogenous Substances.—Of the non-nitrogenous substances fat is by far the most important and abundant. Fat is pretty well distributed throughout the body. It is found in the blood, in special cells under the skin, and in the flesh, between the bundles of muscular fibres. During fattening it is stored up in great quantity in the animal body, which may sometimes contain as much as 4 per cent of the total live-weight, or three times as much as the nitrogenous matter present. The other non-nitrogenous matters are only present in very minute quantities, and need not be mentioned.

In the following table are given the analyses of the edible portions of ten animals examined by Lawes and Gilbert. The whole carcasses were somewhat richer in nitrogen, chiefly on account of their hides and hoofs:—

COMPOSITION OF EDIBLE PORTION OF THE CARCASSES OF OXEN, SHEEP, AND PIGS.

DESCRIPTION OF ANIMAL.	Mineral matter.	Dry nitrogenous compounds.	Fat.	Dry substance.	Water.
Fat calf	4.48	16.6	16.6	37.7	62.3
Half-fat ox	5.56	17.8	22.6	46.0	54.0
Fat ox	4.56	15.0	34.8	54.4	45.6
Fat lamb	3.63	10.9	36.9	51.4	48.6
Store sheep	4.36	14.5	23.8	42.7	57.3
Half-fat old sheep	4.13	14.9	31.3	50.3	49.7
Fat sheep	3.45	11.5	45.4	60.3	39.7
Extra fat sheep	2.77	9.1	55.1	67.0	33.0
Store pig	2.57	14.0	28.1	44.7	55.3
Fat pig	1.40	10.5	49.5	61.4	38.6
Means of all	3.69	13.5	34.4	51.6	48.4

It may be added that of the common farm animals the ox contains the largest percentage of nitrogenous matter.

Matter and Force.—It has long been known that it is beyond the power of man to annihilate the smallest particle of matter. He can alter its shape, can unite different kinds of matter into new combinations, and resolve compound substances into simpler bodies; but he cannot cause matter to cease to exist. It is only in modern times that it has been experimentally proved that *force* is indestructible. Force, like the matter upon which it acts, may be caused to change its form; but it does not thereby cease to exist, nor does it become diminished in quantity. What is force? Heat is force; so also is light. It is force which causes matter to be removed from one place to another, produces chemical combinations and decompositions, keeps our bodies warm, sustains our movements, and enables us to see. Gravitation, magnetism, and electricity are force. As matter is perpetually changing its forms, so also is force. Light is converted into heat, chemical force becomes animal motive power.

Functions of Vegetables.—Plants possess the power of absorbing from the air and soil certain kinds of mineral matter, and of elaborating them into organic and organised substances—starch, albumin, &c. The organisation of mineral matter through the agency of plants is effected by force, the plants themselves being merely mechanisms, and incapable of originating force. The sun is the source from which plants obtain the force necessary to their growth; and as they do not move about or require a higher temperature than that of the air surrounding them, they do not expend much of the motive power which they receive from the solar beams. Now, the force which has caused carbonic acid, water, and ammonia to become sugar, cellulose, oil, albumin, &c.,

is not destroyed. It is stored up in the plant, which has grown, under its influence, perhaps from a tiny acorn to a gigantic oak. When the matter constituting the plant is disorganised, the force which had organised it reappears in one or more forms. If the plant be an oak, it can be *burned*, and the force stored up in it set free as light and heat, which may be directly used for many purposes, or converted into mechanical power by means of the steam-engine.

Functions of Animals.—It is necessary that animals should move about in search of their food; and all of them require to have their bodies kept at a higher temperature than that of the air surrounding them. If a vegetable, instead of being directly burned in a furnace, be disorganised in the body of an animal, the force stored up in the former is set free, and assumes the forms of heat and *animal motive power*. The functions of plants and animals are therefore opposite. The former continuously organise matter and accumulate force; the latter incessantly disorganise matter and expend force. There are many other functions discharged by animals and plants not necessary to be discussed here.

The force contained in the food consumed by animals is disposed of in various ways. A large portion invariably becomes heat, which escapes from the body. Much of it is expended in causing motions (contractions) of the muscles, some of which are involuntary, such as, for example, those of the heart and lungs. The process of reorganising food, so as to assimilate it to the nature of the animal fed upon it, also involves expenditure of force; and the maintenance of mental or nervous power is also sustained by force derived from food. In some cases—as, for example, when a man or a horse works hard—most of the force contained in his food is used up in enabling him to perform his labour.

How Vital Action is sustained.—Carbonic acid, water, and ammonia are, as we have seen, decomposed by plants; a portion of the oxygen contained in the two former is given off, and the rest, together with all the carbon, hydrogen, and nitrogen, is retained and converted into organic substances. In the animal, these substances are reunited with oxygen and converted into mineral substances and urea. The force expended in producing the organic substances is set free in the animal mechanism in the form of heat and energy.

Action of Oxygen upon the Body.—Atmospheric air contains 21 per cent, by volume, of oxygen, and about 0.04 per cent of carbonic acid. In the act of inspiration a man takes into his lungs from 30 to 40 cubic inches of atmospheric air, and he *expires* from his lungs, a few seconds afterwards, very nearly the same volume of air. In the course of twenty-four hours, nearly 400 cubic feet of air are taken into the lungs. If the expired air be examined, the oxygen will be found diminished by from 4 to 6 per cent, and the carbonic acid increased one hundred-fold. The oxygen has been used up in converting the carbon and hydrogen of the tissues and food into carbonic acid and water. It is by this combustion—which, however, is a very slow and gentle one—within the body that its high temperature and vital functions are maintained. Air expired from the lungs is poisonous; and hence the necessity of perfectly ventilating not merely the dwellings of man, but also the places in which the lower animals are housed. It is a fact worth noticing here, that the weight of oxygen taken into the lungs in twenty-four hours exceeds that of the (dry) food taken into the stomach.

Animal Heat.—As the heat of the body is tolerably uniform, the decomposition of the organic matter which produces it must occur equably throughout the system.

The blood of man has a temperature of about 99° Fahr.; that of birds from 106° to 108°; and of warm-blooded reptiles from 84° to 86°. The bodies of animals, like other masses of heated matter, lose heat by radiation and conduction. To prevent waste of heat, nature has clothed the bodies of animals with hair, fur, feathers, and other light porous substances, through which heat passes with difficulty. It is the almost absolutely non-conducting material—a fine *down*—which covers the body of the eider-duck that enables it to resist the extreme cold of the waters of the icy sea, and the still colder atmosphere of the Arctic circle. As animal heat is kept up by consumption of food, shelter and warmth are to some extent substitutes for food. It has been suggested that fattening animals should be kept in houses supplied with artificial heat; but this plan seems hardly necessary, and certainly would not, in the British Islands at least, where fuel is dear, be an economical one. It is sufficient to protect the animals from the piercing blasts, the cold rain, and the snow-drifts of winter. It is well to bear in mind that animals are not likely to get fat, however abundantly supplied with food, if allowed to lie out in open spaces in very cold or very wet weather.

CHAPTER XL.

FUNCTIONS, COMPOSITION, AND DIGESTIBILITY OF VEGETABLE FOODS.

Functions of Foods.—The functions of food may be said to be of a twofold kind—(1) Food serves to build up the animal frame, to furnish the material for the growth of the flesh, fat, bone, and other parts of the animal body, in the case of young or fattening animals, and also to repair the waste of the tissues which is constantly taking place owing to the wear and tear of life; and (2) it serves for the maintenance of animal heat. Foods may therefore be divided into two great classes—foods which *make animal tissue*, and foods which give *heat*. The first class of foods may again be split up into foods which make *flesh* and foods which make *fat*. Every food, whether vegetable or animal in its nature, may be split up into certain groups of substances, and on the proportion in which it contains these substances its value as a food depends. Food of an animal origin may be divided into three groups—*albuminoids*, *fat*, and *mineral substances;* while in foods of a vegetable origin we have, in addition to these substances, *carbohydrates*. The functions performed by these substances, whether of animal or vegetable origin, seem to be similar. As it is only with graminivorous animals that we have here to deal, it will be more convenient to limit ourselves to the consideration of vegetable foods.

The following analyses of animal and vegetable tissue illustrate their difference:—

	Animal. per cent.	Vegetable (Ryegrass). per cent.
Water	75	70
Nitrogenous substances	16	3
Fat	4	1
Carbohydrates	0	24
Mineral substances	5	2

Nitrogenous Substances in Plants.—The nitrogen present in plants, as we have already seen, is chiefly in the form of albuminoids (substances of the type of albumin, casein, and fibrin). The function of the albuminoids is of a varied nature. Of all food constituents they are by far the most valuable. Their functions are more varied than those of other food constituents. In the first place, they, and they alone, are capable of serving as flesh-formers. From this fact they are generally known as *flesh-formers ;* but they can also serve as *fat-formers* and *heat-givers* as well. Thus they act in a threefold capacity. This can be said of no other food constituent. When taken into the animal body they form the albuminoid matter, and also give rise to all other nitrogenous bodies, such as the gelatinous and horny substances, wool, &c. To illustrate the necessity for albuminoids in food, it may be mentioned that in order to make good the waste of nitrogenous tissues going on, on an average—for of course the amount of the waste of nitrogenous tissue differs very considerably, and depends upon the exertion indulged in—an adult man, it has been calculated, requires about 40 grammes (1.4 ounce) daily of digestible albuminoids; while an ox, for every 1000 lb. live-weight, requires at least ½ lb. when quiet in stall.

How far the different members of the albuminoid group differ from one another in their nutritive value is not very well known at present. In the absence of evidence to the contrary, it is assumed that all have practically the same feeding value. To this one exception must be made, and that is with regard to an albuminoid called *gliadin,* which, from its strong resemblance to glue or gelatine, is probably incapable of acting as a flesh-forming food. Foods containing most albuminoids in their composition are regarded as the most concentrated foods. Among these are the *oilcakes.* The seeds of leguminous plants are rich in albuminoids. Rich also in albuminoids are *dried brewers' grain* and *malt-dust.* The *cereal grains,* of which oats is the richest, although containing only about half as much as the foods above mentioned, are also regarded as rich albuminoid foods. Roots are, on the other hand, very poor in albuminoids.

In the urea excreted in the urine we have a means of estimating the amount of albumin oxidised, the former constituting one-third of the latter. When albumin acts as a fat-producer, its power to do so is very much less efficient than fat—100 parts of albumin only yielding 47 parts of fat. The amount of heat produced by the combustion of albumin is also less than half that produced by an equal quantity of fat, although it is greater, according to the most recent investigations, than that produced by the combustion of the *carbohydrates.*

Amides.—A very important class of nitrogenous bodies in plant-tissue are the amides. They have already been referred to in a previous chapter. Their importance is due to the fact that the nitrogen present in plants in the form of amides has till recently been credited to the albuminoids. The usual method of estimating the albuminoids is to estimate the percentage of total nitrogen, and to convert this into albuminoids by multiplying by 6.25, it being assumed that albuminoids contain 16 per cent of nitrogen. The result has been that, in the analyses made in the past, the percentage of albuminoids in many foods has been overstated. Did the amides possess a nutritive value equal to the albuminoids, this mistake would, from a practical point of view, be of less importance. So far as we at present know, however, their nutritive value is very inferior to that of the albuminoids. Thus they are unable to build up nitrogenous tissue, and the heat-giving power of such members of the group as have been investigated is less than half of that possessed by albuminoids. Their food value is therefore very small. The first member of the group to be discovered was *asparagin; betain, leucin, glutamin, tyrosin, glycolcol,* are some of the other members. They seem to be present in all vegetable matter, although in very varying quantities. The foods containing them in least quantities are ripe seeds. It would seem that as plants develop, amides are converted into albuminoids. In the process of germination amides are probably formed. On this account they are found in large quantities in malt-sprouts (30 per cent). It is possible that in the process of growth the nitrogen, first absorbed in the form of nitrates, is converted into ammonia, then into amides, and lastly into albuminoids. This would account for the fact that amides are found in largest proportions in immature vegetation. Amides are formed in small quantities, in the process of digestion, by the action of pepsin on the albuminoids, the chief product being, of course, peptones. The following are the results of recent investigations into the percentage of the total nitrogen present as albuminoids in some of the common foods. These will thus furnish a means of correcting, to a certain extent, misconception due to the older, erroneous, and still commonly used analyses, in which the percentage of amides has not been estimated, and the albuminoids have thus been overstated.

In artificial feeding-cakes and in the grains of cereals over 90 per cent of the total nitrogen is present as albuminoids. In the seeds of such leguminous plants as beans and peas, the percentage of nitrogen present as albuminoids is slightly less; while in the ripe straw of cereals, from the few analyses we possess, it seems to be between 80 and 90 per cent. The same amount is present in meadow and clover hay. A somewhat lower percentage is present in young grass (75 per cent). Potatoes contain about 60 per cent, carrots 52 per cent, turnips 49 per cent, and mangels 37 per cent.

Non-nitrogenous Substances—*Fat.*—From the analyses we have quoted as being typical of vegetable and animal matter, it will be seen that the former is generally very much poorer in fat than the latter. The fat of the animal body is very similar in its nature to the fat in vegetable matter, and the animal has the power of converting vegetable fat into animal fat. The foods richest in fat or oil are those which are also generally richest in albuminoids, and are those commonly known as *concentrated* foods. At the top of the oily foods come feeding oilcakes, which, as a rule, contain 10 per cent or more of oil. Cereals are generally poor in fat (from 1½ to 3 per cent), oats and maize forming an exception, the former containing as high as 6 per cent, the latter 4 to 9 per cent, of fat. Roots contain .1 to .2 per cent, hay and straw 1 to 3 per cent. Fat is usually determined in a food by extracting with ether or bisulphide of carbon. This method, as a rule, gives satisfactory results with regard to the determination of fat in most grains and their residues, as the extract consists of tolerably pure fat. In coarse fodders, however, it is not so reliable, as wax, chlorophyll, &c., are also found in the ether extract. In determining the fat in silage, the results are apt to be high, as each acid, formed in the process of fermentation, is dissolved out along with the fat.

Fat performs a twofold function. It not merely forms fat in the animal body, but it also acts as a heat-giving food. In the latter capacity, indeed, it excels all other food constituents. The amount of heat generated by the different food constituents has been made the subject of various investigations. The following table, taken from Warington's 'Chemistry of the Farm,' p, 108, gives the most recent determinations:—

Fat	229
Albumin	107
Starch	100
Cane-sugar and gum	97
Glucose and milk-sugar	90
Cellulose . . . . (about)	86
Asparagine (an amide)	49

It is highly probable that this latter function may be the one most commonly exercised by the fat of foods.

Carbohydrates.—The carbohydrates are a most important class of food constituents. The nature of the chief members of the group has already been discussed in a previous chapter. Of these, *starch*, *sugar*, and *cellulose* are the most important. Their chief function is as heat-givers, although they also serve, when taken in excess, as Lawes and Gilbert have shown, as fat-producers. They are the most abundant constituents of plant tissue. The foods richest in carbohydrates are the cereals.

Functions of Food Constituents.—While the three classes of food constituents just enumerated have, as it were, their peculiar and characteristic functions to discharge, they may serve, as we have already indicated, in other ways. Thus, while the chief function of the albuminoids is to build up nitrogenous tissue, they can serve as fat-producers as well as heat-producers; and how far they exercise these functions would depend entirely on circumstances. If they are present in a food in an amount more than sufficient to build up or to make good the waste of nitrogenous tissue, their excess may go to form fat or to supply heat. In a similar way the functions performed by fat and the carbohydrates will also be regulated by circumstances. While neither fat nor carbohydrates have the power, as we have seen, of forming nitrogenous tissue, they may indirectly influence its formation by protecting the albuminoids from oxidation, and thus allowing them to exercise their distinctive and most important function—viz., building up nitrogenous tissue. The whole question of the mutual influence of the different food constituents is an interesting and important one, but at the same time not very clearly understood. It is obvious, indeed, that the difficulties accompanying this department of investigation are exceptionally great.

Digestibility of Foods.—The only question in determining the value of a food is not, however, its composition—that is, the proportion in which it contains the different nutrients. Another point of great importance is the digestibility of the food. This, again, is not wholly dependent on the nature of the food, but on the animal eating that food. Thus ruminants, such as sheep and cows, are able to digest a larger proportion of the nutrients in coarse fodder than horses. Speaking generally, the amount digested by different ruminants is about equal. On an average, ruminants digest about 12 per cent more of the organic matter in a food than the horse. It is more particularly with regard to the coarser indigestible foods and the more bulky fodders that this holds true. With regard to concentrated foods, the capacity of different farm animals to digest them does not seem to be subject to much variation. They, it may be added, are the most completely digested of all foods.

The digestibility of foods is a subject still requiring much work. The experiments hitherto carried out to determine the digestibility of different foods have been made with animals themselves. Laboratory experiments, in which pepsin solutions have been utilised, have also been carried out. Theoretically speaking, the different nutrients, when pure, are wholly digestible. Cellulose is an exception. As, however, our methods of food analysis are faulty, and do not always give the same results, considerable difference is found in the digestibilities of certain foods.

The composition of the foods, as well as the mechanical condition in which the nutrient occurs, are largely instrumental in causing difference in the digestibility of foods. Another point which must be taken into account is the fact that even in the same fodders the digestibility varies at different periods of growth. This is more especially the case with regard to what have been termed coarse or rough fodders. The chief reason for the great variation to be found in the digestibility of the plants forming these fodders at different periods of their growth, is owing to the fact that they are rich in cellulose. Cellulose, of all food constituents, differs most in this respect.

We have said that the composition—that is, the proportion in which the other nutrients are present—has an effect on the digestibility of any one constituent in a food. For example, it has been found that the addition of certain carbohydrates (starch) to a food has the tendency to lower the digestibility of both the cellulose and the protein. This action towards decreasing digestibility is less where the food is rich in albuminoids. Thus the combination of hay or straw with starchy foods is not so advisable as their combination with rich nitrogenous foods, since the amount of hay or straw digested is likely to be less in the former than in the latter case. The larger the quantity of albuminoids a food contains, the more digestible is the food likely to be. On the whole, however, the influence of the composition of a food on its digestibility is not very great. The richer a food is in any nutrient, the more digestible is that nutrient.

The quantity of fodder taken does not seem to have much effect in altering the proportion of the matter digested. A point of considerable interest, but one regarding which much misconception seems to exist, is as to the influence of previous treatment of the food on its digestibility. Thus, for example, the effect of drying hay is not to lessen its digestibility. An opinion to the contrary commonly exists among farmers. The origin of this misconception, however, is probably due to the fact that in the drying process loss of soluble matter is very apt to take place, through being washed out by rain. It has been found that heating in the stack diminishes the digestibility of the carbohydrates, and that long keeping also slightly lessens the digestibility of the nitrogenous matter. Another point which is not always taken into account when comparing green and dry fodders is, that they are respectively used at different periods of their growth. The period of growth has a most important influence. Early-cut fodder is superior, both in chemical composition and digestibility, to late-cut fodder. The effect of cooking is also misunderstood. While cooking a fodder may no doubt increase its palatability, and thus augment the amount eaten by the animal, certainly, so far as experiments have shown, it does not increase its digestibility.

We already referred to the fact that the digestive power of different farm animals varies considerably, and that this variation is chiefly seen in coarse bulky foods. These foods are best digested by ruminants, cattle or sheep, whose digestive organs are specially adapted to the treatment of poor and bulky foods, rather than rich and concentrated foods. Thus horses digest from 46 to 58 per cent of the total organic matter of hay, 62 per cent of that of pasture-grass, 72 per cent of that of oats, and 91 per cent of that of maize. Sheep digest larger proportions of hay and grass, and about the same of grain.

Coefficient of Digestibility of different Foods. — The comparative digestibility of some of the commoner foods by ruminants may here be given. In order to compare the digestibility of a food, it is customary to take the total organic matter it contains, and to state the percentage of that. This forms a useful means of comparing foods generally as to digestibility. The digestibility of the different nutrients is similarly obtained by taking the proportion of each nutrient digested for every 100 lb. supplied. The figure denoting this amount is called the digestive coefficient. Thus we have digestive coefficients for the total organic matter of a food as well as for its different nutrients. Of all foods the straw of cereals is the most indigestible. Its digestive coefficient is only about 50 per cent. With regard to hay, the digestive coefficient is somewhat higher, but it varies considerably. The composition of the straw has an important influence on the digestive coefficient: the richer the straw, the greater its digestibility. The digestive coefficient of the cellulose in cereals is lower than that of the cellulose in leguminous plants. The albuminoids and carbohydrates have also a lower digestive coefficient in cereals than in leguminous crops. In concentrated foods the digestive coefficients are very much higher than in the coarse fodders.

Saline Foods.—The importance of saline foods is not so generally recognised as it should be. The reason of this is undoubtedly owing to the fact that most foods contain an abundance of saline ingredients. Common salt, however, is an exception. Salt, besides being a necessary mineral food, indirectly facilitates digestive processes, especially of the albuminoids, and the conversion of starch into sugar. It further stimulates circulation of the blood. It serves also as a useful condiment by increasing the palatability of a food. Many of the common fodders are poor in salt. Among these may be mentioned potatoes, roots (mangels are, however, rich in salt), grain, &c. We have already drawn attention to the fact that the amount of salt found in plants varies very considerably. It is for this reason that in pastures in countries far removed from the sea, the poverty of the herbage in salt has led to the custom of placing a large piece of salt in the centre of the field for the use of the cattle. The necessity of saline foods for animal life has been proved by experiments in which animals have been fed with food from which mineral matter has been carefully extracted, with the result that death has ensued. The symptoms before death are dulness and sleepiness. It has been found that when the amount of mineral matter in food has been small, the amount excreted from the animal body has been correspondingly reduced. It would thus seem that nature can make shift to do with a minimum quantity under such circumstances. Salt, it may be added, increases the excretion of the urine.

CHAPTER XLI.

FODDER CROPS.

A very large area in the United Kingdom is under meadow and permanent pastures. The plants which grow upon these lands belong to various orders, but chiefly to the *Graminaceæ* and *Leguminosæ*. They are used in three different ways: (1) Animals eat them whilst they are growing; (2) they are cut and given in a green state to animals; (3) they are cut and dried, in which state they form hay.

The Foliage and Stems of Green Crops contain much crude matter, and are not so nutritious as their composition seems to indicate.

COMPOSITION OF STEMS AND FOLIAGE OF GREEN CROPS.

	White Turnip.	Swedish Turnip.	Carrot.	Mangel.	Parsnip.
Water	88.0	86.5	84.0	90.0	85.7
[1] Albuminoids	2.5	3.2	3.2	2.0	2.0
Carbohydrates	3.8	4.3	7.2	3.8	6.3
Fibre	3.9	4.2	3.1	2.6	2.6
Ash	1.8	1.8	2.5	1.6	2.4

The leaves of root-crops possess strong purgative properties; carrots and turnips least so. They ought, therefore, to be used with caution. They have been recommended to be used in the form of ensilage. The fact that so much of their nitrogen is non-albuminoid considerably lessens their feeding properties.

Straw.—The straws of cereals and some legumes constitute excellent food for cattle and horses. Considerable variation in the composition of straw occurs. This depends on the kind of straw, and also on the soil and manuring. Summer straw is richer in nitrogenous matter than winter straw, besides being more tender and digestible. Even the manner of sowing affects the quality of the straw. What, however, has a still greater influence is the time of harvest; the earlier that is, the more nutritious the straw. Their composition and nutritive value depend in a great measure upon the time at which they are cut. If allowed to grow until they are completely yellow, they lose much nitrogen, and their soluble albuminoids become in great part less soluble, and consequently less valuable. The greater part of the non-nitrogenous constituents of straws consists of cellulose, which

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[1] As has already been pointed out, the determination of albuminoids is not reliable, as it includes amides. In the case of these crops the proportion of amides is unusually large. The true albuminoids are, in the case of turnips and carrots, only about 50 per cent of the total nitrogen, and in the case of mangels less than 40 per cent, so that in each case the percentages given ought to be halved.

when young and soft is digestible. Even the hard kinds of cellulose are partly digestible. The old belief that straw forms an indigestible fodder is now known to be false. Although it is poor in albuminous substances, yet when used along with other foods it is valuable for its non-nitrogenous constituents. About 50 per cent of the nutrients in straw are digestible (Henneberg and Stohmann). It may be safely affirmed that good straw is superior in feeding properties to bad hay. 100 lb. of good oat-straw, cut whilst somewhat green, usually contain 1¼ lb. of oil, 4 lb. of albuminoids,[1] 10 lb. of sugar, gum, and other carbohydrates, and from 20 to 30 lb. of digestible cellulose. Among the cereals oat-straw is richest; then come barley (especially valued for milch-cows), wheat, and rye. The straw of the leguminous crops (pea and bean) are richer in nitrogenous substances than the straw of the cereals.

Of all animals, sheep are the best adapted for utilising straw as a food.

According to the late Dr Augustus Voelcker, a valuable method of preparing straw for food is by fermenting it. Fermented straw is richer in nitrogenous compounds and is more digestible and palatable than ordinary straw.

Why Hay varies in Composition.—Owing to the great number of species of plants which make up the fodder crops, the different periods of their development at which they are consumed, the great varieties of soils on which they grow, the inconstant climatic conditions under which they are placed, and the differences in the composition of the manures applied to them, their composition is very variable. It is for these reasons that it is so difficult to compare the merits of the various

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[1] In the straw of cereals the true albuminoids amount to from 80 to 90 per cent of the total nitrogen.

COMPOSITION OF STRAWS.

	Water.	Albuminoids.		Oil.	Carbo-hydrates.	Fibre.		Ash.
		Soluble.	Insoluble.			Digestible.	Indigestible.	
*Irish oats, cut green . . .	14.00	4.08	2.09	1.84	13.79	59.96		4.24
* over-ripe . . .	14.00	2.04	3.00	1.25	10.18	65.45		4.07
English oats	16.00	1.29	2.36	1.25	3.19	27.75	41.82	6.34
*Irish wheat, green, changing to yellow	13.00	1.25	1.26	1.22	4.18	75.84		3.25
*Irish wheat, over-ripe .	12.14	0.44	1.41	1.14	3.88	77.76		3.23
Barley, not too ripe	17.50	5.73		1.17	...	71.44		4.52
dead ripe . . .	15.20	0.68	3.75	1.30	2.24	5.97	66.54	3.24
Bean	19.40	1.51	1.85	1.02	4.18	2.75	65.58	3.71
Pea	16.02	3.96	5.90	2.34	8.32	17.74	42.79	4.95
Flax chaff	14.60	47.75		2.82	8.72	18.56	43.12	7.37

* Tbose marked with an asterisk were analysed by Sir C. A. Cameron, the rest by Dr Voelcker.

fodder plants as articles of food. Hay contains a larger percentage of potash and lime than cereals, and a smaller quantity of phosphates.

Grass meant for hay ought to be well manured: their roots being short, they are not so well able to collect their food constituents, and are very much increased by soluble nitrogenous manures.

The Composition of Plants changes during their Growth.—In the young plants, the proportions of water and mineral matters are high. Albuminous substances are abundant in the leaves, and as these constitute the greater portion of the young plant, nitrogen is abundant in it. As the stem increases, the proportion of nitrogen in the whole plant diminishes—the stem consisting mostly of cellulose, which contains no nitrogen. Fat is most abundant in the young plant, but the carbohydrates, especially cellulose, increase with the age of the plant. Clover increases in dry weight until the blossom is matured. Dr Voelcker determined the amount of soluble matter in clover at different stages of its growth. On the 2d of June the soluble matter constituted 40.04 per cent of the dry weight, and on the 28th of July it fell to 29.27 per cent. E. Wolff found that red clover, cut when young, contained 21.9 per cent of albuminoids, but when the plants were old they included only 9.5 per cent. The ash under the same circumstances diminished from 9.8 to 5.6 per cent. Hellriegel and Stöckhardt's experiments in relation to this point confirm Wolff's results. Way found in young grasses 25.9 per cent of albuminoids, and in old ones only 10.9 per cent. The fat was three times more abundant in the young plants. Kühn examined vetches at four periods of their growth, and found that the albuminoids, which on the 23d May amounted to 28.8 per cent, were on the 12th July present to the extent of 15.9 per cent. These and other experimental results show that it is advantageous to cut fodder crops early—that is, not later than the period at which they are in full blossom. The influence of manures on the amount of nitrogenous matter in hay has been shown by German experiments to be very considerable. Thus in hay from a manured field 3 per cent more nitrogenous matter was found than in hay from an unmanured field. Not merely is the quality of the hay affected by the period of growth, but so also is its digestibility; the earlier it is cut, the more digestible it is.

Leguminous plants are more nitrogenous than grasses, and contain twice as much nitrogen as cereals; they are also rich in potash and lime. Hay containing a large proportion of clovers is consequently rich in nitrogen, and animals fed upon it produce a more valuable manure than if supplied with hay composed of grasses alone.

Good and Inferior Grasses.—Amongst the best grasses may be mentioned Italian ryegrass, meadow-barley, crested dogstail, Timothy, meadow-catstail, and sweet vernal. Such grasses as false brome, upright brome (*Festuca elatior*), and soft grass (*Agrostis spica venti*) are very inferior, and should not be purposely grown.

In the following table is given the composition of fodder crops, as compiled by R. Warington. The percentage composition is that of the dried plants (hay), assuming that in each there is 15 per cent of water. The first column of figures shows the percentage of water in the fresh plants. As the composition of the meadow-hay is deduced from the mean results of fifty analyses, and that of clover-hay from the mean results of eleven analyses, they probably show the actual nature of those articles. The other figures, not being based on nearly so many analyses, are not so trustworthy. The true albuminoids in meadow and clover hay amount to about 80 per cent of the total nitrogen; in grasses when young it is slightly less.

COMPOSITION OF FODDER CROPS.

	Water in fresh plant.	Water in hay.[1]	Albuminoids.	Fat.	Non-nitrogenous extractive matter.	Woody fibre.	Ash.
Grasses, mean of eighteen species (Way)	68.8	15	9.4	2.6	38.8	28.5	5.7
Grasses, mean of twenty-one species (Ritthausen and Scheven)	70.8	15	7.8	2.1	35.1	34.0	6.0
Meadow-hay	...	15	9.2	2.8	41.0	25.8	6.2
Red clover	78.0	15	14.2	3.1	37.2	24.8	5.7
White clover	80.0	15	15.7	3.6	36.7	22.1	6.9
Trefoil	80.0	15	15.7	3.3	34.4	25.8	5.8
Vetches	82.0	15	14.5	2.6	35.2	25.9	6.8
Lucerne	74.0	15	14.5	2.5	34.8	26.7	6.5
Sainfoin	79.0	15	13.9	2.6	34.7	28.7	5.1
Crimson clover	82.0	15	12.9	3.0	30.8	32.2	6.1
Kidney-vetch	83.0	15	9.5	2.4	39.5	28.5	5.1

[1] Assumed to be in each case 15 per cent.

Way determined the composition of the hay made from each of the more important artificial grasses. The mean results gave (the water in each case being taken at 16.6 per cent) 15.81 per cent of albuminoids, 3.18 per cent fats, 34.42 per cent non-nitrogenous digestible matters, 22.47 per cent woody fibre, 7.59 per cent ash. Yellow clover was the richest in albuminoids (20.50 per cent), corn-grass being almost equal to it (20.27 per cent). Ryegrass contained only 11.91 and millefoil 8.62 per cent albuminoids. The fat ranged from 3.98 per cent in cow-grass, and 3.89 per cent in hop trefoil, to 2.09 in millefoil.

According to Anderson, the second cutting of grass is equal in composition to the first.

Badly-made Hay.—Anderson found in inferior meadow-hay, one year old, only 4 per cent of albuminoids. It is true economy to cut hay early, and to get it off the field as soon as it is made. In curing hay a certain amount of loss of valuable nutrients seems unavoidable. If it is carried out very carefully, the loss may be minimised so that it may be trifling. On the other hand, if the hay is exposed to much rain in the curing process, a very great loss may take place. This loss falls heaviest, naturally, on the soluble nutrients, which are the most valuable from a food point of view.

Composition of the Grasses.—The analyses (p. 394), by Dr John A. Voelcker, taken from Sutton's 'Permanent and Temporary Pastures,' illustrate the composition of some of the common grasses.

Exhaustive Action of Hay Crops.—A crop of meadow-hay, weighing 2 tons, removes from the soil about 62 lb. of nitrogen, 70 lb. of potash, and 16 lb. of phosphoric acid. From an acre, a crop of clover-hay weighing 2½ tons abstracts about 175 lb. of nitrogen, 110 lb. of potash, and 32 lb. of phosphoric acid.

Occasional Forage Crops.—The *Lentils*, the *Lupines*, the *Birdsfoot*, and the *Melilot* are occasionally grown as forage crops. They are leguminous plants, but, with the exception of the yellow lupine, are not much cultivated. That plant is grown extensively on the Continent, partly as a food, partly to furnish a green manure. It has been grown in England, but not to any extent. It is notable as being the most highly nitrogenous of all coarse fodders. The digestibility of its albuminoids is over 70 per cent, and is about the same as that of vetches and lucerne: its fibre, however, is very much more digestible than that of either lucerne or vetches. Sheep seem to take to it most readily. It flourishes on poor sandy soils. *Rib-grass* (*Plantago lanceolata*) is often found in

	COCKSFOOT.		MEADOW FOXTAIL.		RYEGRASS.		MEADOW FESCUE.	
	Grass in natural state.	Dried at 212° Fahr.	Grass in natural state.	Dried at 212° Fahr.	Grass in natural state.	Dried at 212° Fahr.	Grass in natural state.	Dried at 212° Fahr.
Water	60.74	...	55.58	...	62.01	...	71.04	...
Soluble albuminoids[1]	.25	.62	.50	1.13	.38	1.00	...	...
Insoluble albuminoids[2]	1.50	3.81	2.56	5.75	2.06	5.38	1.13	3.88
Digestible fibre	11.30	28.78	14.22	32.01	7.98	21.01	8.91	30.77
Woody fibre	16.24	41.36	16.42	36.96	17.71	46.62	12.51	43.19
Soluble mineral matter[3]	2.04	5.19	2.58	5.81	2.90	7.64	1.05	3.62
Insoluble mineral matter[4]	.91	2.32	.94	2.11	.78	2.05	.64	2.21
Chlorophyll, soluble carbohydrates, &c.	7.02	17.92	7.20	16.23	6.18	16.30	4.72	16.33
	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
[1] Containing nitrogen	.04	.10	.08	.18	.06	.16	...	...
[2] Containing nitrogen	.24	.61	.41	.92	.33	.86	.18	.62
Albuminoid nitrogen	.28	.71	.49	1.10	.39	1.02	...	...
Non-albuminoid nitrogen	.18	.46	.30	.67	.38	1.00	.18	.62
Total nitrogen	.46	1.17	.79	1.77	.77	2.02	.36	1.24
[3] Containing silica	.35	.89	.37	.83	.05	.13	...	...
[4] Containing silica	.51	1.29	.52	1.17	.32	.84	.39	1.35

our meadows, but it is not a general favourite. *Green rye* is sometimes used as a forage crop, for which purpose many farmers consider it equal to clover. *Chicory* and *Buckwheat* have been employed as fodder crops, but chiefly on the Continent. Amongst the occasional forage plants may be mentioned the *Mustard*, the *Yarrow*, and the *Prickly Comfrey*. Mr Blundell recommends marrows and melons as excellent food for cattle in seasons of drought. He states that he has obtained more than 40 tons of them on a single acre. *Sorghum saccharatum* is a plant which grows well in warm climates, and has been tried in this country. It forms an excellent forage for stock. It is exceptionally rich in sugar. *Rape* is one of the best forage crops which we possess. Two varieties are commonly cultivated—Summer Rape (*Brassica campestris oleifera*) and Winter Rape (*B. rapus*). It is a highly nutritious fodder. The *Cabbage* is an excellent food for cattle, and deserves to be cultivated as a field crop to a far greater extent than it is at present. Weight for weight, it is as valuable as swedes. The outer leaves of the cabbage are the most nutritious, and the young plants are superior to the old. As a fodder crop, the open-leaved varieties are to be preferred to the more compact kinds. The drawback to the use of the cabbage is that it cannot be stored for any length of time, like the turnip or mangel.

The Furze (Gorse, or Whin) has in a few instances been regularly cultivated, and, as a wild plant, it is abundant on vast tracts of poor pastures. It belongs to the leguminous family, and three species are found in the British Islands—namely, the Common Furze (*Ulex europæus*), the Dwarf Furze (*U. panus*), and the Upright or Irish Furze (*U. strictus*). It flourishes on almost any kind of soil, and although benefited by moderate rain, it resists drought in a remarkable manner. The Rev.

Mr Townsend of Aghada, county of Cork, states that he obtained 14 tons of furze per acre. The plant should be cut young. Horses like it, cattle do not refuse it, but it is said that sheep and pigs do not seem to relish it much.

The Comfrey.—The Common Comfrey (*Symphytum officinale*) and the Prickly Comfrey (*S. asperrimum*) are occasionally cultivated as forage crops; and attention has been called to the value of the latter as a crop yielding a large amount of excellent food. These plants require good soils. At first the produce yielded by them is not large; but after two or three years they give three or four cuttings of from 6 to 9 tons each per acre.

COMPOSITION OF VARIOUS FODDER PLANTS.

100 parts of each contain—	Water.	Albuminoids.	Fats.	Sugar, starch, &c.	Woody fibre.	Ash.
Rape	87.06	3.13	0.64	4.00	3.56	1.61
Yellow lupine	89.20	2.38	0.37	3.96	3.22	0.80
Green rye	75.40	2.71	0.89	9.14	10.50	1.36
Sorghum	81.80	2.19	2.55	10.97	4.03	0.99
Rib-grass plantain	84.78	2.18	0.56	6.08	5.10	1.30
Mustard	86.30	2.87	4.40		4.39	2.04
Prickly comfrey	88.41	2.71	...	6.89	...	1.99
Yarrow (dried)	...	10.34	2.51	45.46	32.69	9.00
Chicory-leaves	90.94	1.01	...	6.63	...	1.04
Gorse (cut rather dry in Aug.)	72.00	3.21	1.18	8.20	13.33	2.08
Cattle cabbage, Drumhead (Anderson)—						
Outer leaves	91.08	1.63	...	5.06	...	2.23
Inner leaves	94.48	0.94	...	4.08	...	0.50
Inner leaves (Voelcker)	89.42	1.50	0.08	7.01	1.14	0.85
Cattle melon	92.98	1.53	0.73	2.51	1.65	0.60

CHAPTER XLII.

CROPS FURNISHING SEEDS.

Wheat.—The seeds of wheat constitute the most highly prized of food-grains. In them, as in other seeds, the elements of nutrition exist in a more highly organised condition than in the leaves and stems, and they contain less water. The farina of wheat is chiefly used as food for man, for which it is admirably adapted; but it is occasionally, when cheap, given to cattle. It makes an excellent food, but requires to be supplemented with some oily food, such as linseed-cake. Dr John Voelcker has found, in experiments carried out with sheep, that it forms an excellent fattening food.

By the processes of grinding and sifting, wheat grain is resolved into two parts—*bran* and *flour*. Boussingault found, as the results of twenty-four determinations, from 13.2 to 38 per cent of bran. Payen states that the proportion of gluten diminishes towards the centre of the seeds. The whiter bread is, therefore, the smaller is the proportion of albuminous compounds which it contains. The part nearest the husk is also richest in mineral matter.

During some experiments with twenty-four kinds of wheat grown under identical conditions, Sir J. B. Lawes found the average produce in bushels of dressed corn per acre to be as follows: Rivett's red, 54½; club red wheat, 47⅛; white chaff (red), 45¼; Hallett's golden-drop (red), 44½; red Rostock, 43⅝; Boles's prolific red, 42⅝; brownish red, 40¾; Bristol red, 39½; red Langham, 39¼; Victoria white (Hallett's), 39; Chubb wheat (red), 38½; red nursery, 37¼; Hunter's white

(Hallett's), 35½; Stevenson's white, 35; Australian white wheat, 28.

Bran is used as food for horses and for cattle also. Being rich in nitrogen, it is well adapted for the use of young animals. It is richer in nitrogen than the flour, and is hence a more nutritious food. The following analysis of bran will show that it is a highly nitrogenous food:—

	Per cent.		Per cent.
Water	14.0	Starch, &c.	51.5
Albuminoids	14.5	Woody fibre	10.0
Fat	4.0	Ash	6.0

The following comparative analyses will show the relative percentage of nitrogenous matter and ash in whole wheat, wheat-flour, and bran:—

	Whole Wheat.	Wheat-flour.	Bran.
Albuminoids	13.24	12.22	14.28
Ash	1.90	.67	4.31

Oats have a thick husk, which, unlike the thin skin of the wheat, is not rich in nitrogen; it is also poor in starch, but contains more cellulose and ash than the inner part (oatmeal). The percentage of nitrogenous matter in oats is determined by the thickness and weight of the husk. The kernel of oats is rich in nitrogen, and contains a large quantity of fat—5 to 7 per cent. Indeed the large percentage of the fat is characteristic of oats. Its composition varies very considerably.

Used in the form of mashes, it has a slightly laxative effect. Its ash is rich in phosphoric acid. It is considered a good food for milch-cows.

Grandeau states that there is (contrary to the general opinion) no relation between the weight of oats and their nutritive value. He found that out of nineteen specimens of French-grown and twenty-one of foreign-grown oats, Irish black oats grown in 1874 were the most nutritious; yet they were much lighter than oats of very inferior composition. He recommends that omnibus companies and other large consumers of oats should have analyses made of them before determining the ration to be given to each animal.

The nutritive value of oatmeal is very high, and it has long been a staple food amongst the peasantry of Scotland. No food given to the horse exceeds oats in value, especially if the animal be hard-worked.

The quantity and quality of the grain of the oat yielded by the same soil are affected by the variety sown. This is shown by the following table of the results obtained by Mr Hay from eight different varieties of oats well known in Scotland, and grown under identical conditions:—

Variety.	Produce.		Meal yielded by 100 lb. of grain.
	Grain.	Straw.	
	bush.	cwt.	lb.
Potato oat	69	62½	60⅓
Sheriff ,,	65¾	55½	52⅓
Berlie ,,	55½	55½	58
Hopetoun ,,	56½	56¾	60½
Blainslie ,,	52¼	60½	51¾
Sandy ,,	47	48½	60
Early Angus ,,	48¼	45¾	55⅔
Barbachla ,,	45	49	60½

Barley is a very valuable food for cattle. It is, however, poorer in nitrogenous matter than the other common cereals. Barley is seldom given in its dry state as food for stock; but, generally in a cooked condition, or as malted barley, it is extensively used for feeding stock. For the fattening of pigs barley-meal is especially to be recommended. English and Irish barley appear to be somewhat superior to that grown in Scotland; whilst Irish and Scotch oats are superior to English oats.

Malted barley is made by moistening the grains for about forty-eight hours, and allowing them to germinate on a floor (occasionally turning them) until the plumule, or elementary stem, attains a length equal to about two-thirds of that of the grain; whilst a root (radicle) shoots out to a much greater length. The malt is then dried at a temperature sufficiently high to kill the immature plant, and the radicles and plumules (*malt-dust*) are separated from it by screening. The chief change which takes place during malting is the conversion of about one-eighth part of the starch of the grain into sugar: probably nearly as much starch is converted into soluble compounds—*dextrin*, *maltose*, &c. From 3 to 6 per cent of the weight of grain is lost in the process of malting, exclusive of the amount eliminated in the form of *dust* or *combings*, which is about 3 or 4 per cent.

Many stock-feeders have a high opinion of the nutritive properties of malt, and consider it to be worth more than its equivalent of barley. They consider that it is not only highly digestible itself, but that it promotes the assimilation of other and less digestible foods. It may be pointed out that barley grown for malting purposes must be very carefully manured, and only a small quantity of nitrogenous manure applied. Lawes and Gilbert have carried out elaborate experiments on the comparative value of barley *versus* malted barley. They point out that in the process of malting, while the changes that take place in the composition of the barley in the process of malting may increase its value as a food, there is a considerable loss of valuable food material. It is to be doubted, therefore, whether malted barley can really claim, as some believe, a superiority over unmalted barley as feeding-stuff. The experiments of Lawes and Gilbert certainly are against this assumption. Farmers are free now to prepare malted barley for feeding purposes, which previously was not the case; but, on the whole, the practice does not seem to be indulged in to any extent.

Malt combings (or *dust*), being extremely rich in nitrogen and saline matters, are excellent food, especially for young stock. Being cheap, easily digestible, and an extremely healthy food, they are among the best of grain foods for feeding purposes.

Bere is a species of barley, which it resembles in its proportions of nitrogen and starch; but it contains three times as much indigestible woody fibre. It is an inferior grain.

Rye is not now much used in these countries; but it is a common food for both man and the lower animals on the Continent, especially the northern part of it. It is said to be an excellent food for milch-cows. Judged by its composition, it appears to be somewhat inferior to oats and barley.

Maize (*Indian corn*) was used largely as food by the Irish peasantry during the famine year of 1847, and for some years subsequently. The chief point in the composition of maize is its high proportion of fat, which has been known to reach even 9 per cent, and is generally about 5 per cent. The Galatz round yellow grain we have found to be superior in composition to the flat yellow seed from America. It is somewhat poorer in nitrogenous matter than oats, barley, &c., but it contains more carbohydrates.

Rice is poorer in nitrogen than any of the commonly employed food-grains. Rice-meal is a more commonly used feeding-stuff. It consists of the ground refuse left after the preparation of rice, and is composed mainly of the coatings of the seed with more or less of the adherent starchy matter. It is richer in albuminoids than rice (containing double the quantity), and rich in oil (about 12 per cent). The following is an analysis of rice-meal:—

Water	9.6
Albuminoids	11.3
Oil	12.0
Starch, &c.	51.5
Woody fibre	6.0
Ash	9.6
	100.0

It contains but little fat or ash, and its importance lies in its large percentage of starch. Unless purchased cheaply, it is not so economical a food as maize or oats.

Millet is the seed of several species of *Panicum setaria*, and allied genera, cultivated chiefly in India and other hot countries, but found occasionally in southern and eastern Europe. The grain is small but nutritious, and is much relished by cage-birds and poultry. It possesses about the same composition as poor meadow-hay.

Durra is often called Indian millet, but it is in reality a species of *Sorghum*. It is perhaps the commonest food-grain of Africa, and is largely cultivated in India and other parts of Asia. It is occasionally imported into these countries as food for cattle and poultry. It does not make good bread, but is an excellent material for puddings. It is intermediate in composition between wheat and rice. In the United States and in Germany durra has of late been grown—in the latter country with doubtful success. The following analysis by Voelcker shows its composition:—

Water	11.31
Oil	4.02
Albuminoids	10.06
Starch, &c.	68.10
Woody fibre	3.65
Ash	2.86
	100.00

Its albuminoid percentage is less than the common cereals, but more than that of rice.

Buckwheat.—A genus of the natural order *Polygoneæ*, cultivated largely in Russia, Central Asia, and the United States, and, but to a less extent, in Germany, France, &c. The Germans call its grain *Buchweizen* (from its resemblance to beech-nuts), and from this term its English name is derived. It is often used as human food, but generally as a supplementary, not a staple article. It is said to be as good as barley for cattle, but in these countries it is usually given only to game and poultry. If given to cattle, it should previously be deprived of its hard, indigestible, shell-like husk.

Spelt, though resembling wheat, is regarded as a distinct species (*Triticum spelta*). It is very inferior in flavour, but not so much in composition, to wheat; but it may be grown upon inferior soils, which would not produce satisfactory crops of wheat. It is chiefly found in Switzerland. A variety of spelt (*T. monococcum*) is called *St Peter's corn;* it is a very inferior grain.

COMPOSITION PER 100 PARTS OF SEEDS OF CEREALS

(Deduced chiefly from Wolff's Averages and Cameron's Analyses).

	Water.	Albuminoids.	Fats.	Starch, &c.	Fibre.	Ash.
Wheat . .	15.0	12.0	1.5	67.0	2.8	1.7
Spelt . .	15.0	10.0	1.5	66.8	5.0	1.7
Barley .	16.0	9.5	2.5	63.2	6.3	2.5
Bere . .	14.3	9.0	2.5	59.7	12.0	2.5
Oats .	14.0	11.5	6.0	56.5	9.0	3.0
Indian corn	14.5	10.0	7.0	61.4	5.2	1.9
Millet . .	14.0	14.0	3.0	58.5	8.0	2.5
Buckwheat	14.0	9.0	2.5	60.2	12.0	2.3
Rye (Irish) .	16.0	9.0	2.0	64.0	8.0	1.0
Rice . . .	14.0	5.3	1.0	76.7	2.5	0.7

COMPOSITION OF PARTS OF SEED.

	Wheat.		Maize-meal.	Oat-meal.	Irish oat-meal.	Oat chaff and bulls.	Rye chaff and hulls.	Barley chaff and hulls.	Maize chaff and hulls.	Linseed bolls.	Rye flour.
	Bran.	Flour.									
Water	13	12.6	9.00	8.7	9.26	14.3	14.3	14.3	14	7.50	14.0
Albuminoids	12	11.8	10.00	12.7	16.18	4.0	3.5	3.0	3	24.44	11.0
Fat	2	1.2	4.98	7.5	8.00	1.5	1.2	1.5	1.1	...	1.6
Carbohydrates	50	74.1	71.40	62.0	57.53	28.2	28.2	38.7	39	34.00	72.0
Woody fibre	15	0.7	3.40	7.6	6.99	34.0	46.3	30.0	40	30.73	1.5
Ash	5	0.7	1.22	1.5	2.04	18.0	7.5	13.0	4	3.30	1.6
	100	101.1	100.00	100.0	100.00	100.0	101.0	100.5	101.1	98.97	101.7

The analysis of oatmeal is by Du Jardin-Beaumetz and Hardy, and of Irish oatmeal and maize-meal by Sir C. A. Cameron. Nearly all the other analyses are Wolff's averages. The percentage of true albuminoids is high in the grains of cereals, amounting to on an average 90 per cent of the total nitrogen. In the case of maize it is somewhat less, and in rye it is still lower.

Leguminous Seeds.—The seeds of the bean, pea, and other legumes, differ from cereal grains in containing much larger amounts of albuminoids, and proportionately smaller percentages of starch and fats. Their chief nitrogenous substance is *legumin.* They are characterised, indeed, by their richness in albuminoids, in which respect they exceed all other seeds. The percentage of albuminoid matter is also not so variable in the leguminous seeds as in the cereals, and varies from 22 to 30 per cent of their dry matter, beans and vetches being richer than peas. The digestibility of the leguminous seeds is fairly high. Numerous experiments with beans on ruminants gave a digestible percentage of 84 for albuminoids. In later experiments even higher results have been obtained. On the whole, a digestibility of 90 per cent of their albuminoids may be assumed as the average results of a number of experiments. Seeds of the *bean*, *pea*, *lentil*, *tare*, and *vetch* closely resemble each other in composition. It must be remembered that leguminous seeds are very concentrated foods, and are suitable for supplementing less rich foods.

Oil-seeds are so dear that they are rarely given to cattle. Linseeds contain about 30 to 40 per cent of oil (which replaces starch), and from 20 to 25 per cent ot albuminoids. They have a bland, pleasant flavour, and are greedily eaten by cattle. Mr Horne gave equal money's worth of (1) linseed-cake, (2) linseed, and (3) wheat and barley, to three lots of bullocks. Those fed on the cake increased in weight by 637 lb.; those supplied with the grain 667 lb.; whilst the lot fed with oil-seeds increased 718 lb. The animals, of course, had other foods in equal quantities.

Linseed, being laxative, is a suitable adjunct to beans. A mixture of bruised linseed with chopped and steamed straw is a good substitute for hay, when the latter is scarce.

Rape-seed is not so palatable as linseed; but it is richer in oil, containing from 35 to 45 per cent. Palm-nut kernels contain nearly 50 per cent of oil; hemp-seed about 32 per cent; poppy-seed, 40 per cent; cocoa-nut, 64 per cent; cotton-seed, 30 per cent; and earth-nut, 50 per cent. Walnut-meal, used as a cattle food in France, we have lately found to contain 29 per cent of oil and 28.8 per cent of albuminoids.

COMPOSITION OF OIL-SEEDS.

	Linseed.	Rape-seed. (T. Anderson.)	Rape-seed. (C. A. Cameron.)	Hemp-seed.	Cotton-seed. (T. Anderson.)
Water .	7.50	7.13	7.12	6.47	6.57
Oil. . .	34.00	36.81	41.33	31.84	31.24
Albuminoids .	24.44	20.50	18.00	22.60	31.86
Carbobydrates	30.73	18.73	23.26	32.72	14.12
Fibres .		6.86	5.66		7.30
Ash . . .	3.33	8.97	4.63	6.37	8.91
		100.00	100.00	100.00	100.00

COMPOSITION OF LEGUMINOUS SEEDS.

	Common Beans.	Foreign Beans.	Peas.	Lentils.	Winter Tares (foreign).	Vetches.
Water . . .	13.0	14.5	14.0	13.0	15.5	12.93
Albuminoids	25.5	23.0	23.5	24.0	26.5	27.50
Carbohydrates . .	48.5	48.7	50.0	50.5	47.5	47.80
Fibre . . .	10.0	10.0	10.0	10.0	9.0	7.17
Ash . . .	3.0	3.8	2.5	2.5	1.5	4.00
	100.0	100.0	100.0	100.0	100.0	100.00

The amount of fat in leguminous seeds is only 1 or 2 per cent, except in the lupines, in which it constitutes about 5 per cent.

Over-ripe Grain.—So soon as the upper portion of the straw becomes yellow, no further increase takes place in the weight of the seed. If the grain be not reaped soon after the appearance of this sign, its quality deteriorates and its weight diminishes.

Grain, which is sweet and milky a month before it is ripe, gradually consolidates—the sugar changing into starch, and the milk thickening into the gluten and albumin of the flour. As soon as this change is nearly completed, or about a fortnight before it is ripe, the grain of wheat contains the largest proportions of starch and gluten. If reaped at this time, the bushel will weigh most, and will yield the largest quantity of fine flour and the least bran.

At this period the grain has a thin skin, and hence the small quantity of bran. But if the crop be still left uncut, the next natural step in the ripening process is to cover the grain with a better protection—a thicker skin. A portion of the starch of the grain is changed into woody fibre—precisely as in the ripening of hay, of the soft shoots of the dog-rose, and of the roots of the common radish. By this change, therefore, the quantity of starch is lessened and the weight of husk increased; hence the diminished yield of flour and the increased produce of bran.

Theory and experience, therefore, indicate about a fortnight before it is fully ripe as the most proper time for cutting *wheat*. The skin is then thinner and whiter, the grain fuller, the bushel heavier, the yield of flour greater, its colour fairer, and the quantity of bran less; while, at the same time, the straw is heavier and contains more soluble matter than when it is left uncut until it is considered to be fully ripe.

In regard to *oats*, it is said that the superiority of Ayrshire oatmeal is partly owing to the grain being cut rather *glazy*—that is, with a shade of green upon it; and the straw is confessedly less nourishing for cattle when the crop is allowed to stand till it is dead ripe. Early-cut oats, also, are heavier per bushel, fairer to the eye, and usually sell for more money. A week before full ripeness, however, is the utmost that is recommended in the case of oats, the distance of the top and bottom grains upon the stalk preventing the whole from becoming so uniformly ripe as in the ear of wheat.

Barley cut in the *striped* state is also thinner in the skin, sprouts quicker and more vigorously, and is therefore preferred by the maltsters. It is also fairer to the eye, and generally brings a higher price in the market.

CHAPTER XLIII.

OILCAKES AND OTHER "PURCHASED FOODS."

Oil-seeds are by hydraulic pressure deprived of about three-fourths of their oil. In a powerful press, and at a temperature of about 120° Fahr., they are exposed to pressure varying from 30 to 35 cwt. upon the square inch; the greater part of the oil flows out, and the residue is sold as linseed-cake, rape-cake, &c. The higher the temperature and the more powerful the pressure, the less valuable is the cake.

Linseed-cake.—There are numerous varieties in the market, of which English and American are usually the best. That made from East Indian seed contains rape-seed, and is somewhat inferior to the European cakes. The oil varies in genuine cakes from 8.5 to 13, but is generally from 10 to 11.5 per cent. The albuminoids vary from 25 to 32, but on an average are about 26 per cent. The ash ranges from 5 to 9 per cent, but is usually 5.8 to 7 per cent. Linseed-cake is frequently adulterated with such substances as bran, rape-cake, flax, and straw. Good linseed-cake has a reddish-brown colour, uniform appearance, and pleasant mild flavour and odour. Very dark cakes are generally over-heated, and very white ones adulterated. A quarter of an ounce mixed with an ounce of water should form a moderately stiff paste; if thin, bran or grass-seeds are probably present, and may be seen through a low-power magnifying-glass. From 2 to 14 lb. of linseed-cake are given daily to bullocks, but a larger quantity than 7 lb. is wasteful: 2 to 3 lb. may be given to young animals according to age; ½ lb. per day is sufficient for a sheep. Horses become extremely fond of it. From 2 to 3 lb. per day are the allowances for a working horse. It is said not to be a good food for pigs, as it renders their flesh soft and oily.

Rape-cake.—Judged by its chemical composition, it is equal or even superior to linseed-cake, but experience shows that it is inferior to the latter. This, no doubt, is owing to the acrid flavour which it possesses, and which is occasionally so intense that animals refuse the cake. The best rape-cake comes from Denmark and the north of Germany; it is yellowish-green.

The best way to use rape-cake is in a cooked state, and in combination with other and better-flavoured foods. Steaming it along with chopped straw is a good plan, but to this mixture a little molasses or bruised locust-beans should be added. It is not advisable to give more than 2 or 3 lb. of rape-cake per day to a bullock, unless the cake is unusually free from acrid matters, and is evidently relished by the animal. Indian rape-cake is frequently (but accidentally) mixed with wild mustard or charlock seed, which renders it a somewhat unsafe food, unless used in very moderate quantities. If a portion of such a cake be powdered and heated with boiling water, the pungent odour of mustard will speedily be developed. It may be pointed out, however, that rape-meal made from seed from which the oil has been removed by extraction with petroleum spirit is very free from acrid essential oils.

Cotton-seed Cake.—Opinions differ as to the value of undecorticated (English) cotton-seed cake. Some stock-feeders allege that is a dangerous food, owing to the indigestible particles of cotton which it contains; whilst others assert that they have largely employed this food not only without injury, but, on the contrary, with good results. There are some undoubted cases of the death of sheep caused by accumulations of cotton in their stomachs. On the whole, we prefer the decorticated cake. Undecorticated cotton-cake has a slightly astringent action.

Palm-nut Meal is the residue from palm-nuts, from which the greater portion of their oil has been extracted. Its flavour is rank and oily, but its odour is not altogether disagreeable. The English meal is rich in fats; but the article which, under the name of palm-nut meal, is imported from the Continent, contains only from 7 to 10 per cent of fats, and is otherwise very inferior. Palm-nut meal is (after steeping for some hours in water) a suitable food for calves. It is a good ingredient for a mash for milch-cows and pigs. A mixture of equal parts of palm-nut meal, cotton-seed cake, and Indian corn, is an excellent substitute for linseed-cake.

Cocoa-cake is prepared from the outer shell and a portion of the kernel of the cocoa-bean. It is an excellent food for all kinds of cattle.

Poppy, Nut-oil, and Dodder Cakes are poor in oil, and, unless used when fresh, are by no means good foods. They are often mixed with other cakes by oil-cake manufacturers.

Locust or Carob Beans (pods of the carob-tree or *Ceratonia siliqua*) contain merely a trace of oil, are not rich in albuminoids, but include a large proportion of sugar. They are not fitted for young animals, but are an excellent addition to food of indifferent flavour. It is difficult to grind them.

Molasses contains about 25 per cent of water, 50 per cent of crystalline sugar, 20 per cent of uncrystallisable sugar, and 5 per cent of saline matters. It does not form bone or muscle, being composed of carbohydrates only. It is valuable for fattening purposes. If used in large quantity it should be combined with beans or other highly nitrogenous food. It is alleged that if given in large quantity, molasses injuriously affects breeding animals. It is a laxative food.

Dates have been used as cattle food. They are poor in composition, containing only 2 per cent of nitrogenous matters, 2 per cent of saline substances, and 10 per cent of carbohydrates, chiefly sugar.

Distillery and Brewery Dregs are chiefly given to dairy cows. According to Anderson, 15 gallons of distillery wash equal 100 lb. of turnips. The wash so composed contained 4130 grains of organic matter per gallon (70,000 grains). Draff is now largely and profitably used as a feeding-stuff by being dried. It forms a valuable feeding meal, especially for cattle. Dried grains give on an average 6 per cent of oil, 20 per cent of albuminoids, and 44 per cent of carbohydrates.

AVERAGE COMPOSITION OF OILCAKES, ETC.

	Linseed-cake.	Rape-cake.	Palm-nut kernel cake.	Cotton-seed cake.		Cocoa-cake.	Poppy-seed cake.	Dodder-seed cake.	Locust-beans.
				Decorticated.	Undecorticated.				
Water . . .	7 to 10	10	10	8	12	10	12	12	13
Albuminoids . .	22 " 30	30	16	44	21	20	32	30	4
Oil	9 " 13	10	9	13	5	11	2	8	2
Carbohydrates . .	30 " 36	32	41	21	35	38	36	42	73
Fibre . . .	8 " 10	10	18	6	20	14	9		6
Ash . . .	5 " 8	8	4	7	5	6	8	8	2

CHAPTER XLIV.

ROOTS AND TUBERS.

Roots and tubers differ from the class of foods we have just been considering, in the small amount of albuminoids they contain. They are extremely watery foods.

Turnip Roots.—All the nitrogen in the solid portion of the turnip and other roots is not in the form of albuminoids, a considerable percentage being as amides and nitrates, the true albuminoid only amounting to about 50 per cent of the total nitrogen. Their feeding value is even lower, therefore, than their ordinary analyses seem to indicate. Starch does not exist in turnips, but it has been found in carrots, and also, and in larger proportion, in parsnips. Sugar, pectose bodies, gum, and cellulose, make up the carbohydrates of roots. The Swedish turnip is the most valuable, and the greystone perhaps the most inferior, of turnips. The nutritive value of turnips, like the other crops we have been considering, but even to a greater extent, varies very considerably, and depends on climate, soil, manuring, &c. They contain from 86 to 94 per cent of water, and from 6 to 14 per cent of dry matter. On keeping, the proportion of their water becomes less. They form one of the chief constituents of the winter food of cattle. They are also largely used for sheep. The variation in even the same varieties of turnips, when grown under different conditions of soils and manures, is very considerable. The quantity of nutritive matter in the same variety of turnip varies—in white turnips from 8 to 13 per cent, and in yellow from 11½ to 17 per cent; so that 20 tons of yellow may be as valuable for feeding as 50 tons of white, which is an important fact, and may account for the discrepancies experienced by farmers in feeding stock.[1]

Among the most important of the feeding constituents in the turnip is their saccharine matter. Lawes and Gilbert have determined the average percentages of dry matter and sugar in the following kinds of turnips:—

		Sugar per cent.	
	Dry matter.	Fresh roots.	Dry matter.
White turnips . .	8	3.5 to 4.5	44 to 56
Yellow	9	4 to 5	44 to 56
Swedish	11	6 to 7	55 to 64

Mangel-wurzel Root contains a larger amount of solid (dry) matter than the turnip, and usually produces a heavier crop. When taken out of the ground its flavour is acrid; but when it is stored for some months it becomes far more palatable, owing, apparently, to the conversion of some of its insoluble carbohydrates into sugar. It is said that 75 lb. of mangels equal in

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[1] See Stephens' 'Book of the Farm,' vol. i. 264.

nutritive power 100 lb. of turnips. It is grown very extensively in England and Ireland, but in Scotland to a smaller extent. It requires a warm climate. It is alleged to produce scour in cattle when used in a fresh condition, but the storage of the roots for a few months apparently removes this property.

Parsnips are richer in dry matter than mangels, and they include a considerable amount of starch. Their nitrogenous constituents consist chiefly of casein —those of the turnip and mangel being principally albumin. Their food equivalent is about double that of the turnip. Parsnips are used as human food, but they are also occasionally given to pigs.

Beetroot is extensively produced in many Continental countries, and used as a substitute for cane-sugar; it has not been cultivated in these countries to any extent as yet, although numerous experiments prove that it is quite feasible to do so with great success as an excellent food for cattle. It contains about double the quantity of dry matter found in turnips. Its value as a food is due to the large quantity of sugar it contains—as high as six per cent. The late Dr Voelcker was of opinion that it might be largely substituted, with great benefit by farmers, in place of mangels; for although a less heavy crop might be obtained, it has to be borne in mind that it is a richer food than mangels. Beetroot pulp is largely used as a food on the Continent. It is the refuse from the beet after its treatment for the extraction of sugar.

The Carrot bears some resemblance to the parsnip, but it is very much richer in sugar, and poorer in starch. It is deficient in nitrogenous matters, and is not, therefore, suitable for young animals; but it is greedily eaten by all kinds of farm animals.

Kohl-rabi, though allied to the turnip, differs widely from it in its mode of growth. Its bulb—an enormous expansion of its underground stem—is well-flavoured, contains as much nutritive matter as the best swedish turnips, stores well, and is not much liable to the ravages of insects. As it projects above the soil, it can be "eaten off" by sheep without being first *pulled.*

The following is an analysis of the kohl-rabi by Dr Anderson:—

	Bulbs.	Tops.
Water	88.74	86.68
Albuminoids	2.75	2.37
Sugar, &c.	8.62	8.29
Woody fibre	.77	1.21
Ash	1.12	1.45

The Radish contains 95 per cent of water, and is therefore but poor food. It might, however, under certain circumstances, be found a good *stolen* crop, as it can be grown within a month.

The Potato produces the best tubers used as food by man and the lower animals. Its acreable yield is usually good, and the composition of the tuber is greatly superior to that of any of the roots above described. The composition depends on various conditions, similar to those determining the composition of other crops. The dry matter may vary from 18 to 30 per cent; the albuminoids from 1.3 to 4.5 (the true albuminoids only amount to about 60 per cent of the total nitrogen, see p. 379), and the starch from 12 to 27. It contains a mere trace of fat, and very little sugar. The defects of the potato as a staple food are its small proportions of fat[1] and albuminoids. Coarse kinds of potatoes are often given to oxen, horses, and pigs—especially the last-named animals. They should be given along with other foods when used for cattle.

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[1] On an average 0.73 per cent, of which about half exists in the peel. —EICHORN.

COMPOSITION OF SEVEN VARIETIES OF POTATO.

100 parts contain—	Champions.	Regents.	White Rock.	American.		Red-skinned Flourball.	Belgians.
				Early Rose.	Goodrich.		
Water . .	72.50	79.87	77.42	77.38	77.08	76.11	72.03
Albuminoids .	2.28	1.52	1.62	1.58	1.69	1.90	2.11
Fats . .	0.73	0.50	0.63	0.65	0.60	0.68	0.75
Carbohydrates	21.63	15.68	17.67	17.67	17.87	18.44	21.83
Cellulose .	1.84	1.76	1.82	1.92	2.00	2.06	2.36
Ash . .	1.02	0.67	0.84	0.80	0.76	0.76	0.92
	100.00	100.00	100.00	100.00	100.00	100.00	100.00

The Jerusalem Artichoke resembles the potato in being valuable only for its tubers. The plant may be grown on any soil save a very wet one, and it gives a good produce. The tuber contains about as much dry matter as that of the potato, but it includes very little starch, that substance being replaced by inulin. It keeps well, and is relished by most of the animals of the farm. It is largely used on the Continent, but it is not much cultivated in these countries.

AVERAGE COMPOSITION OF ROOTS AND TUBERS.

	Swedes.	White Turnips.	Aberdeen Yellows.	Mangels.	Sugar Beet.	Carrots.	Parsnip.	Potato.	Jerusalem Artichoke.
Water . . .	89.46	92.00	90.56	88.00	83.50	87.50	85.00	75.55	80.0
Albuminoids . .	1.45	1.08	1.40	1.40	1.30	1.20	1.36	2.06	2.0
Fat . . .	0.20	0.15	0.20	0.20	0.12	0.20	0.34	0.75	0.3
Sugar . . .	4.60	3.00	3.90	5.60	10.50	6.90	3.00	0.56	15.6
Carbohydrates .	2.55	2.21	1.90	2.91	2.30	2.07	7.90	17.98	
Insoluble cellulose	1.12	0.96	1.04	1.13	1.24	1.10	1.40	2.12	1.3
Ash . . .	0.62	0.60	1.00	0.76	1.04	1.03	1.00	0.99	1.1
	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.3

Overgrown Roots.—It is not advisable to force, by excessive manuring and thinning out, mangels and turnips to attain to "monstrous" proportions, as is so often the case. Overgrown roots contain an excessive proportion of water, are inferior in flavour, and do not keep; besides, an acre of monster roots generally yields less actual nutriment than an acre of moderate-sized ones of much less gross weight. This is well shown by the following experiment:[1]—

Mangels and turnips were grown on the home farm of Mr W. Young, Brockley Park, Queen's County. Half of each crop was grown by itself, and the other moieties in alternate drills with each other. They were manured with 35 tons of dung, 3 cwt. of superphosphate of lime, 1 cwt. of nitrate of soda, and ½ cwt. of Peruvian guano per Irish acre. The drills were 28 inches apart, except one small crop of mangels, which were thinned out very widely, and which were grown on half a rood—the site of a former accumulation of dung. The following table shows the results of the experiment:—

VARIETY OF ROOT.	Average weight of each root.	Water.	Albuminoids.	Sugar.	Pectose, fibre, &c.	Ash.	Average produce per acre.	
Mangels.	lb.						tons	cwt.
1. Carter's mammoth long red mangel	6 to 7	84.30	0.80	4.36	9.68	0.86	38	3
2. Hogg and Robertson's long red mangel	6 to 7	84.80	0.72	5.55	8.29	0.64	44	12
3. Carter's yellow intermediate mangel	6	82.85	0.90	7.40	8.25	0.60	42	8
4. Hogg and Robertson's orange globe mangel	6	84.69	0.81	5.60	7.74	1.16	33	3
5. Carter's mammoth, same as No. 1	18	92.55	0.40	1.50	4.34	1.21	70	0
Turnips.								
6. Hogg and Robertson's champion swede turnip	7	89.06	0.70	9.70		0.54	40	0
7. Select, or Hogg's Norfolk red globe turnips	6	90.06	0.62	8.77		0.55	30	0

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[1] On the Undesirability of Growing very Large Roots. Paper read before Royal Ag. Society of Ireland, by Sir C. A. Cameron.—Irish Farmers' Gazette, June 1873.

Useful conclusions are deducible from some of the results in the field and the laboratory, stated in the foregoing table. We learn from them, for instance, that no good results, but rather the contrary, can be obtained by growing monster mangels or turnips. Since the introduction of green-crop husbandry into these countries, it appears to have ever been the farmer's ambition to exceed his neighbours in the production of gigantic mangels and swedes. It has always been the practice, too, of writers in agricultural journals to encourage the growth of roots of abnormal dimensions. This practice has been carried out to an extreme and mischievous extent. By "spoon-feeding" (as it is not inaptly termed) a few roots, it would be easy for a man with several perches of a garden to produce more promising roots for show purposes than a farmer could who grew his 20 acres of roots in an ordinary, and, we may add, a proper manner. At Brockley Park, Carter's mammoth long red mangels were sown in two plots. The mangels sown in one plot were not thinned out widely, but were allowed to grow rather closely together. In the other plot the mangels were supplied with a very large amount of manure, because the plot was the site of a former manure-heap. The mangels here were thinned out widely, so as to allow room for the rapid and extensive development of the roots. The acreable yield of the mangels which had been moderately manured and kept close together amounted to 46 tons 15 cwt., whilst the mangels which had been abundantly manured and widely thinned out produced a crop of about 70 tons per acre. Now, if the large roots and the small ones were equally nutritious, it would, of course, be desirable to grow the former; but when we compare the composition of the mangels of plot 1 (thickly sown) with those of plot 5 (thinly sown), we find an absolute and important difference in favour of the former. The thickly-sown roots contained 15.7 per cent of solid or nutritive matter, which, the acreable yield of the crop being 46 tons 15 cwt., was at the rate of 19,782 lb. weight of dry food per acre. The thinly-sown roots contained only 7.47 per cent of solid or dry matter; and as the acreable return from these large roots was 70 tons, that would yield only 11,681.6 lb. weight of dry food per acre. In producing the large roots, the farmer would incur more expense than if he cultivated the small ones; for instance, he would have to apply more manure, and his cartage would be far greater. If Mr Young grew 10 acres of mangels like No. 5, he would have to cart 700 tons from the field to the stores, and yet he would have in this crop only as much solid food as would be contained in about 450 tons of the smaller mangels, No. 1.

Ensilage.—Of late years a most important process for the preservation of fodder for live stock has been introduced. The application of *ensilage* dates in this country from 1882. It consists in preserving green food by excluding air. This is generally done by storing the fodder in a *silo*. Various kinds of silos have been used, some being underground. A very important development, however, in the history of ensilage was made in 1885, when it was discovered that a silo was not necessary for the process, and that the green fodder might be preserved in stacks. This has given a great impetus to the movement, which has made great progress during the last year or two, and is steadily increasing. The principle upon which ensilage is based has long been recognised, as is testified to by the custom of storing grain in underground pits for preservation so long practised in many Eastern countries. The application of ensilage to fodder crops was first practised in Germany. It has also been practised in France for a number of years, from which country the custom was imported into Britain.

The movement was largely fostered by a private Ensilage Commission which sat in 1883. The rapidity with which it was taken up may be inferred from the fact that in 1884, 610 silos were in existence in Great Britain, while in 1887 the number had increased to 2694. Instead of building new silos at first, many barns were converted into silos. When the silo has been filled with fodder, the fodder is subjected to great pressure for the purpose of excluding the air. Various methods of obtaining this pressure are in use. At first the pressure was obtained by employing dead-weight on the top of the silo. Various mechanical contrivances have also been used, such as hydraulic presses, &c.

In keeping fodder for some time, as is done in the process of ensilage, a certain amount of fermentation is inevitable. The result is that a sour taste is generally imparted to fodder. *Silage* has been divided into two classes—*sweet* and *sour* silage. Sweet silage, it is supposed, may be best made by allowing the temperature of the mass to rise at first to a considerable height—120° to 140° Fahr., and thereafter submitting it to great pressure. This temperature probably kills the bacteria effecting acid fermentation.

The following analyses by Dr A. Voelcker will illustrate the composition of different samples of silage :—

	Silage from clover and ryegrass.	Silage from meadow-grass.
Moisture	75.80	74.40
Albuminous compounds[1]	2.53	2.56
Sugar and other carbohydrates soluble in water	1.43	2.99
Crude vegetable fibre	18.31	17.90
Mineral matter (ash)	1.93	2.15
	100.00	100.00
[1] Containing nitrogen	0.40	0.40
Volatile acids, calculated as acetic acid	0.01	0.02
Non-volatile acids, calculated as lactic acid	0.01	0.02

The composition of silage, of course, will depend largely on the crops out of which it is made. Meadow-grass is, in this country, the most commonly used; but clover, ryegrass, maize, tares, lucerne, sainfoin, turnip-tops, and a variety of plants, may be used.

The advantage of the stack over the silo in making silage is obviously very great, as it necessitates no special outlay in the way of building apparatus. A larger proportion of the silage, it is held, is lost in the former case than in the latter. The great value of silage is in enabling the farmer to store green fodder in a wet season. This is one of the most important of the many advantages which ensilage offers. The difficulty of successfully making hay in Scotland and many parts of England is considerable, owing to the prevalence of wet seasons. Ensilage thus renders the farmer independent, to a large extent, of the nature of the season. It also enables him to utilise for feeding purposes many crops which he would otherwise not be able to use.

The Ensilage Commission, already referred to, sum up their Report on its general advantages in the following words: "The chief advantages of silage-making against hay-making is its comparative independence of the weather; that the fodder is handled while green, without any risk of the tender and nutritious leaves being lost on the ground as in hay-making; that the resulting silage is succulent and palatable; and that on purely grazing farms it is now possible to obtain a portion of the grass crop for winter in such a state as to equal the effect of summer-fed grass for the purposes of the dairy."

CHAPTER XLV.

MILK.

Milk may be described as the secretion of the mammary glands of mammals. In general composition the milk of different animals is practically the same, so far at any rate as is at present known. Considerable variation occurs, however, in the relative proportions of the different constituents. These are *water*, *casein*, and other *albuminoids*, *fat*, *sugar*, and *mineral salts*, and certain other bodies in minute quantities.

Colour of Milk.—Milk is generally white in colour, with a faint bluish or yellowish tinge. Under abnormal circumstances, however, it assumes a blue, green, yellow, or black colouration. These colours are produced by the action of certain ferments. This abnormal colouration is not to be confounded with the blue colour so characteristic of skim-milk ("London sky-blue"), and which is due to its poverty in fat. The opacity of milk is not only due to the fat-globules, but also to the casein, a certain portion of which is, in an insoluble condition, suspended in the milk, as well as to a small quantity of phosphate of lime. This is proved by the fact that even separated milk—that is, milk from which the fat has been removed—is distinctly opaque.

Composition of Milk.—The normal constituents of fresh milk may be divided into the following groups of substances:[1]—

(*a*) ALBUMINOIDS: *Casein*, *nuclein*, *albumin* (*lactalbumin*); *globulin*, a *peptone?* *lactoprotein?* and *hemialbumose?*

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[1] See 'Dictionary of Applied Chemistry' (Thorpe), vol. ii. p. 602.

(*b*) EXTRACTIVE MATTERS: *Urea, creatinin;* traces of *lecithin, cholesterin,* and *hypoxanthin.*

(*c*) ORGANIC ACIDS: *Lactic acid, citric acid,* and *acetic acid.*

(*d*) CARBOHYDRATES: *Sugar of milk,* and a second carbohydrate discovered by Ritthausen.

(*e*) OTHER ORGANIC BODIES: *Alcohol, lactochrome,* an organic colouring matter, and a bitter principle.

(*f*) INORGANIC ACIDS (in combination): *Phosphoric, hydrochloric, sulphuric,* and *sulphocyanic acids.*

(*g*) BASES: *Potash, soda, lime, ferric oxide, magnesia,* and *ammonia.*

(*h*) GASES (in solution): *Carbonic acid, oxygen,* and *nitrogen.*

As to the presence of some of these substances doubt exists; and with regard to others, they are present in the merest traces. The important solid constituents of milk are *casein, albumin, fat, milk-sugar,* and *ash.* The nature of these substances has already been described in an earlier chapter. The following comprehensive table after König gives the average composition of the milk of different animals:—

	Water.	Casein.	Albumin.	Ash.	Milk-sugar.	Fat.
Human .	87.41	1.03	1.26	0.31	6.21	3.78
Cow . .	87.17	3.02	0.53	0.71	4.88	3.69
Ewe . .	80.82	4.97	1.55	0.89	4.91	6.86
Goat . .	85.71	3.20	1.09	0.76	4.46	4.78
Mare . .	90.78	1.24	0.07	0.35	5.67	1.21
Ass . .	89.64	0.67	1.55	0.51	5.99	1.64
Sow . .	84.04	7.23		1.05	3.13	4.55
Bitch . .	75.44	6.10	5.05	0.73	3.08	9.57
Buffalo .	81.41	5.85	0.25	0.87	4.15	7.47
Camel .	86.57	4.00		0.77	5.59	3.07
Cat . .	81.63	3.12	5.96	0.58	4.91	3.33
Mule . .	91.50	1.64		0.38	4.80	1.59
Lama . .	86.55	3.00	0.90	0.80	5.60	3.15
Elephant .	67.85	3.09		0.65	8.84	19.57
Porpoise .	41.11	11.19		0.57	1.33	45.80

Condition in which Fat is present in Milk.—A point of very great interest, and one which has been made the subject of much discussion, is as to the exact condition in which the solid constituents are present in milk; that is, as to whether milk is a *solution*, an *emulsion*, or a *mixture*. With regard to the condition of one of these constituents, namely, the fat—which may be seen to be present in the milk under the microscope in the form of minute globules[1]—much difference of opinion has existed. Till recently it was believed that these fat globules are surrounded by an *albuminous membrane* which is ruptured when the milk is churned, and that this albuminous envelope prevents the globules from coalescing and solidifying in the milk.[2] This belief, however, is no longer held by the leading authorities on the subject, and the liquid state of the fat in the globules may be explained as being due simply to their isolation. It is an example of what is chemically known as *superfusion*. Probably also, as Babcock has suggested, the isolation of the globules may be helped by the formation which takes place in milk, on keeping a short time, of small quantities of a body resembling blood-fibrin, whereby the milk is rendered less limpid. In churning, coalescence of the fat-globules takes place, and as the

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[1] In size these globules are very minute, and vary in diameter from .0015 to .005 millimetres. Experiments have shown that the breed of cows affects the size of the globules, those in the milk of good milking breeds being larger than those in the milk of cows giving an inferior quantity of milk.

[2] In milk a strange anomaly is met with, and that is, that the fat, though the temperature of the milk is far below its melting-point, remains in a liquid condition. This fact, it was supposed, bore strong testimony in favour of the membrane theory.

When milk is allowed to stand, the milk-globules, owing to their lower specific gravity, speedily rise to the surface, and form a layer of cream. The larger globules rise first, and it is doubtful whether the smaller globules ever come to the surface. This accounts for the invariable presence of fat in small quantities in skim-milk.

temperature of the dairy is very much below the melting-point of the fat, solidification at once ensues. The older explanation, therefore, that churning ruptures the envelope enclosing the globules, and thus permits the fat-globules to coalesce, can no longer be regarded as correct.

Condition of the Casein and other Solid Constituents.—With regard to the casein and other solid constituents, it is probable that a certain portion of the casein, as well as some of the lime, magnesia, and phosphoric acid, are in a state of suspension in the milk, and that the opacity of the milk, as has already been pointed out, is due not alone to its being an emulsion of fat, but also to the presence of these substances in an insoluble condition. This belief is inferred from the fact that if milk is filtered through a porous cell, only a certain portion of the casein, magnesia, lime, and phosphoric acid pass through into the filtrate. According to Hammersten, casein is held in solution in the milk by the neutral phosphates of the alkalies. The coagulation of milk, which takes place, as we shall immediately see, when an acid is added to it, is accounted for, according to this theory, by the conversion, by the acid, of the *neutral* phosphates of the alkalies into *acid* phosphates. The solid bodies in milk may therefore be described as being partly in a state of *emulsion* (fat), partly in a state of *suspension* (part of casein, lime, magnesia, phosphoric acid), and partly in a state of *solution* (part of casein, mineral matter, &c.).

Specific Gravity of Milk.—Milk, as is to be expected from its nature, has a higher specific gravity than water. The milk of different animals varies slightly. In general it may be said to vary from 1.018 to 1.045. That of human milk may be put at 1.032, and cow's milk at 1.028 to 1.035. The average of English cows, according to Vieth, is 1.032, and the average of German cows is 1.031 (Fleischmann).

Reactions of Milk.—The reaction exhibited by milk towards vegetable colouring matters varies. Human milk is normally alkaline in its reaction, whereas that of carnivorous animals is generally acid. An interesting point with regard to cow's milk is that it exhibits both an acid and alkaline reaction, the so-called *amphioteric* reaction. Milk on fermenting, however, rapidly becomes acid.

Cow's Milk.—Of the milk of different animals, that of cows has been most fully investigated. In composition it varies—a point of very great importance in connection with the detection of its adulteration. Its average composition has already been given in the preceding table. A fuller analysis is the following (Munro): Average composition of one pint of cow's milk. The specific gravity of the milk is 1.032, a pint weighs 20 ounces and 280 grains, and is made up of—

	Ounces.	Grains.	Per cent.
Water	17	419	87.00
Lactose or milk-sugar .	0	415½	4.60
Casein and lactalbumin .	0	361	4.00
Butter fat	0	334	3.70
Ash or mineral matter . .	0	63	0.70
Total .	20	280	100.00

Conditions influencing Variations in Composition of Milk. — Much discussion has taken place with regard to the conditions influencing the composition of cow's milk. Among these may be mentioned *breed*, *age*, period of *lactation*, &c., as well as, but to a lesser extent, the *character of the food*—for example, the amount of water drunk. The extent, as well as the exact nature of the influence exerted by these different conditions, is a matter largely of mere speculation as yet.

That food has an influence on the quality of milk there can be no doubt, although to what extent this takes place is still a subject of discussion. Certain foods have been found by experiment to have a distinct effect in increasing the quantity of milk. Among these may be mentioned brewers' grains, fodders, &c. That the richness of the milk as well as its quantity may be improved by richness of diet, is only natural to suppose. More important determining influences are the breed and individual characteristics. The influence of food is practically limited to the ratio of solids to water in the milk. It would seem from the most reliable researches that the influence of food on the relative proportions of casein, fat, &c., is slight. Possibly the fat may to a certain extent be influenced by the feeding, but sufficient data on this point are still awanting. Fodder of a succulent nature increases the percentage of water.

Other causes in addition to those mentioned determine the composition of the milk. Exertion of a severe character, the season of the year, and the time of day, may all be mentioned as affecting the composition of the milk. For example, milk drawn in the evening is richer than that drawn in the morning. It has also to be noticed, that cows giving a large quantity of milk, on the whole give a milk of poorer quality (containing more water) than that from cows which give a less quantity. Again, even at the same milking, the milk first drawn from the udder is more watery than the last portion.[1] This is due to the fact that a separation of fat takes place in the udder. Milk varies in composition according to the length of time which has elapsed since

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[1] Reiset found in the first portion of milk drawn from the cow from 1.8 to 5.9 per cent of fat, and in the *strippings* from 6.6 to 10 per cent. Peligot, Parmentius, Voelcker, and others have obtained similar results

calving. A few weeks after calving the yield of milk is at its maximum, and after the seventh week gradually diminishes. But while the quantity begins to diminish, the quality steadily improves—that is, it becomes more concentrated. The longer the time that elapses from one milking to another, the more watery is the milk. The poorest milk is received in April, whereas the richest is in the autumn. The reason of this is that in the autumn the quantity of the milk is much more limited, and the quality is therefore higher.

Milk-fat.—The fat of cow's milk, which is the chief ingredient in butter, seems to be composed of a mixture of several compound fats. The chemical composition of a fat has already been referred to in a previous chapter. We may remind the student that a fat is a body made up of *glycerin* in combination with *fatty acids*. Fats, therefore, are *glycerides*. Glycerides may be decomposed when heated with either soda or potash. The glycerin is set free, and the fatty acids unite with the potash or soda to form soap. This in its turn can be decomposed by adding a strong acid, when the fatty acid is again set free, the strong acid taking its place. The chief fatty acids in butter-fat are *palmitic*, *stearic*, and *oleic;* butter-fat is therefore chiefly composed of the glycerides of palmitic, stearic, and oleic acids. The glycerides of the following fatty acids are also present in smaller quantity—namely, *stearic*, *butyric*, *caprylic*, *caproic*, *myristic*, *lauric*, and *capric* (*rutic*). Some of these are probably not present in the milk when freshly drawn, but are the products of decomposition, changes due to fermentation, &c. Neither butyrin, caprylin, nor caproin are present in fresh milk, for example.

The three chief constituents, however, of butter-fat are palmitin, stearin, and olein, which together form about 91 per cent of butter-fat. It is to the presence of the volatile and soluble fatty acids that the peculiar qualities of butter-fat are due; and the detection of adulteration in butter largely depends on this fact. The fatty acids which characterise butter-fat are more volatile and more soluble than those which are common to most other fats.[1] The amount of volatile acid in it is one of the most valuable distinguishing tests of butter-fat. It is important to notice that the composition of butter-fat varies slightly, this variation being due to diet and the season of the year.

Some of these have already been described in a previous chapter—viz., palmitin, stearin, and olein. With regard to *butyric acid* ($C_4H_8O_2$), it may be mentioned that there are two isomeric forms known—normal butyric acid and iso-butyric acid. When combined, as butterine with glycerine, it is inodorous, but in the free state is a colourless transparent liquid, possessing a sour burning flavour, and an odour resembling that of rancid butter. It exists in combination with glycerin in ordinary butter to the extent of 2 per cent, and is also found in flesh-juice.

Caproic acid ($C_6H_{12}O_2$) also occurs in two isomeric forms. It exists in a large number of plants, and has an odour resembling that of the goat, hence its name from *capra*, a goat.

Caprylic acid ($C_8H_{16}O_2$) has a feeble, rather unpleasant odour.

Capric or rutic acid ($C_{10}H_{28}O_2$) is a solid fatty substance. Its odour resembles that of caproic acid, and

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[1] Butyric, caproic, caprillic, and capric acids are all soluble in water, the others being insoluble. The glycerides of these acids, and also olein—that is, the glyceride of oleic acid—are liquid at ordinary temperatures, the rest are all solid. The quality of the butter depends on the proportion in which the liquid and the solid fats are present in the butter. Hard butter is butter in which palmitin and stearin predominate; in soft butters the olein and liquid fats.

its flavour is very sour and burning. All these acids are present in rancid butter, milk, and cheese.

Milk-fat in appearance is a pale yellowish body, solidifying at 26.5° C. (79.7° Fahr.). It melts between 29° C. (84.2° Fahr.) and 41° C. (105.8° Fahr.). Its specific gravity, according to Fleischmann, is .92 to .93. Its percentage composition, according to Blyth, is as follows:—

Olein	1.477
Palmitin and stearin	1.750
Caproin, caprylin, and rutin	.003
Butyrin	.270
	3.500

Albuminoids in Milk.—The chief albuminoids in milk are *casein* (which varies from 2 to 4½ per cent), *peptone* (from .08 to .1 per cent), and *lactalbumin* (from .1 to .4 per cent). The amounts of the other albuminoids present in milk have not been determined. The albuminoids, other than casein, preponderate in the colostrum. Casein is distinguished from them by being coagulated by acids and by rennet. The chemical nature of casein is not very clearly understood. It is probably similar to alkali-albumin, although in certain points they are different. For example, casein is precipitated by rennet, while alkali-albumin is not. When milk is heated the casein is not coagulated, but the other albuminoids are. The milk albumin (*lactalbumin*) is in a state of complete solution, and is similar to the serum albumin of the blood.

Milk-sugar, which is one of the principal constituents, and which varies in cow's milk from 3 to 6 per cent, has already been described in a previous chapter.

Salts.—The mineral matter in milk is made up of phosphates, citrates, and chlorides, with phosphates of the alkalies and alkaline earths. The amount of ash in milk may be said to vary from .65 to .85 per cent.

Colostrum is the scientific term given to the first milkings (beastings) yielded by the cow after calving. It is a turbid liquid of a yellowish or brownish colour, very rich in casein, with a peculiar smell, salty taste, and acid reaction. Its specific gravity (at 15° C.) is 1.04 to 1.08. What characterises colostrum is the large percentage of total solids it may contain, and which may amount to over 25 per cent. Of this, one-half consists of albuminoids. The large amount of albuminoids in colostrum often causes coagulation to take place on boiling. The solids in colostrum diminish daily, and in about ten days the liquid becomes ordinary milk. Microscopically, colostrum is seen to differ from ordinary milk by the possession of granular bodies, the so-called *colostrum corpuscles.* They are four or five times as large as ordinary milk-globules, and resemble in appearance white blood-corpuscles, from which they are considered to be derived (Heidenhein). The fat in these corpuscles is more readily dissolved than that in milk-globules. The composition of a sample of colostrum is as follows:—

Water	78.8
Fat	3.5
Albuminoids	12.7
Sugar	4.2
Ash	.8
	100.0

Abnormal Milk may vary very considerably in its composition, and may contain such bodies as fibrous clots, mucus, pus, blood-corpuscles, and colouring matters, &c.

Variation in Composition of Milk.—From what has been above stated, it will be seen that a very considerable variation exists in the composition of cow's milk. It is probable, however, that in the popular mind this variation is thought to be greater than is actually the case. In extreme cases the total solids have shown as great a variation as 6 per cent—that is, from 10 to 16 per cent of total solids. Of these, as has already been pointed out, the casein may show a variation of from 2 to 4½ per cent, and the milk-sugar from 3 to 6 per cent. The greatest variation, however, is found in the fat, which in certain cases has been found to be under 2 per cent, and in other cases to amount to 9 per cent. Of all the constituents, the ingredient most constant is the ash or mineral matter, which rarely varies a tenth of a per cent. But whilst the milk of individual cows may show, under abnormal conditions, such variation, the results of a very large number of analyses go to show that the composition of ordinary dairy milk—that is, the mixed milk of a number of cows—is fairly constant. It is this fact that renders it possible to institute certain milk standards, and serves the analyst as a guide for detecting adulteration in milk.

In forming an opinion as to whether a sample of milk is genuine or not, the following considerations have to be taken into account—namely, the amount of total solids, the amount of fat, the amount of ash, and the amount of water. We need scarcely say that the chief adulterant of milk is water. The Society of Public Analysts has drawn up the following standards as the minimum amount of the total solids, fat, and solids not fat, which are likely to exist in a sample of genuine milk :—

Total solids	11.5
Fat	3.0
Solids not fat	8.5

It must be borne in mind that the quality of average milk is very much higher than the above standards put it. Thus, Sir Charles Cameron has never found the total solid matter in the mixed milk of a herd of dairy cows to fall below 12 per cent. The milk of fifteen cows was daily examined for a whole year by Müller and Eisentuch for the Royal Agricultural Society of Sweden. The solids never sank to 11.5 per cent, and only on four occasions were they lower than 12 per cent. The average composition of the milk of forty-two cows kept at Glasnevin Model Farm in 1880 was as follows:—

Water	86.80
Solid matters	13.20
Including fats	3.82
Ash	0.71

The average yield per cow was 6.37 quarts per morning, and 3.63 quarts per evening = 10 quarts. The percentage of solids varied from 11.5 to 16.8, and of fats from 2.88 to 5.40. The evening's milk was slightly richer than the morning's. Old cows' milk was richest.

Testing Milk.—The *lactometer* is simply a hydrometer, or instrument for determining the specific gravity of liquids. If milk have a specific gravity of 1030, that of water being 1000, then a mixture of equal weights of water and milk would have a gravity of 1015—and so on. This mode of testing is liable to mislead, because the specific gravity of pure milk is not constant. As a rule, milk which is well *watered* has a low gravity; but if milk be both *watered* and *skimmed*, it will retain the normal specific gravity of pure milk. The reason of this is, that the removal of cream from milk increases the specific gravity of the latter, the fats which form the larger portion of the solids of the cream being lighter than water. Various other simple means for testing milk have been devised, such as the *cremometer*, *galacto-*

meter, *lactoscope*, and *lactobutyrometer*. Some of these instruments consist of simply graduated cylinders, into which a certain quantity of milk is introduced and allowed to stand for a certain period; the amount of cream formed on the surface of the sample is then read off. Others consist of similar cylinders into which ether and alcohol are added along with the milk. None of these methods can be said, however, to give strictly accurate results. They are convenient for comparative tests.

Changes on keeping Milk.—Milk commences to undergo changes from the moment it is drawn from the udder. These changes are due, as every one now knows, to the action of ferments. In order, therefore, to clearly understand the changes which milk undergoes on keeping, it will be necessary to make a few general remarks on the action of different ferments on milk.

Ferments in Milk.—Of all liquids, milk is the most liable to fermentation; and this is owing to the fact that milk is the most nutritious of all liquids, and is thus best suited to nourish and develop life of all kinds—a fact which is often expressed by the statement that milk is the most perfect of all foods.

Milk free from Germs in the Cow's Udder. — So speedily does milk undergo fermentative change, and seemingly under all conditions and kinds of treatment, that it was at first believed that ferments—or micro-organisms effecting fermentation—were present in the milk when it left the cow's udder. Pasteur, however, contended that this was not the case; and that he was right, experiments carried out more than thirty years ago by the great surgeon, Sir Joseph Lister, conclusively proved.

It must be clearly understood, therefore, that milk when it leaves the cow's udder is free from ferments, and in this condition is not subject to fermentative change, and can be kept fresh an indefinitely long period of time. Since, however, the air is full of germ life of all kinds, the difficulty of keeping the milk free from germ contamination is very great. The very fingers of the milkers and the teats of the cow, as well as the vessels receiving the milk, are apt to be sources of germ contamination themselves, unless very great precautions are taken. The conditions, therefore, necessary to obtain milk free from microbes are the careful washing and cleansing of the teats and hands, and the vessel in which the milk is received, with some antiseptic (or substance which kills all germ-life), and thereafter keeping the milk protected from unfiltered air; for it has been found that air filtered through such a substance as cotton-wool is rendered free of all microbes. Milk thus obtained free from microbes is technically known as *sterile* milk, and is capable of being kept, as has just been mentioned, for an indefinite period of time without souring. It is thus specially suited for use on board ship, where fresh milk is difficult to be obtained. So rapidly does milk become contaminated by bacteria, that as many as from 60,000 to 100,000 of them per cubic centimeter have been found a few minutes after milking; while from cow's milk six hours old there may be from 2,000,000 to 6,000,000. The temperature at which the milk is kept largely influences the number of bacteria,—the lower the temperature the fewer the number of bacteria.

The Nature of Fermentation in Milk.—The number of different microbes which have been already identified in milk is considerable, although it probably bears a small relative proportion to those still unknown. Among the changes produced in fermentation are those of the *curdling*, and the accompanying *souring* of milk; its acquiring a *rancid* or *bitter* flavour; its tendency to become *viscous*, *slimy*, or *ropy*. Among the more uncommon changes are those evidenced by the production of strange colours, such as *blue*, *red*, *green*, *yellow*, *black*, &c., while still less common is the *alcoholic* fermentation of milk. Sometimes in the decomposition of milk highly poisonous benzene derivatives are produced—among which diazobenzene (tyrotoxicon) is most important. This poisonous substance sometimes has been found in such articles as ice-cream, &c., in the preparation of which milk is used.

Organised and Unorganised Ferments.—It must be pointed out that the ferments present in milk may be divided into two kinds. We have first what have been called *chemical* ferments or *unorganised* ferments. To this class of ferments the name *enzymes* has been applied. The other class of ferments are known as *true*, *living*, or *organised* ferments. They are distinguished from one another by certain properties. Thus the chemical ferments are soluble in water, whereas the organised ferments are not. The former class of ferments can only effect a certain amount of fermentative work, whereas there is no limit to the amount of work the organised ferment may effect. A most important relationship exists between these two classes of ferments, for most true ferments give rise to a chemical ferment, which is one of the products of their action. For this reason it is often difficult to know whether certain fermentative changes are caused by organised or unorganised ferments. As general examples of chemical fermentative action, we may cite the conversion of starch into sugar by *diastase*, the dissolving of albuminoids by *pepsin*, and the coagulation of milk by *rennet*—a different kind of fermentation from that producing a similar coagulation of milk when it is allowed to sour.

With regard to true or living ferments, very considerable differences exist among them.

Influence of Temperature on Ferments.—The difference is best seen in the effect of heat upon them, some being killed at very much lower temperatures than others; and our knowledge of this fact is of enormous value in enabling us, by altering the external conditions, to develop or check any class of fermentation we desire. And here we may draw the reader's attention to a most important point. Ferments develop by means of *spores*. Now, it is a singular fact that these spores or young microbes, instead of being more easily killed than the ordinary microbe, are very much less susceptible to the influence of external conditions, such as heat or cold. The consequence of this is that they are often able to withstand for a lengthened period a far higher temperature than that which would at once prove fatal to the parent microbe.

Butyric Fermentation.—A good example of this is furnished by the spores of a microbe which produces that rancidity in milk which resembles in its flavour that of rancid butter. It has been found that the spores of this bacillus are able to withstand the boiling temperature of water without being killed. In the butyric bacillus we have also an example of a ferment which is independent of another external condition necessary for the development of most ferments—viz., the presence of oxygen. In this respect bacteria may be divided into two classes, those requiring oxygen called *aërobic*, and those like the butyric ferment, which do not require it, and which are called *anaërobic*.

As a rule, however, most spores are killed by the boiling temperature of water, so that by boiling milk we generally kill ferments, and check nearly all kinds of fermentation.

Influence of Intermittent Heating of Milk.—The above fact which has just been explained as to the ability of spores to resist a higher temperature than the microbes, explains the reason for a custom which has often puzzled many. In order to preserve milk from souring, it is often heated—not necessarily to boiling temperature—at stated intervals from time to time. When the milk is first heated it may contain a number of germ-spores not killed by the heat employed. By the time the milk is next subjected to heat most of these spores have developed into germs, and are then killed by the heat. The result of such treatment is to kill the germs as soon as they are developed.

Influence of Cold on Milk.—The rate of fermentation in milk is regulated by temperature; but while a high temperature is fatal to the bacteria effecting fermentation, so also is an extremely low temperature. The method of preserving milk by cooling it is the most commonly adopted. The most favourable temperatures for the different kinds of ferments vary considerably—the most favourable for a large number being somewhere between 90° and 100° Fahr. In this fact is to be found the explanation of the much more effective action of the application of cold to milk immediately after milking, than at some subsequent period; for the temperature of new milk is just about the most favourable temperature for the rapid development of fermentation. Milk cools slowly, especially in summer-time; hence the bacteria get a good start, and develop more abundantly in an hour in warm milk than they would do in four or five hours in milk at the ordinary temperature. In the words of Dr Conn, an eminent specialist on this subject, "If the milk is cooled to a low temperature immediately after it is drawn, the bacterial growth is checked at once, and will not begin again with much rapidity until the milk has become warmed once more. The warming will take place slowly, and therefore the cooled milk will remain sweet many hours longer than that which is not cooled. It frequently happens from this cause that a milkman finds his morning's milk will sour earlier than the milk of the night before. The milk drawn in the evening is put in a cool place at once, and becomes quite cool during the night, whilst the morning's milk is at once put in cans and taken for delivery." It may be here pointed out that when milk is partially frozen, the composition of the frozen milk is considerably different from that portion remaining liquid, which contains a larger percentage of milk solids.

Chemical Changes effected by Fermentation.—Having thus discussed the general nature of fermentation in milk, let us investigate the chemical changes which accompany fermentation. After milk has been drawn from the cow and exposed to the air, it loses carbonic acid gas and takes up oxygen. If allowed to stand for some time, the fat, as every one knows, forms a layer on the surface (cream), and the lower portion becomes white, developing at the same time a higher specific gravity. At ordinary temperatures the milk-sugar very speedily undergoes lactic fermentation (and in certain cases even alcoholic fermentation), the milk becoming acid. Vieth has found that the specific gravity of the milk increases. Thus a sample of milk which half an hour after milking had a specific gravity of 1.0296, was found sixteen hours later to have a specific gravity of 1.0309.

Coagulation and Souring of Milk.—On standing for some time milk gradually turns sour and coagulates. The souring of the milk, as a rule, is caused by the action of the lactic ferment—an interesting fact about which is, as Sir Joseph Lister long ago pointed out, that it is only found in the neighbourhood of the dairy. If, therefore, milk is kept free from this ferment in the dairy, and removed to some other place, it does not sour so quickly. The souring of milk may, however, be caused, as has already been pointed out, by ferments other than the lactic. Indeed, the power of decomposing milk-sugar into lactic acid seems to be a property possessed by a large number of bacteria. The coagulation which ensues on milk turning sour is caused by the oxidation of the milk-sugar into lactic acid, and is substantially the same as that produced by the addition of acids. This coagulation is simply the precipitation of the casein, which carries down with it other substances. In certain countries hydrochloric acid is used to effect this coagulation in the process of cheese-making. The rate at which coagulation takes place is of course determined by the temperature and other circumstances. The same quantity of acid will effect a different amount of coagulation at different temperatures; the higher the temperature the greater the amount of coagulation will be. As illustrative of this, Soxhlet has found that milk coagulates at the following temperatures in the following times:—

At 39°	C.	(102°	Fahr.)	in 19 hours.
At 25°	"	77°	"	in 29 "
At 20°	"	68°	"	in 48 "
At 17.5°	"	63.5°	"	in 63 "
At 15°	"	60°	"	in 88 "
At 10°	"	50°	"	in 99 "

The same observer kept milk for fourteen days without much change in taste at from 1° to 2° C. (33.8° to 35.6° Fahr.) Boiling temperature is sufficient to destroy the organisms causing the coagulation of milk. A point of much interest in lactic fermentation is that it only continues for a certain time, as indeed is the case with many other kinds of fermentation. When it has proceeded to a certain extent the acid generated becomes fatal to the life of the ferments causing it, and it ceases. Consequently, when much over 1 per cent of lactic acid is generated, lactic fermentation no longer goes on. The lactic organism has been found to develop best at a temperature between 35° and 42° C. (95° to 107.6° Fahr.), and to be checked at a temperature above 42° C.

Coagulation by Rennet.—The curdling of milk for cheese-making is chiefly effected in this country by means of the addition of rennet. Rennet is the fourth stomach of the young calf salted and dried, and essence of rennet is commonly prepared by digesting the stomach in a 5-per-cent solution of salt. It has been till recently erroneously supposed that the action of rennet in thus coagulating the milk is similar to the coagulation due to the formation of lactic acid, or that caused by the addition of strong acids. This is not the case. The action of rennet is due to its containing a chemical ferment, to which the name *chymosin*, *pixine*, *lab*, or *rennet diastase* has been given. This ferment acts upon casein, but not on milk-sugar or albumin.

With regard to curdling by means of the addition of rennet, Duclaux—an investigator to whose researches we owe a great deal of our knowledge on the fermentation of cheese—has calculated that its action is so potent that one part of the pure ferment is capable of coagulating *a million parts of the casein.*

Preservation of Milk.—Various methods have been adopted for the preservation of milk. Among the simplest of these is the subjecting of the milk to the action of heat or cold. As we have already seen, by subjecting milk to a very low temperature, or to a very high temperature, the action of bacteria effecting the fermentation of milk is checked. The temperature most favourable for fermentative action may be said to be between 50° and 170° Fahr. By cooling the milk, therefore, below 50°, or by heating it above 170° Fahr., the keeping properties of the milk are very much increased. But milk may also be preserved in other ways. One of them is by introducing antiseptics, such as *borax*, *boracic acid*, *salicylic acid*, *saltpetre*, &c. While the use of certain of these antiseptics can scarcely be said to have any very serious deleterious effect, their use is for many reasons to be deprecated. The preparation of sterilised milk by submitting the milk to a sufficiently high temperature to kill all germ-life, and thereafter preserving the milk hermetically sealed, has been attempted to be carried out on a practical scale with a fair measure of success.

Condensed Milk.—The most common way of preserving milk, however, is by condensing it. Condensed milk, of which there are various kinds in the market, is generally prepared by evaporating down the milk, and subsequently mixing it with a large proportion of sugar (not less than 12 per cent). The concentrated milk thus obtained, when the air is carefully excluded, is found to keep unchanged. The following analyses of condensed milk, as produced by different manufacturers, will show its composition:—

Analyses made by Hehner.

	Water.	Fat.	Albuminoids.	Milk-sugar.	Cane-sugar.	Ash.
Anglo-Swiss Co.—						
Made in Switzerland .	24.13	8.67	13.67	10.82	40.48	2.23
Made in England . .	25.63	6.13	12.65	12.50	41.21	1.88
Norwegian condensed milk	28.85	9.21	8.98	14.14	36.74	2.08
Geiber & Co.'s condensed milk . . .	23.68	9.74	9.80	12.93	44.80	2.05
Nestle's Swiss milk .	15.30	8.85	9.98	13.62	50.08	2.17

Condensed milk has also been prepared in America and Switzerland without the addition of sugar: such milk, however, is not found to keep so well.

In America the process adopted in preparing unsweetened condensed milk varies somewhat. The milk is generally first sterilised by heating, and subsequently condensed in vacuum to half or one-third of its bulk. The following are analyses of unsweetened milk:—

	Water.	Fat.	Albuminoids.	Milk-sugar.	Ash.	Analyst.
Mean of ten analyses of American unsweetened milk	45.59	15.67	17.81	15.40	2.53	HEHNER
Unsweetened milk .	57.96	16.02	8.50	16.32	2.20	VOELCKER
Unsweetened milk .	51.72	14.33	11.69	19.51	2.75	VOELCKER

Kephir and Koumiss.—In conclusion, we may refer to two beverages made from milk, and which are interesting on account of the fact that they illustrate a kind of fermentation very rarely found in milk—viz., *alcoholic.* The beverages referred to are *kephir* and *koumiss.* The former of these two drinks has been long known to the inhabitants of the Caucasus. Milk, it may be mentioned, does not readily undergo alcoholic fermentation by the action of yeast, although minute quantities of alcohol are produced in ordinary lactic fermentation. In order to obtain kephir, a special ferment called kephir grains, the nature of which is not exactly known, is introduced into the milk. Alcoholic fermentation speedily ensues, with the result that the milk-sugar is converted into carbonic acid, alcohol, and lactic acid. Presumably also certain decompositions of the milk-fat take place. Kephir takes two to three days before it is ready for use. It has a slightly sour taste, and is largely used in Russia, and it has lately been used medicinally. Koumiss is of a similar nature. It is prepared by the Tartars from mare's milk. The common method is by adding one part of old koumiss to ten parts of fresh milk, and warming the mixture with repeated stirring. Imitation koumiss has been made in Switzerland from cow's milk by adding a little sugar and yeast to skim-milk.

The following analyses by Fleischmann and Suter-Naef may be quoted :—

	(Koumiss, Mare's Milk.)	Swiss Koumiss.
Water . . .	91.53	90.34
Milk-sugar . . .	1.25	2.10
Lactic acid . .	1.01	.19
Casein . . .	1.91	1.86
Milk-fat . .	1.27	1.78
Alcohol . .	1.85	3.21
Carbonic acid . . .	.88	.17
Mineral matter . . .	.29	.51

Influence of Breed on Quality of Milk.—The influence of breed on the quality, as well as on the quantity, of milk, is a point of considerable interest. The belief is common that the small-sized kinds of cows are best for the dairy. As the results of milk-trials with the different breeds of cows at the London Dairy Show, it has been found that the milk from Dutch cows ranked lowest in quality, while that from Jersey cows ranked highest. F. J. Lloyd found that the solids in a number of samples of milk from Jersey cows ranged from 13 per cent to 19 per cent, the difference being due almost entirely to difference in fat, which varied from 4.10 per cent to 9.50 per cent. In the analyses of a number of samples from shorthorn cows, a variation of from 11 per cent to 15 per cent existed; this variation was similarly due almost entirely to difference in fat.

Yield of Milk.—The yield of milk from different cows varies within considerable limits, and may be taken at from 5 to 2½ gallons per day. According to Stephens' 'Book of the Farm,' taking the stock of cows in this country as a whole, the average yield of milk is between 430 and 450 gallons each per annum. Cows of the heavier milking breeds should give from 700 to 900 or 1000 gallons each in twelve months.

Cream-raising.—A most important point for the student of dairy science is in connection with the separation of the milk-fat or cream from the milk. When milk is permitted to stand, a separation of the fat-globules takes place, as we have already seen. The rate at which this separation takes place depends, however, on a variety of circumstances. Among these, one of the most important is temperature. Another is the shape of the vessel in which the operation is allowed to take place. Formerly it was considered that shallow pans were best suited for setting milk. It is now, however, believed that a more economical method is by using deep pans. Latterly the separation of the fat from the milk has been effected by means of centrifugal separators, as well as by other carefully devised apparatus. When the milk is drawn from the cow it should be carefully strained before being introduced into the vessels in which the setting operation is being conducted. These may be made of glass, glazed earthenware, or tinned iron. Zinc vessels ought not to be used, as the action of sour milk on the metal is considerable. Wooden vessels are unsuitable, being with great difficulty kept clean. Lead vessels are largely used, but they are not so good as tinned iron pans. The cream should be skimmed off after the milk has set for twenty-four hours, and any cream that afterwards ascends can be removed by one or more skimmings. When the cream is kept so long on the milk that it becomes sour, the butter made from it is always inferior. In the working of the centrifugal separators, of which the De Laval is the chief, new milk, fresh from the cow, is introduced into a chamber, which revolves at an enormous rate. The cream is thus very speedily separated from the milk. So rapidly is this effected that 150 gallons of milk can be separated in an hour. Another method for hastening cream-raising is by cooling the milk in specially constructed pans, by means of cold water or ice. In some cases the milk is slightly warmed before being introduced into the pans. In Devonshire a scalding system is in use. The milk, after having been allowed to stand for some time, is submitted to a temperature of about 180° Fahr., and then allowed to cool.

Cream.—The composition of cream varies somewhat according to the method in which it is obtained. The chief difference in composition between milk and cream is of course in the larger percentage of fat the former contains. Cream also is richer in albuminoids than milk. This is due to the fact that the albuminoids seem to mechanically adhere to the fat. The percentage of fat is generally not much under 20 per cent, and sometimes is as high as 50 per cent, or even higher in specially prepared creams. A richer quality of cream is obtained, as a rule, by the mechanical separator, which removes, on an average, from 10 to 15 per cent more fat from the milk than the ordinary method. According to König, the analyses of thirty-six samples of cream are as follows:—

	Minimum.	Maximum.	Mean.
Milk-fat	8.17	70.20	25.72
Albuminoids	2.20	7.40	3.70
Sugar	.74	4.57	3.54
Ash	.14	3.49	.63
Water	22.83	83.23	66.41

The size of the fat-globules in milk is supposed to have an important bearing on the suitability of milk for butter-making. The specific gravity of cream may be stated at .90.

Skim-milk.—For the reasons above stated, which influence the composition of cream, skim-milk is found to vary in its composition. It is a bluish-white fluid of 1.034 to 1.037 specific gravity. Although the percentage of fat in skim-milk is trifling, it is never entirely devoid of it. As a rule, the fat is under 1 per cent, and is sometimes as low as under .5 per cent when the centrifugal separator has been used for the separation of the cream. It contains about 10 per cent of solids, 5 per cent of which is milk-sugar. For purposes of comparison it may be well to append the following table (Fleischmann), giving the analyses of fresh milk, cream, and skim-milk :—

	Fresh milk.	Cream.	Skim-milk.
Water	87.55	28.58	90.11
Total solids	12.45	71.42	9.89
Fat	3.64	67.63	.46
Casein	2.73	1.17	2.88
Albumin	.68	.25	.49
Ash	.71	.12	.72

CHAPTER XLVI.

BUTTER AND CHEESE.

Butter.—In butter-making the object of the butter-maker is to extract from the milk as much fat as possible. In butter-making various systems may be followed. Sometimes the milk, as well as the cream, is churned; but, as a rule, butter is made by churning the cream only. When milk or cream is agitated for a length of time the fatty matter gradually separates and collects in lumps of butter. There are several circumstances in connection with churning to which it is of interest to attend. In the churning of cream it is usual to allow the cream to stand in cool weather for several days, until it becomes sour. In this state the butter comes sooner and more freely. If, however, the cream becomes too sour, the butter is certain to be inferior.

Ripening of Cream.—The ripening of cream, as this preliminary souring process is known, is a most important step in the manufacture of butter. It is a subject, however, the science of which is little understood. It is extremely difficult to know, for example, to what extent the cream should be allowed to ripen or become sour.

The chief object of ripening cream is for the purpose of obtaining the maximum amount of butter from the cream, as well as for the influence it is admitted to have on the flavour and keeping properties of the resulting butter. Attempts have been made to estimate the acidity in the cream with a view of knowing when a sufficient degree of ripeness has been obtained, but at present this test is far from satisfactory, and a more important point to attend to is the regulating of the temperature of the cream during the ripening process. How souring of cream should admit of more complete separation of butter-fat in churning is not very clearly understood as yet. It is probably due to the fact, as Babcock has suggested, that the acidity generated in the ripening process prevents the fibrin in milk from coagulating, and thereby retaining the fusion of the fat-globules. We have already referred to the importance of maintaining a low temperature during the ripening period, for this also retards the coagulation of the fibrin. The production of flavour in butter is also an important result due to the ripening process. It would seem from recent researches that the flavour in butter is due to the action of certain bacteria. Of these, one has already been isolated, and it is highly probable that the cultivation of certain ferments, with a view to ripening cream by artificially inoculating it, may be in the future largely practiced, and may have a most important effect in securing greater uniformity in the quality of butter than has hitherto been possible. Cultures of cream-ripening bacteria are already in use in some German dairy factories.

Proper Temperature for Ripening.—The temperature at which cream ought to ripen is a subject which has been much discussed. Probably 60° Fahr. (15.5° C.) ought not to be exceeded, although a temperature as high as 65° Fahr. has been recommended. The temperature of course has a direct influence on the rate at which cream ripens. At a temperature of 60° Fahr., the ripening process goes on pretty quickly, and should be ready in from ten to twenty hours. At a lower temperature a longer period is necessary. In cold weather the temperature may be slightly raised without injuring the cream.

Churning of Milk. — The older custom of churning the whole milk instead of the cream still obtains in many parts of the country. It is claimed for it that the yield of butter is greater, and that the appliances required are fewer. With regard to the yield of butter, however, it may be doubted if this is the case, especially when the more modern methods of separating the cream by means of centrifugal separators are adopted. It is also to be urged against the older method that the quality of butter produced by it is not so good. Too rapid churning is injurious to the quality of butter. The motion of the churn should at first be slow—from twenty to twenty-five rotations per minute; but so soon as the cream cracks, then the strokes may be increased to forty, which, when the butter is freely coming, should be reduced to twenty per minute. When the churning has ceased, the buttermilk is drawn off and a little cold water introduced into the churn, which for a few seconds is again set in motion, and then the butter is taken out of it. Prolonged churning injures the quality of butter by incorporating cheesy matters with it.

During churning, milk increases in temperature (from 55° to 60° Fahr.), absorbs oxygen, becomes sour, and evolves gas. The vents with which churns are usually provided should be occasionally opened to allow this gas to escape. Milk which has been frozen can be churned very quickly. This is probably due to a certain alteration which takes place in the fat-globules. These, when frozen, assume an angular form instead of a spherical. The above fact has led to attempts being made to churn fresh milk, but it is found that practically the only suitable way of obtaining butter from whole milk is by allowing it to sour before churning.

Composition of Butter.—As already pointed out, butter is almost entirely made up of the fat of the milk, which in its turn is composed of a mixture of fatty acids along with glycerine. The percentage of fat in butter may be said to range from 78 to 90 per cent (average 82 per cent); but butter contains other substances in addition to fat. The other chief ingredient is water; and while a certain quantity of water is an invariable ingredient of butter, an excess has to be regarded as detrimental. Ordinary samples of butter contain from 8 to 16 per cent of water. A certain percentage of water in butter improves its appearance very much, but an excessive quantity—say over 16 per cent—affects its keeping qualities, besides being liable to be regarded as an adulterant. Butter also contains a small quantity of curd, which consists of casein, milk-sugar, and lactic acid. This varies from .2 to 5 per cent, but is generally from .5 up to 2 per cent. It is to the presence of the curd in the butter that its decomposition is chiefly due. In the manufacture of butter, therefore, it is highly desirable to expel as much of the butter-milk by washing and kneading the butter as can be done without injuring its quality and deteriorating its value. The question of washing and kneading butter is a much-discussed one among practical butter-makers, and hardly admits of discussion in a work of this kind. While it is desirable, as far as the keeping quality of the butter is concerned, to expel as much of the butter-milk as is possible, the flavour of the butter, which is largely due to the retention of a certain amount of the butter-milk, must be considered. It has been suggested that water purified by boiling should only be used for this purpose. In kneading butter, care should be taken not to destroy the grain. In appearance commercial butter varies from whitish to a deepish yellow. It is more or less granular, and the more perfect this granular condition, the higher the quality.

Preservation of Butter.—The decomposition of butter, as we have already pointed out, is due in the first place to the presence of varying quantities of curd. The casein and the milk-sugar which make up the curd are peculiarly liable to undergo fermentative action. Even a small percentage of curd may induce decomposition, seeing that it is so intimately mixed with the butter-fat, and the decomposition started in the butter-milk speedily induces decomposition in the butter-fat, with the result that the butter becomes rancid.[1] It is on this account that salt has been used as a preservative,—salt, as is

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[1] This has been proved by the fact that pure butter-fat, obtained from butter by melting it, and clarifying the fat by filtration, can be kept for a considerable time unchanged, provided it can be kept from the action of air and light.

well known, being an excellent antiseptic. The quantity of salt in butter is very variable. According to Bell, it may be present from .4 to 15 per cent; as a rule, however, it runs from 2 to 7 per cent. There seems to be no very clear distinction between salt and fresh butter, since what amount of salt constitutes a salt butter seems to depend on local custom. As a rule, butter containing 1 per cent or less may be regarded as fresh butter. The mean of eighty-nine analyses by König is as follows:—

COMPOSITION OF BUTTER.

Fat	83.11
Curd	.86
Salt (ash)	1.19
Water	14.14
Milk-sugar	.70

Packing Butter.—In packing butter the great object to be attained is the most perfect exclusion of air from this perishable article. In filling the firkin (or other vessel), the butter should be pressed firmly against the bottom and sides. If the vessel be only partially filled, the surface of the butter should be furrowed, so as to allow the next addition to unite the more perfectly with the butter first placed *in situ.* It is better to fill vessels by degrees; about 6 inches of butter from each churning will be a sufficient quantity, and in a large dairy two or more firkins can be simultaneously filled. When the butter has reached within an inch of the top of the vessel, the remaining space should be filled with dry salt, *not with pickle*, as is too often the case. Butter does not improve as cheese does by age, therefore the sooner it is sold the better.

Adulteration of Butter.—The common adulterants in butter are an excessive quantity of water (or it may be even an excessive quantity of salt), and the admixture of fats of animal or vegetable origin. The latter form of adulteration has been in the past by far the most common; but of late years much ingenuity has been expended in working into butter a large quantity of extraneous water, in such a way that the eye does not detect the circumstance. The manufacture of *margarine*, or, as it was formerly known, *butterine*, is carried out on an enormous scale. There can be no doubt that margarine, if carefully prepared, is a perfectly wholesome article of diet, and has proved a great boon to the poorer classes, as furnishing a cheap butter substitute. Much margarine, however, has been sold in the past in place of genuine butter. So extensively was this practised that certain legislation has had to be enacted, whereby the perpetration of such a fraud is rendered extremely difficult. Margarine, which is now largely manufactured in America, as well as elsewhere, is, as a rule, made up of beef-fat. Its flavour is given by the addition of varying proportions of genuine butter.

Cream-raising Trials.—As illustrating the results obtained by different means of cream-raising, some trials carried out recently at the Yorkshire College, Leeds, may be cited. The object of these trials was to determine whether the shallow-setting system, the Jersey creamer, or the mechanical separator, was the most economical for butter-making. Six gallons of milk were tested by each process, the cream obtained being made into butter. The following are the results of four days' amount of butter obtained, and value:—

	Total four days.		Average four days.		Average value per lb.		Total value.	
	lb.	oz.	lb.	oz.	*s.*	*d.*	*s.*	*d.*
Separator . .	7	7¾	1	14	1	2¾	9	2½
Jersey creamer .	6	7½	1	9¾	1	2½	7	9¾
Shallow pan .	5	13	1	7¼	1	1¾	6	7¾

AVERAGE COMPOSITION OF SEPARATED AND SKIMMED MILK.

	Separator.	Jersey creamer.	Shallow. pan.
	Per cent.	Per cent.	Per cent.
Total solids	9.32	9.75	9.41
Fat	.33	.57	.73
Water	90.68	90.25	90.59
	100.00	100.00	100.00

AVERAGE COMPOSITION OF BUTTER.

	Separator.	Jersey creamer.	Shallow pan.
	Per cent.	Per cent.	Per cent.
Fat	84.60	84.92	85.25
Casein	.58	.42	.31
Mineral matter	.85	1.06	1.02
Water	13.96	13.60	13.45
	99.99	100.00	100.03

In these tables the superiority of the mechanical separator over the other methods is very obvious. There is a net gain of 2s. 6¾d. by separating 24 gallons of milk by mechanical separator over that obtained by setting milk in the ordinary way—that is, a gain of 1¼d. per gallon. The Jersey creamer is also shown to be superior to the ordinary method, although the gain is only ½d. per gallon. These results also show the superiority of the mechanical separator over the ordinary methods in effecting the removal of the fat.

The Dairy.—In this connection, a few words may be said on the importance of dairy arrangements. Contamination of milk takes place very easily and in a variety of ways. For example, milk may be contaminated from the air, by gases emanating from sewers and privies containing disease germs, or by using contaminated water for washing the dairy and milk utensils. Butter is also a most delicate article, and readily absorbs and is injuriously affected by putrescent organic matters and foul gases.

For these reasons, too great importance cannot be paid to the construction and arrangement of the dairy. It should not be situated near pig-stye, stable, leaking sewer, or dung-heap. It should be cool and free from damp, and should have preferably a northern aspect, so as to prevent excess of heat in summer. Proper ventilation should be ensured, and the flooring should be of some non-absorbent material such as cement. There should be no drain in the dairy. The udders of the cow should be washed, and the milk-vessels should also be thoroughly cleansed both before and after use. Greatest care should be taken to see that the hands of the milkers are perfectly clean. In the words of Professor J. Muir, "The successful practice of dairy-farming depends upon two things—absolute cleanliness and attention to detail. On the first point there must be no compromise allowed—indeed none is possible—and unless all utensils are perfectly clean they must be made so before use. The second point is also essential, and nothing must be thought too little for notice. A turn of the churn too much or too little in butter-making, or a degree or two more or less in temperature in making either cheese or butter, will make all the difference between a good or a bad return, between profit and loss."

Cheese.—Considerable variation in the methods used in cheese-manufacture exists in this country. It is impossible here to enter into any details with regard to these; indeed in cheese-making a great deal depends on details, which it is wellnigh impossible to describe in text-books. Cheese may be made from whole milk, or from milk enriched with cream, or cream itself, as well as from skim- and butter-milk.

Manufacture of Cheese.—As we have already seen, when milk is left to itself for a sufficient length of time it becomes sour and curdles. This takes place sooner in warm weather, and in vessels which have not been cleaned with sufficient care. The curdling of milk in this case is due, as we already saw, to the formation of lactic acid. We have also seen that the curdling of milk is effected by the addition of rennet. Now it is from the curd produced by either process, when salted, pressed, and dried, that cheese is manufactured. As a rule, however, in this country cheese is made from curd precipitated by rennet.

Before discussing the different points in the manufacture of cheese, it will be well to give a general outline of the process usually followed.

After coagulation of the milk by rennet, the curd is broken up by means of a knife or wire apparatus, to facilitate separation from the whey, which is drawn off. The curd is then permitted to stand for some time in order to admit of a certain amount of acidity being generated, salt is then added, and after pressing and drying, the curd is allowed to ripen in the curing-room.

The following general points may be noticed in the manufacture of cheese:—

Acidity.—A point of very great importance, and one which has given rise to much discussion, is the amount of acidity which should be generated in the milk or in the curd. In the manufacture of some cheeses the milk is allowed to develop a certain degree of acidity before the addition of the rennet; in other cases the milk, as freshly obtained from the cow, is coagulated by rennet; while, lastly, acidity is sometimes produced by slightly heating the curd along with the whey, before separation, and allowing it to stand for some time. Generally in the manufacture of *Cheddar* and other hard cheeses the former system is pursued, while in the manufacture of *Stilton* cheese the latter system is adopted. Sometimes the desired acidity in the milk is induced by adding a little sour whey to fresh milk; but this is regarded by many as a highly undesirable practice. A certain amount of acidity seems necessary to give flavour to the cheese; on the other hand, the flavour may be spoiled and the cheese rendered bitter by an excess of acidity. The influence of acidity on the subsequent ripening of the cheese, and on its keeping qualities, seems to be considerable; but the exact nature of its influence, and the exact manner in which it acts, is not very clearly understood. It seems highly desirable that the curdling of the milk should be produced, or at any rate helped, by its acidity as well as by rennet. It has been found that curd coagulated by acid alone is apt to become hard and incapable of proper ripening, whereas where rennet is alone used a proper amount of shrinkage of the curd does not take place, and the curd is rendered not sufficiently hard to permit of sufficient separation of the whey. The former reason explains why excess of acidity in milk before addition of rennet may produce too hard a cheese.

The preparation of rennet, as well as the amount of rennet used, are also of great importance, as these have a considerable influence on the quality of the cheese. The rate at which coagulation of milk goes on depends on the temperature of the milk, as well as on the amount of rennet used. The warmer the milk, within certain limits, the quicker the coagulation. The quality of the milk will decide also the quantity of rennet to be used, rich milk requiring more rennet to effect its coagulation than poor milk. The advantage of using rennet extract of a known strength will be seen to be very considerable, as permitting of much more accurate work than the older custom, according to which rennet was made on the farm. In cold milk rennet acts very slowly. Its action is most rapid at about 100° Fahr., and ceases at about 130° Fahr. The most suitable temperature for coagulation by rennet in cheese-making is about 80° Fahr.; but the temperature varies somewhat in different systems, and for different cheeses. Coagulation, on an average, takes from forty to sixty minutes.

Separation of Curd from Whey.—After complete coagulation, care ought to be exercised in cutting the curd not to bruise it too much, so as to prevent loss of fat; sometimes the curd is at this stage scalded with hot whey, the object being to harden it. When the acidity is generated by heating the whey and the curd before separation, heat should be applied very gradually. The temperature to which it may be raised should be from 98° Fahr. to 102° Fahr., according to the time of year. After the whey is separated from the curd it is ground down and packed evenly in press-vats. The object of this grinding is to admit of it being evenly packed, and to facilitate the escape of the whey, as also to permit of mixing with the salt. The amount of salt added is regulated by the richness of the curd in fat—that containing much fat requiring less salt. A usual allowance is from 2 to 2¼ lb. of salt per 1 cwt. of curd. Salt retards fermentation, and if used in too great quantity may very seriously impair the ripening process. The quantity of salt added, therefore, must be regulated by the consideration of whether the cheese is to be quickly or slowly ripened. Salt, it may be also added, checks the development of acidity. It is important that the salt should be evenly and thoroughly mixed with the cheese. In the manufacture of some cheeses the quantity of salt added is very slight, salt after the manufacture being rubbed in on the surface. Sometimes the cheese is floated in a strong brine for several days.

Cheddar Cheese.—Among the most important cheeses manufactured in this country is the *Cheddar*, which is made from whole milk. The process usually pursued consists in adding the evening's milk to the morning's milk, the temperature of the milk being brought to 80° Fahr. or higher. If the acidity is not sufficient a little sour whey may be added. Rennet sufficient to produce complete coagulation in an hour is then added. When a certain colour is desired to be produced in the cheese, *anatto* is sometimes used before adding the rennet. It is added to the milk before coagulation. It is important to have the rennet thoroughly mixed with the milk. This is usually done by stirring the milk for ten minutes or so. After an hour the curd will be found to be ready for cutting or breaking. This must be carefully done, as already pointed out, and the curd should be reduced to small pieces. The whey should be of a greenish colour and clear. Whitish whey indicates a loss of curd. A portion of the whey is then removed and heated. It is then returned to the cheese-vat and mixed with the curd, the object being to scald the curd. Care must be taken not to permit the temperature to rise above 90° Fahr. The scalding process is generally performed twice, the temperature to which the curd is brought on the second occasion being about 10° higher. The effect of the scalding process is to harden the curd and permit of its more effectual separation from the whey. In the more modern process of Cheddar-making scalding is effected by heating the vat by hot water or steam, thus obviating the necessity of heating the whey. After the whey has been run off the curd is allowed to remain in the vat for about half an hour, covered up with cloths to prevent it cooling too rapidly. In very warm weather, however, the difficulty is not in preventing it cooling too rapidly, but in cooling it sufficiently rapidly. The curd is then twice cut up, after about half an hour's interval in each case, and removed to the cooler. When dry it is then removed to the curd-mill, where it is reduced to small pieces. After salting it is wrapped up in cloth and transferred to the cheese-press, where it is subjected to great pressure. The last step in the process is the ripening, which takes place in the cheese-room, and which goes on for several months. The temperature during this process should be from 60° to 65° Fahr.; the higher temperature being maintained during the first six weeks.

Stilton and other Cheeses.—In the manufacture of some cheeses, such as *Stilton*, pressure is not used at all. Where a tender curd is required a smaller quantity of rennet is used for curdling.

It is well known that the best cheese is produced when cattle are at grass; the largest quantity of cheese, as well as the best in quality, being produced in September and October. In this country cheese is made from cow's milk; on the Continent ewe's and goat's milk are also used.

Composition of Cheese.—In composition cheese varies considerably. When the casein is coagulated by the rennet the fat-globules of the milk are retained in the curd. In addition to *casein*, which is generally the largest ingredient, cheese contains a variable proportion of fat. The amount of fat depends on the richness of the milk from which it is produced. In many Continental cheeses made from cream fat is often more abundant than casein. The other ingredients are *water*, *ash* (including the salt added), and a small quantity of *lactic acid.* Good cheeses contain from 30 to 35, inferior kinds from 38 to 45, per cent of water. Rich cheeses contain from 25 to 35 per cent of fat, and about the same proportion of casein; in cream cheeses the fat may be over 60 per cent; while skim-milk cheeses are practically destitute of fat. The ash, lastly, may vary from 3 to 10 per cent.

The following analyses will illustrate the composition of some of the more commonly used cheeses :—

SOFT CHEESES.

	Water.	Casein.	Fat.	Ash.
Neufchatel	37.87	17.43	41.30	3.40
Fromage de Brie	51.87	18.30	24.83	5.00
English cream	...	2-3	50-68	...
Camembert	51.30	19.00	21.50	4.70
The Roquefort	11.84	85.43	1.85	...
″ (two months old)	19.30	43.28	32.30	...

HARD CHEESES.

	Water.	Casein.	Fat.	Ash.
American	22.59	37.20	35.41	4.80
″	31.80	36.00	28.70	3.50
Cheddar	27.83	44.47	24.04	3.66
″	28.34	47.03	21.01	3.62
Dunlop	38.46	25.87	31.86	3.81
Gloucester	21.41	49.12	25.38	4.09
″	35.82	37.96	21.97	4.25
Parmesan	27.56	44.08	15.95	5.72
Stilton	32.18	24.31	37.36	3.93
″	38.28	23.93	30.59	3.20
Gruyere	40.00	31.25	24.00	3.00
″	34.68	31.41	28.93	3.85
Gorgonzola	43.56	24.17	27.95	4.32
Skim	43.14	49.79	0.86	6.21

Ripening of Cheese.—The manufacture of cheese is, in every respect, a very much more complicated process than the manufacture of butter, and our knowledge of the fermentative changes going on in the ripening of cheese is comparatively slight. In keeping milk the great object aimed at is to exclude micro-organic life and to prevent fermentative action. In butter, although, as we have seen, fermentative action plays a not unimportant part in producing flavour, it is desirable to exclude bacteria. With cheese, however, the case is entirely different, since it may be described as a product of fermentation from beginning to end. While curd is a good soil for the majority of organisms, it is better suited, undoubtedly, for the development of some than of others. Although we do not know much regarding the nature of the different ferments active in the ripening process, we have empirically discovered the temperature at which these ferments develop best.

It has been suggested, as explanatory of the striking fact that the manufacture of certain cheeses is practically limited to certain districts (*Camembert*, *Neufchatel*, &c.), that the organisms active in the fermentation of these cheeses are only found in the locality where the cheese is made. The most important investigations on this question have been made by M. Duclaux. He has investigated the manufacture and ripening of *Cantal* cheese. This cheese is said to contain ten or more micro-organisms, six of which are said to be essential to its proper ripening.

In ripening a cheese steadily loses water. There is a development of carbonic acid and a decomposition of the fat. According to Blondeau, the casein is slowly converted into fat; but this point is extremely doubtful.

In certain cheeses the presence of moulds is very common. *Roquefort*, for example, contains veins of green moulds, and so highly esteemed is this green mould that it is specially cultivated. It is specially prepared by being grown on wheat and barley bread, and is incorporated into the curd from which the cheese is formed. Its development is further favoured by storing the cheeses in cellars or caves at a temperature of 40° or 50° Fahr. *Gorgonzola*, another cheese, also contains green moulds.

Yield of Cheese.—A point of some interest is the amount of cheese yielded by a certain quantity of milk.

For hard cheeses a gallon of milk is generally reckoned as capable of yielding 1 lb. of cheese. In some experiments on cheese-making 1000 gallons of milk produced 8 cwt. of cheese; the same quantity of milk, partially skimmed, gave 6 cwt. 2 qr. 16 lb. of cheese and 1½ cwt. of butter; a third 1000 gallons, skimmed, produced 6 cwt. 24 lb. of cheese and 2½ cwt. of butter; and lastly, a fourth 1000 gallons, partly skimmed and the skimmings added to the balance of the whole milk, produced 3 cwt. 12 lb. of skim-milk cheese and 4 cwt. 3 qr. of rich cheese.

CHAPTER XLVII.

FOOD-RATIONS.

A question of the very highest interest to the feeder of live stock is the question of food-rations. The question, it must be at once frankly admitted, is as yet comparatively little understood, despite much valuable experimental work conducted especially in Germany. The subject is not suited for full treatment in an elementary text-book such as the present; we shall consequently refer merely to one or two points of especial importance.

Albuminoid or Nutritive Ratio.—The suitability of a food for feeding purposes is largely indicated by what is known as its *albuminoid or nutritive ratio.* This denotes the proportion of the digestible albuminoids to the digestible non-nitrogenous nutrients—the carbohydrates and the fat. Inasmuch as the heat-giving power of fat is, weight for weight, two and a half times as great as the carbohydrates, the albuminoid ratio of a food is thus got by *multiplying the percentage of the fat in a food by 2½, adding the product to the percentage of digestible carbohydrates, and finding the ratio of the percentage of digestible albuminoids to the amount thus obtained.*

To illustrate this point, let us calculate the albuminoid ratio of a food containing 25 per cent of digestible albuminoids, 10 per cent oil, and 40 per cent digestible carbohydrates. In the first place, we have to multiply the 10 per cent of oil by 2½, which gives us 25; this added to the 40 per cent of carbohydrates gives 75. The albuminoid ratio of such a food is therefore 25 : 75, or 1 : 3.

The first point, therefore, in considering the suitability of a food for feeding purposes, is to ascertain its *albuminoid* ratio. Before, however, being able to calculate this from the ordinary chemical analyses of foods, we must know the coefficient of the digestibility of their different nutrients (see p. 384). The following table, compiled from those of Kühn and Wolff, shows this for some of the common foods. The numbers express the coefficients of digestibility of the different nutrients—*i.e.*, the percentage of the total amount of the different nutrients present in the food which is digestible. (See Table I.)

TABLE I.—DIGESTIBILITY OF FEEDING-STUFFS.

	Albuminoids.	Fat.	Nitrogen—free extract.	Crude fibre.
	Average.[1]	Average.	Average.	Average.
Green Fodder.				
Pasture-grass	75	66	79	73
Meadow-grasses	70	65	79	69
Pasture-clover	78	64	78	67
Potato-tops	42	24	60	36
Hay.				
Meadow-hay (experiments on ruminants)	57	46	63	58
Meadow-hay " " horse	62	20	56	42
Rowen	61	46	66	63
Clover-hay	70	64	73	53
Straw.				
Wheat	26	27	40	52
Rye	25	32	36	56
Oat	38	30	42	61
Barley (inferior)	15	38	51	52
Bean	51	55	61	36
Pea (very good)	60.5	46	64	52
Grains.				
Maize (swine)	85	76	94	34
Maize (sheep)	79	85	91	62
Maize (horse)	78	63	94	100
Oats (experiments on ruminants)	74	82	73	21
Oats " " horse	87	78	77	26
Barley " " ruminants	77	100	87	20
Barley " " swine	78.	69	90	20
Beans " " ruminants	90	97	94	63
Beans " " horse	86	8	93	69
Peas " " swine	88	58	97	74
Bye-products and refuse.				
Rape-cake (experiments on cows and oxen)	85.4	88	78	11
Rape-cake " " sheep	75.9	69	78	3
Linseed-cake (experiments on oxen)	87	91	91	26
" " " goats and sheep	83	90	71	62
Palm-nut cake and meal experiments on ruminants	98	98	94	82
Cocoa-nut cake (experiments on swine)	74	83	89	60
Cotton-seed cake " " sheep	74	91	46	23
Wheat-bran, fed dry " " oxen	88	80	80	20
Wheat-bran, fed dry " " sheep	75	50	70	37
Spelt-bran " " "	73	88	91	?
Rye-bran " " swine	66	57.5	74.5	9
Brewers' grains	85	80	100	..
Malt-sprouts	80	80	100	..
Sour milk (experiments on swine)	96	95	99	..
Flesh-meal " " ruminants	95	98	..	..
Flesh-meal " " swine	97	87	..	..
Fish-guano " " ruminants	90	76	..	..
Dried blood " " "	62	100	100	..
Dried blood " " swine	72	..	92	..

---

[1] Of course the coefficient of digestibility varies in the case of even the same kind of food, and the animal eating it, as has already been pointed out. In these tables the averages of a large number of experiments are given, and in the case of certain foods the variation in the amount digested is also stated.

Albuminoid Ratios of Common Foods.—The following table (taken from Stephens' 'Book of the Farm,' Div. ii. p. 281) gives the albuminoid ratio of some of the commoner foods :—

	Albuminoid ratio.
Cotton-cake, decorticated	1 : 1.5
" " undecorticated	1 : 2.0
Linseed-cake	1 : 2.4
Rape-cake	1 : 1.6
Beans	1 : 2.5
Peas	1 : 3.1
Wheat-bran	1 : 5.2
Malt-dust	1 : 3.5
Brewers' grains	1 : 3.0
Oats	1 : 6.1
Barley	1 : 7.9
Maize	1 : 9.5
Pasture-grass	1 : 5.9
Clover-hay (new)	1 : 7.4
Meadow-hay (medium)	1 : 9.4
Barley-straw	1 : 19.0
Oat-straw	1 : 22.3
Vetches	1 : 9.8
Swedes	1 : 9.8
Turnips	1 : 10.1
Mangels	1 : 17.0
Potatoes	1 : 17.2

The most suitable ratio for a food varies according to whether the animal is a young *growing* animal or an *adult* animal; and further, whether the object is to fatten, to produce milk, or to get work out of the animal.

Ratios for Different Animals.—The younger the animal the higher is the ratio required. This is natural when we reflect that the chief function of food in the case of young animals is to build up tissue. (Food for a young animal ought also to be rich in mineral ingredients, for the formation of bone, &c.) This fact is well illustrated by the nutritive ratio of cow's milk, which is 1 : 3.6. *Colostrum*, the milk produced immediately after birth, has a still higher ratio—viz., 1 : 0.5.

For young animals, speaking generally, a ratio of 1 : 4 or 1 : 5 should be maintained; while for adult animals 1 : 6, and for fattening animals 1 : 8, may be regarded as most suitable.

Amount of Food.—Lastly, the amount of food required for different animals has to be considered. Here the object aimed at must be again borne in mind. For example, where an animal is kept at rest and the object is simply to afford it what is called a *maintenance diet*, the amount of food required is reduced to a minimum. In the case of oxen it has been found that a food, containing about *half a pound* of digestible albuminoids and about *eight pounds* of digestible non-nitrogenous matter, per 1000 lb. live-weight, was sufficient to furnish a maintenance diet. On the other hand, in the case of a milch-cow or a working horse, a very different diet is necessary.

Tables II. and III., giving the results of numerous experiments on this subject, may be found to be helpful to stock-feeders.

TABLE II.—FEEDING STANDARDS.

A.—Per Day and per 1000 *lb. Live-weight.*

No.			Total organic substance.	Nutritive (digestible) substances.			Total nutritive substance.	Nutritive ratio.
				Albuminoids.	Carbohydrates.	Fat.		
			lb.	lb.	lb.	lb.	lb.	
1	Oxen at rest in stall		17.5	0.7	8.0	0.15	8.85	1 : 12
2	Wool sheep coarser breeds		20.0	1.2	10.3	0.20	11.70	1 : 9
	finer breeds		22.5	1.5	11.4	0.25	13.15	1 : 8
3	Oxen moderately worked		24.0	1.6	11.3	0.30	13.20	1 : 7.5
	heavily worked		26.0	2.4	13.2	0.50	16.10	1 : 6.0
4	Horses moderately worked		22.5	1.8	11.2	0.60	13.60	1 : 7.0
	heavily worked		25.5	2.8	13.4	0.80	17.00	1 : 5.5
5	Milch-cows		24.0	2.5	12.5	0.40	15.40	1 : 5.4
6	Fattening oxen 1st period		27.0	2.5	15.0	0.50	18.00	1 : 6.5
	2d ″		26.0	3.0	14.8	0.70	18.50	1 : 5.5
	3d ″		25.0	2.7	14.8	0.60	18.10	1 : 6.0
7	Fattening sheep 1st period		26.0	3.0	15.2	0.50	18.70	1 : 5.5
	2d ″		25.0	3.5	14.4	0.60	18.50	1 : 4.5
8	Fattening swine 1st period		36.0	5.0	27.5		32.50	1 : 5.5
	2d ″		31.0	4.0	24.0		28.00	1 : 6.0
	3d ″		23.0	2.7	17.5		20.20	1 : 6.5
9	Growing cattle.							
	Age.	Average live-weight per head.						
	Months.	lb.						
	2-3	150	22.0	4.0	13.8	2.00	19.80	1 : 4.7
	3-6	300	23.4	3.2	13.5	1.00	17.70	1 : 5.0
	6-12	500	24.0	2.5	13.5	0.60	16.60	1 : 6.0
	12-18	700	24.0	2.0	13.0	0.40	15.40	1 : 7.0
	18-24	850	24.0	1.6	12.0	0.30	13.90	1 : 8.0
10	Growing sheep.							
	5-6	56	28.0	3.2	15.6	0.8	19.6	1 : 5.5
	6-8	67	25.0	2.7	13.3	0.6	16.6	1 : 5.5
	8-11	75	23.0	2.1	11.4	0.5	14.0	1 : 6.0
	11-15	82	22.5	1.7	10.9	0.4	13.0	1 : 7.0
	15-20	85	22.0	1.4	10.4	0.3	12.1	1 : 8.0
11	Growing fat pigs.							
	2-3	50	42.0	7.5	30.0		37.5	1 : 4.0
	3-5	100	34.0	5.0	25.0		30.0	1 : 5.0
	5-6	125	31.5	4.3	23.7		28.0	1 : 5.5
	6-8	170	27.0	3.4	20.4		23.8	1 : 6.0
	8-12	250	21.0	2.5	16.2		18.7	1 : 6.5

TABLE III.—FEEDING STANDARDS.

B.—Per Day and per Head.

		Total organic substance.	Nutritive (digestible) substances.			Total nutritive substance.	Nutritive ratio.
			Albuminoids.	Carbohydrates.	Fat.		
Growing cattle.							
Age.	Average live-weight per head.						
Months.	lb.	lb.	lb.	lb.	lb.	lb.	
2-3	150	3.3	0.6	2.1	0.30	3.00	1 : 4.7
3-6	300	7.0	1.0	4.1	0.30	5.40	1 : 5.0
6-12	500	12.0	1.3	6.8	0.30	8.40	1 : 6.0
12-18	700	16.8	1.4	9.1	0.28	10.78	1 : 7.0
18-24	850	20.4	1.4	10.3	0.26	11.96	1 : 8.0
Growing sheep.							
5-6	56	1.6	0.18	0.87	0.045	1.095	1 : 5.5
6-8	67	1.7	0.17	0.85	0.040	1.060	1 : 5.5
8-11	75	1.7	0.16	0.85	0.037	1.047	1 : 6.0
11-15	82	1.8	0.14	0.89	0.032	1.062	1 : 7.0
15-20	85	1.9	0.12	0.88	0.025	1.047	1 : 8.0
Growing fat swine.							
2-3	50	2.1	0.38	1.50		1.88	1 : 4.0
3-5	100	3.4	0.50	2.50		3.00	1 : 5.0
5-6	125	3.9	0.54	2.96		3.50	1 : 5.5
6-8	170	4.6	0.58	3.47		4.05	1 : 6.0
8-12	250	5.2	0.62	4.05		4.67	1 : 6.5

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