MORTON'S HAND BOOKS of the FARM

Nº I.

CHEMISTRY OF THE FARM

BY

R. WARINGTON. F.R.S.

SIXTH EDITION

REVISED AND ENLARGED

VINTON & CO. LTD. 9, NEW BRIDGE STREET.

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THE present volume is one of a series discussing the Cultivation of the Farm, its Live Stock, and its Cultivated Plants, Farm and Estate Equipment, Dairying, and Farm Labour, the Chemistry of Agriculture, and the Processes of Animal and Vegetable Life. Among the writers who have been engaged on them are Messrs. T. BOWICK, the late W. BURNESS, G. MURRAY, the late W. T. CARRINGTON, the Rev. G. GILBERT, Messrs. JAMES LONG, J. HILL, SANDERS SPENCER, and the late J. C. MORTON, Professors G. T. BROWN, J WORTLEY-AXE, and J. SCOTT, the late Professor JAMES BUCKMAN, Dr. MAXWELL, T. MASTERS, F.R.S., and Mr. R. WARINGTON, F.R.S.

PREFACE

TO THE SIXTH EDITION.

As about 27,000 copies of this little book have been printed during the last ten years in England, the United States, and Belgium, I am encouraged once more to do my best to improve it, and to make such alterations and additions as the progress of Agricultural Chemistry seems to demand.

The largest additions will be found in the chapters relating to Manure, Animal Nutrition, Food, and the Dairy. The new theory of the partial nutrition of leguminous plants through their root tubercles has been adopted. The isodynamic values now ascertained for the various constituents of foods have also been introduced; and for the first time the comparative value of different foods, and the ratio of the albuminoid to the non-albuminoid matter in each food, have been calculated on the basis of these values.

The general aim of the book is, as before, to supply students with a concise Handbook of Agricultural Chemistry, describing the more important facts of the science, and especially those having a practical bearing on agricultural operations. To teach chemistry, or the operations of practical agriculture, is not attempted.

R. W.

February, 1891.

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THE

CHEMISTRY OF THE FARM.

CHAPTER I.

PLANT GROWTH.

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The first step towards a knowledge of plant chemistry must be an acquaintance with the materials of which plants are built up.

The Constituents of Plants.—The most abundant ingredient of a living plant is *water*. Many succulent vegetables, as turnips and lettuce, contain more than 90 per cent. of water. Timber felled in the driest time seldom contains less than 40 per cent. of water.

If a branch of a tree is burnt, the greater part is consumed and passes away in the form of gas, but there is left behind a small quantity of white ash. The same happens if any other part of a plant is burnt. The constituents which form the dry matter of plants may be thus conveniently divided into two classes—the combustible, and the incombustible.

The *combustible* part of plants is made up of five chemical elements—carbon, oxygen, hydrogen, nitrogen and sulphur; without these no plant is ever produced. Carbon generally forms about one-half of the dry combustible matter of plants. Nitrogen seldom exceeds 4 per cent. of the dry matter, and is generally present in much smaller amount. Sulphur is still smaller in quantity. The remainder is oxygen and hydrogen.

The carbon, hydrogen, and oxygen form the cellulose, lignin, pectin, gummy matters, starch, dextrin, sugar, fat, and vegetable acids which plants contain. The same elements united with nitrogen form the amides and alkaloids; and further united with sulphur the still more important albuminoids, which are essential constituents of all plants.

The *incombustible,* cr ash constituents, form generally but a small part of the plant. The timber of freely-growing trees contains but 0·2—0·4 of ash constituents in 100 of dry matter. In seeds free from husk the ash is generally 2—5 per cent. of the dry matter. In the straw of cereals 4—7 per cent. In roots and tubers 4—8 per cent. In hay 5—9 per cent. It is in leaves, and especially old leaves, that the greatest proportion of ash is found; in the leaves of root crops the ash will amount to 10—25 per cent. of the dry matter.

The incombustible ash always contains five chemical elements—potassium, magnesium, calcium, iron, and phosphorus, besides sulphur already mentioned. Iron is present in only very small quantity. These five elements, though forming a very small portion of the plant, are indispensable to its life. Besides the elements just named, an ash will generally contain sodium, silicon, and chlorine, with frequently manganese, and perhaps minute quantities of other elements. The supplementary elements just named are not apparently essential to plant life, though some of them discharge useful functions in the plant.

The metals above-named occur in the plant as salts, being combined with phosphoric, nitric, sulphuric, and various vegetable acids, of which formic, acetic, oxalic, malic, tartaric, and citric acid are the most common. The metals are also frequently present as chlorides. Phosphorus occurs in the form of phosphates; silicon is present as silica. Sulphur occurs partly as sulphates, and partly as a constituent of albuminoids. In the ash of plants the bases of the nitrates, and of the salts of vegetable acids, are found in the form of carbonates.

It is usual to speak of the combustible ingredients of a plant as *organic*, and of the incombustible ingredients as *inorganic*. This distinction is scarcely accurate, as those ash constituents which are indispensable parts of plants have, during the life of the plant, as much right to be called "organic" as albumin or cellulose.

In the following table will be found the average composition of a crop of meadow grass weighing five tons when cut, and producing one and a-half ton of hay; this will illustrate what has just been said as to the constituents of plants. Further information as to the composition of crops will be found on pp. 48—49.

COMPOSITION OF A CROP OF MEADOW GRASS.

Water			8,378 lbs.
Carbon	1315	Combustible matter	2,613 lbs.
Hydrogen	144		
Nitrogen	49		
Oxygen and Sulphur	1105		
Potash	56·3	Ash	209 lbs.
Soda	11·9		
Lime	28·1		
Magnesia	10·1		
Oxide of iron	·9		
Phosphoric acid	12·7		
Sulphuric acid	10·8		
Chlorine	16·2		
Silica	57·5		
Sand, &c.	4·5		
Total crop			11,200 lbs.

Plants obtain the elements of which they are built up partly from the soil, and partly from the atmosphere. From the soil they obtain, by means of their roots, all their ash constituents, all their sulphur, and nearly the whole of their nitrogen and water. From the atmosphere they obtain, through the instrumentality of their leaves, the whole, or nearly the whole, of their carbon, with probably small quantities of nitrogen and water.

Function of the Leaves.—1. *Assimilation.* — The source of vegetable carbon is the carbonic acid gas present in the atmosphere. Carbonic acid and the other gases of the atmosphere pass through the cuticle of the plant, and are dissolved by the cell sap: carbonic acid is much more soluble in water than the nitrogen and oxygen which make up the bulk of the atmosphere. The dissolved carbonic acid is decomposed within the chlorophyll cells of the plant under the influence of light, oxygen being evolved, and the carbon retained by the plant. The carbonic acid being thus removed from the cell sap, it becomes capable of dissolving a fresh supply. All green parts of a plant share in this power of decomposing carbonic acid, but it is pre-eminently the function of the leaves. The decomposition of carbonic acid does not proceed in darkness, or at a very low temperature. The rays of light most active in effecting the decomposition are the orange-red rays; the green, violet, and dark red rays of the spectrum have scarcely any influence. The rays of light absorbed by chlorophyll are, in fact, the ones which accomplish the chemical work.

The decomposition of carbonic acid by green plants during daylight is of the utmost importance in maintaining an atmosphere suitable for the respiration of animals. An animal in breathing inspires atmospheric air; it expires air in which a part of the oxygen has been replaced by carbonic acid; the result of animal life is thus to accumulate carbonic acid in the atmosphere. Such accumulation would be injurious to the health of animals, but is prevented by the growth of plants. It has been calculated that an acre of forest, producing annually 5755 lbs. of dry matter, will consume the carbonic acid produced by the respiration of 15·4 men.

Besides carbonic acid, plants are apparently capable of absorbing a small quantity of ammonia through their leaves. The uncombined nitrogen of the atmosphere is not appropriated by the leaves of green plants. When rain occurs after severe drought, water may be taken up to some extent through the leaf.

Plants which have no chlorophyll cells, and possess consequently no green colour, do not decompose carbonic acid. We have familiar examples of such plants in the broomrape and dodder of our clover fields, and in the common fungi. The broomrape and dodder are fed by the juices of the plants on which they live as parasites. The fungi derive their carbon from the decayed vegetable matter in the soil.

2. *Formation of Organic Matter.*—The oxygen gas given off by a green plant exposed to light is so nearly equal in volume to the carbonic acid decomposed, that apparently the whole of the oxygen contained in the carbonic acid is returned to the atmosphere; the reaction is, however, really more complicated, as water is probably decomposed at the same time as the carbonic acid.

The exact nature of the reaction which takes place when carbonic acid is decomposed in the chlorophyll cells is still unknown. It is probable that formaldehyde is first produced, according to the following equation:

$$CO_2 + H_2O = CH_2O + O_2.$$

From formaldehyde glucose is possibly derived by a process of condensation:

$$6CH_2O = C_6H_{12}O_6.$$

The formation of *carbo-hydrates* in the plant is plainly dependent on the presence of nitrogenous matter, phosphates, potash, and the other essential ingredients of plant-food; a plant poorly provided with these substances produces only a small quantity of carbo-hydrates, however much it be exposed to light. The formation of glucose and starch is therefore regarded by some as due to a splitting up of the nitrogenous protoplasm, the nitrogenous residue left combining with formaldehyde, and thus reconstituting the original nitrogenous matter.

The carbohydrate starch ($C_6H_{10}O_5$) is among the earliest products; it is an insoluble substance, and is converted into sugar (glucose) for the nourishment of distant parts of the plant, to which it is conveyed by the movement of the sap. In parts where growth is taking place, and new cells are being formed, the sugar of the sap is converted into cellulose, the substance which forms the cell walls, and of which the whole skeleton of the plant primarily consists. The conversion of glucose into starch, or of starch into glucose and cellulose, presents no chemical difficulties, as all these substances are carbo-hydrates, that is, they are composed of carbon and the elements of water.

The mode in which *albuminoids* are formed in the plant is not certainly known; probably the nitrates taken up by the roots are converted into ammonia, the ammonia into amides, and the amides finally into albuminoids.

The *fatty* matter of a plant may be formed from carbo-hydrates; or possibly from the splitting up of albuminoids.

The *vegetable acids* in a plant are probably formed by oxidation; most likely by the oxidation of some of the carbo-hydrates.

We have just referred to oxidation as taking place in the plant. This is always going on in the interior during life, and as a result the plant is continually consuming a small quantity of oxygen, and giving out a small quantity of carbonic acid, an operation precisely similar to animal respiration. This action is not readily perceived during the daytime, being hidden by the opposite action of the chlorophyll cells, which absorb carbonic acid and evolve oxygen. If a plant is placed in darkness the respiratory action becomes manifest. The oxidation of matters already formed is an important means for the production of new bodies.

3. *Transpiration.*—Another important function of leaves consists in the transpiration of water. This transpiration takes place through the cuticle of young leaves, but in older leaves chiefly occurs through small openings, known as stomata, which are most abundant on the under side of the leaves. Transpiration takes place chiefly in light; it will occur abundantly, even in an atmosphere saturated with water, if the plant be only exposed to sunshine. The amount of water evaporated from the surface of a growing plant is very large. Land that has lately borne a crop is always much drier than a bare fallow.

The results of transpiration to the plant are most important, the evaporation of water from the leaves being a principal cause of the rise of the sap, and the consequent drawing up of water from the soil containing plant food in solution.

Function of the Roots.—The roots of a plant are the organs by which it absorbs water from the soil, and with this water a variety of food elements are introduced.

1. *Assimilation of Ash Constituents.*—The roots take up the soluble salts, and all the diffusible substances (those capable of passing through a membrane) which are present in the water which they draw from the soil. The plant may thus receive a number of substances not actually required for its nutrition.

The feeding power of roots is not, however, confined to the taking up of ready-formed solutions, they are also capable of attacking some of the solid ingredients of the soil, which they render soluble and then appropriate. This important action of roots exists in different degrees with different plants. The action takes place only at the points of contact between the root-hairs and the particles of the soil, and is brought about by the acid sap which the roots contain. This action of the roots plays an important part in the supply of phosphoric acid and potash to the plant, as these substances, especially the former of them, exist in the soil in difficultly soluble forms, and are rarely found in solution in the water present in soils.

An apparently selective power is exerted by plants, some soluble ash constituents being taken up in much larger quantity than others, which may actually be more abundant in the soil. A striking example of this is the assimilation of potassium in preference to sodium salts. This selective action of the roots is quite explainable by the known laws of diffusion. When ingredients of the sap are removed out of solution by becoming part of the tissues of the plant, the diffusion of such substances from the soil will continue: while salts not appropriated by the tissues can continue to enter by diffusion only so long as the solution in the soil is stronger than that in the plant.

2. *Assimilation of Nitrogen.*—Besides furnishing the plant with its ash constituents, the root has the important function of supplying nitrogen; this is nearly always taken up in the form of nitrates. A plant is capable of making use of nitrogen in the form of nitric acid or ammonia; it is also, according to several experimenters, able to assimilate nitrogen when in the form of urea, uric and hippuric acids, and

several other amide bodies. The facility, however, with which ammonia, and other nitrogenous substances, are converted into nitric acid in the soil is so great that nitrates become by far the most important source of nitrogen at a plant's disposal.

Recent investigations have shown that in some cases the feeding power of roots is modified to a very considerable extent by their union with another vegetable organism. Thus, according to Frank, the absorption of food from the soil is in the case of oak, beech, hornbeam, hazel and chestnut, mainly accomplished through the medium of a fungus, the mycelium of which completely covers the root, and is united with it. A remarkable instance of such an action is afforded by leguminous plants. All the members of this family have tubercles on their roots, unless the plant has been grown from seed in a sterilised soil. These tubercles are occasioned by the invasion of an organism, present in the soil, the character of which has not yet been fully studied. When the seeds of peas, lupins or vetches, are sown in sterilised sand, containing the necessary ash constituents of plants, but no nitrogen, only a small, dwarfed growth is obtained, and the roots are not furnished with tubercles. If, however, a minute quantity of ordinary soil is added, tubercles appear on the roots, and the plant now grows vigorously. At the end of the experiment it is found that the quantity of nitrogen in the crop is far greater where tubercles have been formed than where they are absent: indeed, in the former case, the quantity of nitrogen in the crop and soil at harvest much exceeds that originally present in the sand, seed, and added soil. This gain of nitrogen has been derived from the free nitrogen of the atmosphere. These very remarkable results have been obtained by several independent investigators. They supply a much-needed explanation of the remarkable power of assimilating nitrogen possessed by leguminous plants.

Destination of the Ash Constituents.—The very weak solutions taken up by the roots are concentrated in the upper parts of the plant, the water being rapidly evaporated by the leaves, as already mentioned. The essential ash constituents are employed in the formation of new tissues. The non-essential ash constituents which have been taken up by the roots are partly disposed of in a solid form, as a permanent incrustation of the older tissues. The soluble salts which are not thus disposed of at first accumulate in the sap. They are finally more or less removed from straw, and probably from other old tissues, by the washing effect of rain.

The deposition of silica upon the external tissues of wheat, barley, and other graminaceous plants is a familiar example of the excretion of a non-essential ash constituent. Silica is also abundant in the old leaves, and in the outer bark of many trees, and is commonly found as an incrusting constituent of old tissues. Insoluble calcium salts, frequently the oxalate, are also deposited as incrusting matters in old tissues. These incrustations are indirectly of service to the plant, as they tend to harden the tissues, and thus protect them from injury.

Soluble non-essential ash constituents, as chloride of sodium, are found abundantly in the succulent parts of plants when such ash constituents have been present in the soil. They generally diminish in quantity as the plant matures, and are never stored up in the seed

Both the amount and composition of the ash of succulent plants, as meadow grass, clover, and mangel, are greatly influenced by the character of the soil, and the manure applied. The ash of a seed, on the other hand, is very constant in composition, the result of the selective power of the plant.

Of the particular action of the ash constituents within the plant little is known. Phosphoric acid and potash are undoubtedly the most important of the ash constituents; they are always found concentrated in those parts of the plant where cell growth is most active, as, for instance, in a growing bud, or in the layer (cambium) between the wood and bark of a tree; they are also abundantly stored up in the seed.

Silica being the most abundant ash constituent of wheat, barley, oats, and other graminaceous plants, was long supposed to be essential for their growth, and to be the ingredient on which the stiffness of their straw chiefly depended. It has been shown, however, that maize and oats may be successfully grown without any supply of silica, and with no perceptible difference as to the stiffness of the stem. The grass growing on peat bogs also contains scarcely any silica, though silica is abundant in ordinary hay. Silica may, however, discharge useful functions. In Wolff's experiments, although the presence of silica made little difference in the weight of the oat plant, it considerably increased the proportion of corn.

Germination.—A seed is constructed with the purpose of developing a young plant. It contains the "embryo," or germ, which is always extremely rich in albuminoids, fat, phosphates, and potash. It also contains a store of concentrated plant food, intended to nourish the young plant till its root and leaf are developed. In some seeds, as those of beans and turnips, this store of food is chiefly located in the "cotyledons," or rudimentary leaves; in other seeds, as those of the cereals, there is a reserve of food outside the embryo, in the "endosperm." In the seeds of the cereals, and of many other plants, the chief ingredient of the reserve matter is starch. Another class of seeds, of which linseed and mustard-seed are examples, contains no starch, but in its place a large quantity of fat.

For germination to take place, moisture, oxygen, and a suitable temperature are necessary. Under these conditions the seed swells, oxygen is absorbed, a part of the carbonaceous ingredients is oxidised, heat is developed, and carbonic acid evolved. During these changes the solid ingredients of the seed gradually become soluble. The starch and fat yield sugar. The albuminoids are converted into peptones and amides—as, for instance, asparagine. These changes are principally accomplished by the agency of ferments (enzymes) contained in the seed. With the soluble food thus formed the radicle and plumule are nourished. They rapidly increase in size, emerge through the coats of the seed, and, if the external conditions are suitable, soon commence their separate functions as root and leaf. The process of germination may be easily studied in the ordinary operation of malting barley.

Seeds buried too deeply in the soil may not germinate for lack of oxygen. Or if germination takes place the plumule may fail to reach the surface, the store of food in the seed being exhausted before the soil is penetrated and daylight reached. The smaller the seed the less should be the depth of earth with which it is covered.

Plant Development.—The development of the plant after germination follows a regular course. With an *annual*, which produces seed and dies during the first season, we have first a great development of root and leaf, which collect and prepare materials for growth; next comes the formation of a flower stem; and lastly, the production of flower and seed; after which the plant dies.

The materials furnished by the root preponderate in the young plant, which is always extremely rich in nitrogen and ash constituents; but as the plant matures the proportion of carbon compounds derived from the action of the leaves steadily increases. A cereal crop contains at the time of full bloom all the nitrogen and potash which is found in the mature crop; the assimilation of phosphoric acid continues somewhat later; the increase of carbon and silica proceeds as long as the plant is in a green state.

When seed formation begins an exhaustion of the other parts of the plant sets in; starch, albuminoids, phosphoric acid, and potash, are transferred from the root, leaf, and stem, and stored up in the seed. If the season is a good one, and the development of the seed fully accomplished, the straw of a cereal crop will be found at harvest to be very thoroughly exhausted; while in seasons of limited production, or deficient maturity of grain, the straw will retain far more of the materials acquired during growth. For the same reason straw cut while the crop is still green is far more nutritive than when perfect ripeness has been attained.

With a *biennial* or *perennial* crop the case is somewhat different. The first development of root and leaf is the same as in an annual; but towards the end of summer there is a storing up of concentrated plant food in the root, tuber, or stem, to serve for the commencement of growth in the following spring. In a biennial root crop, the turnip for instance, the root attains a great size in autumn, the leaves dying after transferring to the root their most important constituents. The next season the root throws up a flower stem, and the store of matter accumulated during the preceding autumn is consumed in the production of seed. With the production of seed the root is exhausted, and the plant dies.

In trees plant food is stored up at the end of summer in the pith, the pith rays, and in the layer between the wood and bark. The leaves which fall in autumn have lost nearly all their starch, albuminoids, phosphoric acid and potash, these having been transferred to the stem. By the action of the sun in spring-time the new buds swell, the sap rises, the starch and other matters deposited in the wood during the previous autumn are re-dissolved, and employed for the production of new growths. The sugar found in maple sap in spring-time results from the transformation of starch stored up in the preceding autumn.

CHAPTER II.

THE ATMOSPHERE AND SOIL.

The Atmosphere.—Its composition—The carbonic acid, ammonia, and nitric acid which it supplies—The quantity of combined nitrogen, chlorides, and sulphuric acid contained in rain. *The Soil.*—Its constituents—Properties of sand, clay, calcareous matter, and humus—The relation of soil to water—Its relation to heat—The plant food contained in soil, its quantity and condition—Oxidation in the soil, nitrification—Movements of salts in soil, losses by drainage—The absorptive power of soils—Influence of tillage, and draining—Soil burning.

The Atmosphere.—One hundred volumes of air contain nearly 79 of *nitrogen,* and 21 of *oxygen,* with very small quantities of other constituents.

The free nitrogen of the atmosphere is apparently made available to leguminous crops through their root tubercles (p. 10); there is no satisfactory evidence that it serves as a plant food to other crops.

We have already stated that the whole of the carbon of plants is obtained from the *carbonic acid* present in the atmosphere: 10,000 volumes of air contain nearly 3 volumes of carbonic acid, or about 1 lb. in 3,200 cubic yards of air. An acre of a good wheat crop will obtain from the atmosphere in four months 1 ton of carbon, a quantity corresponding to a column of air 3 miles in height. The small amount of carbonic acid in the atmosphere is made sufficient by the action of winds, which bring an enormous quantity of air in contact with both soil and plant.

The atmosphere also contains a very small and variable quantity of *ammonia*. Schlœsing found near Paris an average of 1 lb. of ammonia in 26,000,000 cubic yards of air. Müntz and Aubin found at the top of the Pic du Midi 1 lb. of ammonia in 44,000,000 cubic yards. According to Schlœsing the quantity is greatest in warm southerly winds. The ammonia of the air is directly absorbed by plants to a small extent; it is chiefly rendered available through absorption by the soil, and by means of rain, which brings it in solution to the earth.

The atmosphere also furnishes a small amount of *nitrous* and *nitric acid.* The nitrogen and oxygen of the atmosphere combine under the influence of electric discharges, nitrous acid being formed; this is converted into nitric acid by the action of ozone, or peroxide of hydrogen. Nitric acid may also be formed in the atmosphere by the oxidation of ammonia by ozone and peroxide of hydrogen.

The amount of nitrogen in the form of ammonia and nitric acid annually carried to the soil by *rain,* varies in different years and places. At Rothamsted, in Hertfordshire, the amount of nitrogen as ammonia in the rain, mean of five years, is 2·4 lbs. per acre; the nitrogen as nitrates and nitrites about 1 lb.; the organic nitrogen a similar quantity. The *total nitrogen* is thus about 4·4 lbs. per acre.* The average of many experiments on the continent (excluding Paris) gives 10·18 lbs. of nitrogen per acre. The continental average is above the truth for the open country, many of the determinations having been

* The quantities here given are those obtained in recent experiments with improved methods. The rain includes the snow, hail and dew deposited on the rain gauge.

made near towns. In tropical rain the proportion of nitrogen as nitrates is generally considerably increased.

Chlorides are always present in rain, especially in the neighbourhood of the sea. At Lincoln, New Zealand, the chlorides in the rain are equal, on an average, to about 88 lbs. of common salt per acre per annum; at Cirencester they amount to about 40 lbs.; at Rothamsted the quantity is about 24 lbs.

The *sulphates* found in rain at Rothamsted, mean of five years, correspond to about 17 lbs. of sulphuric anhydride per acre, yearly.

The quantity of chlorides in the rain at Rothamsted is apparently sufficient for the crops on the farm, mangels possibly excepted. The sulphates will also to a considerable extent meet the demands of most cultivated crops.

The Soil: 1. *Constituents.*—All soils have been produced by the disintegration of rocks, through the prolonged action of water, air, and frost. The character of a soil largely depends on the character of the rock from which it has been derived. Primitive and igneous rocks yield soils rich in potash; fossiliferous rocks produce soils rich in phosphoric acid. The principal ingredients of soils are sand, clay, carbonate of calcium, and humus; as each of these preponderate the soil is said to be sandy, clayey, calcareous, or peaty.

Sand is either composed of pure quartz (silica), or consists of fragments of more complex minerals—mica, for example. When the former is the case, the sand will supply no plant food; but in the latter case the gradual decomposition of the mineral will slowly increase the ash constituents available for the plant.

Clay is a hydrated silicate of aluminium, produced by the decomposition of felspar and other silicates. Pure clay is a colloid body; the amount present in any soil is extremely small. The purest natural clays are mainly composed of a very fine sand, which has the same general composition as the true clay associated with it. Pure clay is a powerful cement, causing the coarser particles of the soil to cohere. A pure silicate of aluminium would furnish no food to a plant; clay always, however, contains some potash, and frequently a notable quantity. It has also the important property of absorbing and retaining phosphoric acid, ammonia, potash, lime, and other substances necessary for plant nutrition.

Carbonate of calcium is beneficial to the soil in many ways. It preserves the clay in a coagulated condition, thus making heavy soils friable and pervious to water. It enables clay to exercise its absorbent power on various salts, which would otherwise escape its action. It also promotes the decomposition of vegetable matter, and the formation of nitrates in the soil. The presence of some salifiable base is essential for the performance of the chemical operations belonging to a fertile soil; the salifiable bases usually present are either carbonate of calcium, or the alkalis derived from the decomposition of silicates. The calcareous matter of soil supplies lime to the plant; limestone also generally contains phosphoric acid.

The *humus*, or decayed vegetable matter of soils, has its origin in the dead roots and leaves of a previous vegetation, or of a previous organic manuring. It acts effectively as a cement in sandy soils, holding the particles together; in a clay soil it increases the porosity. Humus is the principal nitrogenous ingredient of soils. A black soil, rich in humus, is sure to be also rich in nitrogen; a soil destitute of humus will contain scarcely any nitrogen. The fertility of virgin soils is largely due to the nitrogenous humus which they contain. Humus appears to possess in part an amide nature; it yields ammonia and soluble nitrogenous bodies when acted on by acids or alkalis, and probably, to a much less extent, under the action of water.

2. *Relation to Water.*—The power of absorbing water from damp air known as *hygroscopicity,* is scarcely at all possessed by sand, but to a greater degree by clay and humus. Schlœsing found that while dry siliceous sand absorbed nothing, a strong clay absorbed 3·5 per cent., and a garden soil 5·2 per cent. Water thus absorbed is insensible, and can have little direct influence in plant nutrition. All soils condense water from the atmosphere when their temperature is below the dew point.

Sand has the least, and humus the greatest capacity for *retaining water.* Schlœsing found that fine sand, saturated with water, and thoroughly drained, retained 7 per cent.; a clay soil 35 per cent.; and a forest soil 42 per cent. Light sandy soils thus suffer most from drought, while applications of farmyard manure, or the ploughing in of green crops, increase the water-holding power of a soil by increasing the proportion of humus.

Capillary attraction, by which water is raised from the subsoil to the surface in dry weather, depends on the distance between the particles of the soil; it is least in open sandy soils composed of coarse particles, and greatest in the case of loam or clay.

Evaporation is greatest when the soil is occupied by a crop, and will be in proportion to the activity of its growth and the extent of its root development. On uncropped soil evaporation is greatest when the soil is consolidated, and the conditions are consequently favourable to capillary action. The presence of stones on the surface tends to diminish evaporation. Evaporation is least when the surface soil has been broken up by tillage, as the subsoil water cannot then reach the surface by capillary attraction. The amount of water draining through a soil depends on the amount of the evaporation, and is most simply expressed as equal to the rainfall, minus the quantity evaporated.

3. *Relation to Heat.*—A soil shaded by a crop is far cooler than a bare soil. Dark-coloured soils absorb the greatest amount of heat from the sun's rays, and light-coloured soils least. The presence of humus is thus favourable to soil warmth. Quartz sand is an excellent conductor of heat; chalk is a bad conductor. A soil rich in sand will thus be warmed or cooled more rapidly, and to a greater depth, than a soil containing but little sand. Water has a very considerable effect in cooling a soil, partly from its high specific heat, and partly from the immense consumption of heat during its evaporation. During spring and summer a wet soil is always colder than a dry one. The drainage of wet land will thus result in a greater warmth of the surface soil, and consequently an earlier growth in spring.

4. *Plant Food in Soil.*—The proportion of plant food present in soils is very small, even when the soil is ex-

tremely fertile. The surface soil (first nine inches) of a pasture may contain when dry 0·25 of nitrogen per cent., while soil of the same depth from an arable field may yield 0·10—0·15 per cent., and a clay subsoil 0·05 per cent. A good surface soil may contain 0·20 per cent. of phosphoric acid, or not unfrequently a smaller quantity. Potash varies much, rising to 1·0 per cent. or more in some clay soils, but being generally much smaller.

The weight of soil on an acre of land is, however, so enormous, that small proportions of plant food may amount to very considerable quantities. Nine inches' depth of arable soil (clay or loam) will weigh, when perfectly dry, about 3,000,000 or 3,500,000 lbs. A pasture soil will be lighter, the first nine inches weighing when dried and the roots removed about 2,250,000 lbs. Supposing, therefore, a dry soil to contain 0·10 per cent. of nitrogen, phosphoric acid, or potash, the quantity in nine inches of soil will be from 2,250 lbs. to 3,500 lbs. per acre.

A large part of the elements of plant food contained in soils is present in such a condition that plants are unable to make use of it. An acre of soil may contain many thousand pounds of phosphoric acid or of nitrogen, and yet be in a poor condition; while a dressing supplying 50 lbs. of readily available phosphoric acid, or nitrogen, in the form of superphosphate or nitrate of sodium, may greatly increase its productiveness.

The fragments of silicates or limestone present in soil, as stones, gravel, and sand, are as a rule of little value to a plant, the elements of plant food which they contain being mostly in too insoluble a condition to be attacked by the roots. These fragments of rock may, however, be slowly decomposed by the mechanical action of frost, and by the chemical action of water, and their contents thus gradually made available to the plant. The solvent power of the water in a soil is greatly increased by the carbonic acid, and perhaps also by the humic acids it holds in solution. Water containing carbonate of calcium in solution is especially capable of attacking silicates.

The chemical analysis of a soil, though always of great value, does not enable us to fix its degree of fertility owing to the imperfect information it affords as to the condition of the plant food.

5. *Oxidation in Soil.*—The materials from which the nitrogen of soils is originally derived contain generally a large proportion of carbon. In the roots and stubble of cereal crops the relation of nitrogen to carbon is 1 : 43; in those of leguminous crops 1 : 23; in moderately-rotted farmyard manure about 1 : 18. In the soil these materials are oxidised, chiefly by the action of various living organisms (insects, worms, fungi, bacteria), large quantities of carbonic acid being produced. As a result of this loss of carbon, we find that the surface soil of a pasture (roots removed) will contain about 1 of nitrogen to 13 of carbon; the surface soil of an arable field about 1 : 10; and a clay subsoil 1 : 6.

The nitrogen contained in humus is not in a condition to serve as a general plant food; cereal crops are apparently unable to appropriate it; some crops may, however, possibly assimilate some humic matters. For the nitrogenous matter of humus to become available to crops it must be further oxidised; this is accomplished by certain bacteria in the soil, carbonic acid, ammonia, and finally nitric acid being produced. The nitrifying bacterium occurs abundantly in the surface soil; the depth to which its action extends depends on the porosity of the subsoil. Nitrification only takes place in a moist soil, sufficiently porous to admit air. It is also necessary that some base should be present with which the nitric acid may combine: this condition is usually fulfilled by the presence of carbonate of calcium, nitrate of calcium being produced. Nitrification is most active at summer temperatures; it ceases apparently near the freezing-point.

Oxidation is most active in soils under tillage. In arable land the production of available plant food is at its maximum, and so is also the waste by drainage. The nitrogenous humic matter of arable land is maintained only when the new supply from crop residues and organic manures is equal to the amount annually oxidised. In an untilled pasture or forest soil, on the other hand, a considerable accumulation of organic matter may take place, the annual residue of dead roots and leaves being generally in excess of the means of oxidation. In a peat bog oxidation is further checked by a high water level, which excludes air from the soil; here an unlimited accumulation of organic matter may take place if plants capable of growing under the circumstances are present.

6. *Movements of Salts in Soil.*—If water is allowed to drain through a soil it carries with it a part of the readily soluble matter which the soil contains. The substances chiefly removed by the water will be carbonate of calcium, and the nitrates, chlorides, and sulphates of calcium and sodium. When heavy rain falls these substances are washed into the subsoil, and partly escape by the nearest outfall into the springs, brooks, and rivers.

The loss of nitrates from highly manured land during a wet season is very considerable, and will frequently be equal to several hundred pounds of nitrate of sodium per acre. When dry weather sets in evaporation takes place at the surface of the soil, the water of the subsoil is slowly brought again to the surface by capillary attraction, and the salts it contains are concentrated once more in the upper soil, forming in some rare instances a white crust of salt upon the surface. Capillary attraction has little influence in the case of sandy soils.

Besides the rapid movements of salts due to a movement of the water in the soil, they have also a slow movement due to their molecular diffusive power, by which their particles continually pass from a stronger solution to one weaker. This movement is always in action in moist soil, and tends to the equal distribution of all soluble matter. If a dressing of nitrate or chloride of sodium is applied to moist soil, the manure will dissolve and slowly spread downwards, even before rain falls. Again, when a heavy rain has washed all soluble salts out of the surface soil, they will slowly rise again by diffusion as soon as rain ceases.

Of the soluble and diffusible salts occurring in soil the nitrates are of the greatest importance as plant food. The quantity of nitrates in a surface soil will vary greatly, depending on the richness of the soil in nitrogen, the previous conditions as to temperature and moisture, the extent of recent washing by rain, and on whether the soil is or is not under crop. Where a crop is growing the nitrates will be kept nearer the surface, the evaporation of water from a growing crop being far greater than from a bare soil. The nitrates will also be constantly taken up by the roots and employed as plant food. The loss of nitrates by drainage is thus far less when the land is under crop than in the case of a bare fallow.

7. *Absorptive-Power of Soil.*—The surface of a moist fertile soil is capable of absorbing ammonia from the atmosphere. This absorption may proceed continuously if the ammonia absorbed is continuously converted into a nitrate. The amount that may be so absorbed may apparently become considerable when the soil is in a suitable condition as to porosity, and as to its capacity for effecting nitrification. Whether free nitrogen is ever brought into combination by any of the constituents of soil is at present a disputed point.

If a solution containing phosphoric acid, potash, or ammonia is poured on a sufficiently large quantity of fertile soil, the water which filters through will be found destitute of these substances. This retentive power of soil for phosphoric acid, potash, &c., is of the utmost importance in agriculture. The action is a complex one. All salts are doubtless retained to some extent by soil through mere mechanical adhesion; salts, thus feebly retained, as nitrates and chlorides, can be easily removed by washing with water. Other substances are, on the contrary, retained by chemical affinity; these are not removed by washing, or but to a small extent. The ingredients of the soil which exercise a chemical retentive power, are the hydrates of ferric oxide and alumina, the hydrous silicates of aluminium, and humus.

Ferric oxide is a common ingredient of soils; to it the red colour of many soils is owing. To the presence of ferric oxide the retention of phosphoric acid is chiefly due, an insoluble basic phosphate of iron being produced. Alumina acts in the same manner. Ferric oxide and alumina have also a retentive power for ammonia and potash, but the compounds formed are more or less decomposed by water. To the hydrous silicates the permanent retention of potash and other bases is probably chiefly due. Humus has a great absorbent power for ammonia. Other bases, as magnesia and lime, are also retained by soil, but in a less powerful manner than are potash and ammonia.

Soils destitute of carbonate of calcium retain very little potash or ammonia when these are applied as salts of powerful acids, as for instance as chlorides, nitrates, or sulphates. When carbonate of calcium is present the potassium or ammonium salt is decomposed, the base is retained by the soil, while the acid escapes into the drainage-water united with calcium. The addition of marl, chalk or lime may thus greatly increase the retentive power of a soil for bases.

The fertility of a soil is nearly connected with its power of retaining plant food. In the case of a soil containing clay, only traces of phosphoric acid, ammonia, or potash are ever found in the drainage-waters. Sandy soils, from their smaller chemical retentive power and free drainage, are of less natural fertility, and dependent on immediate supplies of manure.

There can be little doubt that the active plant food contained in soil, which is capable of being taken up by roots, exists either in solution, or in the states of combination just referred to—that is, in union with ferric oxide, hydrous silicates, and humus. Different crops have very different powers of attacking these various forms of plant food.

8. *Tillage and Draining.*—The operations of tillage and draining serve in many important ways to increase the amount of plant food which is at the disposal of a crop; some of these have been already noticed.

By tillage, and the action of frost, the surface soil is pulverised, and brought into an open porous condition, favourable both for the distribution and action of roots. As the absorbent power of roots resides entirely in the root-hairs, a finely divided condition of the soil is essential for the rapid development of a plant. Capillary attraction is diminished by tillage, and the land consequently suffers less from drought; the amount of drainage is at the same time increased. By the destruction of weeds the whole of the plant food is left available for the crop. Another important result of tillage is that the soil is thoroughly exposed to the influence of the air. Soils containing humus or clay will absorb some ammonia from the atmosphere, and thus increase their store of nitrogen. The oxidation of the nitrogenous organic matter of the soil, and the production of nitric acid, have been already noticed, as also the disintegration and solution of the particles of rock contained in soil. Of the various results brought about by tillage, the increased production of nitrates must be ranked among the most important.

By means of pipe-drainage the various chemical actions just mentioned are carried down to a greater or less extent into the subsoil, for, as the water level is lowered, the air enters from above to fill the cavities in the soil. By draining the depth to which roots will penetrate is also increased, for roots will not grow in the absence of oxygen, and rot as soon as they reach a permanent water level. In a water-logged soil deoxidation is active, the nitrates present are destroyed, a part of the nitrogen being evolved as gas; the soil may thus suffer a considerable loss of plant food.

Natural drainage in stiff soils is effected by original fissures, by cracks produced in dry weather, and especially by channels left on the decay of deeply-rooted crops, and by worms. The porosity of stiff soils is largely increased by the two agencies last named.

9. *Burning.*—Burning is occasionally resorted to as a means of increasing the available plant food, and improving the texture of a heavy soil. The soil is burnt in heaps, which are then spread over the land. If the soil contains limestone, it is easy to see that the phosphates of the limestone may become more available by the complete disintegration which attends the conversion into lime. The lime will also attack the silicates of the soil at a high temperature, and liberate a part of the potash from its insoluble combinations. To produce the best results it is essential that the burning should take place at a low temperature. This treatment by burning is a very extreme one, and can be recommended only in few cases; it must always be attended with an entire loss of the nitrogen in the soil burnt. The ploughing in of burnt clay is of use in improving the texture of heavy land.

CHAPTER III.

MANURES.

Difference between natural vegetation and agriculture—Necessity for manuring. *Farmyard Manure.*—Circumstances which influence its character—Losses in preparation—Changes during fermentation—Its average composition—Slowness of its effect—*Seaweed—Guano—Fish Manure—Sulphate of Ammonium—Nitrate of Sodium—Soot, Dried Blood, Powdered Horn, and Woollen Refuse—Meat Meal, Meat Guano—Bones—Oilcakes—Phosphatic Slag and ground Phosphates—Superphosphate—Gypsum—Lime, Chalk, and Marl—Potassium Salts—Common Salt—Application of Manures.*—Importance of thorough distribution—Best time for application. *Return for Manure Applied.*—Increase from nitrogenous manures—Effect of residues of previous manuring.

In the natural vegetation of a forest or prairie the soil suffers no diminution of plant food. The elements taken from the soil are returned to it on the decay of the plants which the soil has nourished, or on the death of the animals which have fed on these plants. Under these circumstances the surface soil becomes rich in carbon and nitrogen, the quantity contributed by the atmosphere at first exceeding, and then balancing, all losses. The surface soil also becomes rich in the ash constituents of plants, these being collected from the subsoil by the roots, and left at the surface on the decay of the plant. A virgin soil thus generally contains an abundance of plant food, and will produce large crops without manure.

As soon as land is brought under the plough the oxidation of the organic matter previously accumulated commences. The vegetable and animal produce of the land are also now consumed off the soil which has reared them. Provision must consequently be made, sooner or later, to return to the land a part at least of the plant food removed from it, if permanent fertility is to be maintained. Hence the necessity for manuring.

The most complete return to the land would be accomplished by manuring it with the excrements of the men and animals consuming the crops. This is partially done by the application of farmyard manure; but the congregation of men in cities, and the difficulty of employing sewage with profit, prevent this plan being thoroughly carried out. The farmer is thus generally obliged to purchase manures for the land in exchange for the crops and stock sold off it.

On very poor soils it is necessary to make a very complete return of all the elements of plant food removed by the crops, but in most soils there is an abundance of some one or more of these elements, and a partial manuring will consequently suffice. With high farming the contributions to the soil may be in excess of the exports, and the land consequently increase in fertility. The nature of the exhaustion resulting from the growth of particular crops, and the economic application of manure to meet their special requirements, will be considered in Chapter IV.; the losses during a rotation of crops in Chapter V.; the losses by the sale of animal products in Chapter VI.

Farmyard Manure consists of the liquid and solid excrements of the farm stock, plus the litter employed. Its composition will vary according to the character of the animals contributing to it, the quality of their food, and the nature and proportion of the litter. This part of the subject will be discussed in Chapter IX.

The treatment of the manure is most important. A large proportion of the nitrogen is voided in the form of urine, and generally the richer the diet the higher will this proportion be. If, therefore, the liquid manure is lost, or the solid matter is washed by rain, and the washings are allowed to drain away, serious losses of nitrogen and potash will occur. Hence the superiority of box manure to that made in an open yard.

It must also be recollected that the urea, which forms the chief nitrogenous ingredient of urine, is speedily changed by fermentation into carbonate of ammonium, and as this is a volatile substance a considerable loss of nitrogen will easily occur. This loss takes place chiefly in the first few days, while the manure is in the stall; it is greatest with animals yielding a concentrated urine, as horses and sheep. The loss may be diminished by a liberal use of litter, and especially by using peat, spent tan, sawdust, or peat moss instead of straw. The addition of earth (not sand or chalk) to straw increases its power of retaining ammonia. Sprinkling powdered gypsum also diminishes the loss of ammonia. The ammonia present in fresh manure gradually disappears, apparently combining with the organic substances arising from the decomposition of the litter.

Farmyard manure rapidly undergoes fermentation. If placed in a heap the mass gets sensibly hot, and a large quantity of carbonic acid, and some marsh gas, are given off. Fermentation is most active when the manure lies loosely, more air then coming in contact with it; it is least active when the manure heap is consolidated. When fermentation occurs in consolidated, moist manure, in a place protected from rain, a considerable part of the carbonaceous matter is destroyed, but little loss of nitrogen takes place; if, however, the manure gets dry and mould appears, a serious loss of free nitrogen may occur. Rotten manure, when well made, is more concentrated than the fresh, having greatly diminished in weight during fermentation, with but little loss of valuable constituents. Some of the constituents have also become more soluble. Manure heaps in the open field should be protected from waste by covering them with a layer of earth 6 inches thick.

Farmyard manure will contain from 65 to 80 per cent. of water. The nitrogen may be 0·40 to 0·65 per cent., or higher, if produced by highly fed animals, or with peat moss litter. The ash constituents will be 2·5 to 3 per cent., exclusive of the sand and earth always present. Of these ash constituents 0·4 to 0·7 will be potash; and 0·2 to 0·4 phosphoric acid. One ton of farmyard manure will thus supply 9—15 lbs. of nitrogen, a similar amount of potash, and 4—9 lbs. of phosphoric acid.

Farmyard manure is a "general" manure; that is, it supplies all the essential elements of plant food. The immediate return from an application of farmyard manure is much less than from the same amount of plant food applied in artificial manures. The effect of farmyard manure is spread over a considerable number of years, its nitrogen being chiefly present not as ammonia but in the form of carbonaceous compounds, which decompose but slowly in the soil.

Farmyard manure improves the physical condition of the soil, by increasing the proportion of humus present.

Seaweed.—This manure when fresh is, on the whole, similar in value to farmyard manure. It becomes more valuable as it loses water.

Guano.—This manure consists chiefly of the dried excrements of sea fowl. When guano has been deposited in the absence of rain it contains a large amount both of nitrogenous matter and phosphates. If exposed to rain the original nitrogenous matter is decomposed, and the nitrogen volatilised in the form of carbonate of ammonium; the guano remaining is then almost purely phosphatic. Ichaboe guano, for example, is a recent deposit, containing about 12 per cent. of nitrogen, and 10 per cent. of phosphoric acid; while Arbrohlos guano is a phosphatic guano, containing 1 per cent. of nitrogen, and 33 per cent. of phosphoric acid. The largest deposits of guano are on the Peruvian coast and the adjacent islands. The present imports contain 4—8 per cent. of nitrogen, 14—23 per cent. of phosphoric acid, and 2—4 per cent. of potash. From its great variation in composition guano should always be purchased on analysis.

In a nitrogenous guano the nitrogen is chiefly present as uric acid, and as ammonium salts. The strong smell of a damp guano is due to carbonate of ammonium. The phosphoric acid exists principally in the form of phosphate of calcium, but in nitrogenous guanos a small part exists as phosphate of ammonium, a salt readily soluble in water.

Damp Peruvian guano is sometimes treated with a small proportion of sulphuric acid, it is then called "*Dissolved guano.*" Such guano contains no volatile carbonate of ammonium, and nearly the whole of the phosphates has become soluble in water.

Nitrogenous guano is a highly concentrated manure, and may be employed with excellent effect for corn crops, potatos, and roots. Phosphatic guanos may be employed for turnips, but such guanos are more usually converted into superphosphate before they are applied to the land.

Fish Manure.—This consists of fish refuse dried and powdered. It contains usually 7—8·5 per cent of nitrogen. That made from cod contains 13-14 per cent of phosphoric acid as phosphate of calcium, and that made from haddock and herring 6—9 per cent. If much oil is present the value is diminished, as the manure decomposes more slowly in the soil.

Sulphate of Ammonium.—This substance is prepared from the ammoniacal products of gas works, coke ovens, bone distilleries, &c. In its crystallised form it is the most highly nitrogenous of all the manures at a farmer's disposal, containing 24—25 per cent. of ammonia, or 19·8—20·6 per cent. of nitrogen.

It should be ascertained that the manure is free from sulphocyanate of ammonium, as this substance is very injurious to plants. If sulphocyanates are present, a solution of the salt will become blood-red on the addition of ferric chloride.

Sulphate of ammonium is a "special" manure, valuable solely for its nitrogen. It is a powerful manure for corn crops, for which it is best employed in conjunction with superphosphate. Admixture with phosphates and potassium salts is more necessary for obtaining a profitable result with ammonium salts than it is when nitrate of sodium is employed.

The ammonia is converted into nitrates in a few days or weeks after the application of the salt to a moist, fertile soil. The use of sulphate of ammonium is attended with some loss of lime to the soil, as both the sulphuric acid, and the nitric acid subsequently formed, unite with the lime of the soil, and the resulting salts are more or less removed by drainage. Ammonium salts produce little effect in soils destitute of lime.

Nitrate of Sodium.—An enormous deposit of the crude salt, containing much chloride of sodium, is found in Peru. The nitrate sent to this country has been purified by crystallisation; it contains 95—96 per cent. of real nitrate, or 15·6—15·8 per cent. of nitrogen. The most usual impurity is common salt.

This manure, like the preceding, is valuable solely for its nitrogen. It is an excellent manure for all crops requiring artificial supplies of nitrogen, especially corn crops and mangels. For corn crops it is best employed together with superphosphate. Nitrate of sodium should not be mixed with a damp superphosphate, else nitric acid will be lost on keeping. The two manures may be mixed immediately before use; or the superphosphate may be sown with the corn, and the nitrate applied afterwards as a top dressing.

The return from the use of nitrate of sodium is generally greater than from the use of the same quantity of nitrogen as sulphate of ammonium. The nitrate is especially better in dry seasons; in wet seasons the ammonium salt sometimes has the advantage.

Nitrate of sodium is especially suited for clay land. The soda which it leaves in the soil apparently helps to render the potash and phosphates in the soil available to crops. It is quicker in its action than any other nitro genous manure, and is therefore the best manure to employ when a late dressing has to be given.

Soot, Dried Blood, Powdered Horn, and Woollen Refuse are all purely nitrogenous manures. *Soot* owes its value to the presence of a small and variable quantity of ammonium salts. In good house soot the nitrogen may be 3·5 per cent. *Dried blood* is an excellent manure, containing 9—12 per cent. of nitrogen. *Hoofs and horns* are extremely rich in nitrogen, the proportion being usually 15 per cent. *Shoddy*, and other forms of wool, are very variable in composition, owing to the different proportions of water, cotton, dirt, and grease which they contain; the nitrogen will generally range from 5 to 8 per cent.

The nitrogen of blood, horn, wool, and hair is not in a form suitable as plant food. Blood readily decomposes in the soil, yielding first ammonia, and then nitric acid. Horn, wool, and hair decompose much more slowly, and their effect is spread over many years.

Soot is generally employed as a top dressing for spring corn. Dried blood is an excellent manure for wheat. Wool and hair are chiefly used for hops.

Meat Meal, Meat Guano.—This is the residue from the manufacture of meat extract. It varies in composition according to the amount of bone ground up with the meat fibre. The nitrogenous kinds contain 11—13 per cent. of nitrogen, and 0·6—3·0 per cent. of phosphoric acid. The phosphatic kinds contain 6—7 per cent. nitrogen, and 14—17 per cent. phosphoric acid.

Bones.—These are largely employed as manure; the fat is usually first extracted by steaming. Commercial bones contain about 3·6 per cent. of nitrogen, and 23 per cent. of phosphoric acid, existing as phosphate of calcium. Bones that have been boiled to extract the gelatin contain about 1·4 per cent. of nitrogen, and 29 per cent. of phosphoric acid.

Bones decompose but slowly in the soil, especially on heavy land; their effect is thus spread over several years. The finer the bones have been ground the more immediate is their effect. Bones are usually employed for pasture, and for turnips.

Oilcakes.—Cakes of little or no value for feeding purposes are used when ground as manure; their value is considerable, as they contain a good deal of nitrogen, with phosphates and potash. See p. 139.

Phosphatic Slag, and Ground Phosphates.—Some phosphates when finely ground may be successfully employed as manure without previous conversion into superphosphate. The phosphates most suitable for this purpose are Thomas' slag, phosphatic guanos and bone-ash. *Phosphatic slag* contains generally 15—20 per cent. of phosphoric acid; it is now employed in enormous quantities. The soils most suitable for such manures are those rich in humus, and poor in carbonate of calcium; these being the conditions (presence of humic and free carbonic acid) most favourable to the solution of phosphate of calcium. Moorland and pasture soils are especially suitable for such treatment. Thomas' slag is an effective manure for swedes and early turnips. Undissolved phosphates must be employed in extremely fine powder.

Superphosphate.—An abundance of mineral phosphates (phosphates of calcium) occur in nature; many of these are so little soluble that their effect as manure is but slight; by treating them with sulphuric acid (sp. gr. 1·55) the sparingly soluble tricalcic phosphate is converted into phosphoric acid, or into soluble monocalcic phosphate, sulphate of calcium being at the same time produced. Superphosphate is thus a mixture of phosphoric acid and monocalcic phosphate, with gypsum, and various impurities (as sand, and compounds of iron and aluminium), derived from the original mineral. A superphosphate will generally contain more or less of undissolved phosphate; this amount will be more considerable if the manure is badly made.

The value of a superphosphate chiefly depends on the percentage of "*soluble phosphate*" present. By this term analysts do not mean monocalcic phosphate, but the quantity of tricalcic phosphate rendered soluble.

Besides the soluble phosphate, and the undissolved phosphate, a superphosphate will frequently contain what is known as "*reduced phosphate*,"—that is, phosphate which was once soluble but has now lost this character. The diminution of soluble phosphate during the storing of superphosphates chiefly occurs when the manure has been made from materials containing ferric oxide and alumina, and is due to the formation of ferric and aluminic phosphate. The proportion of reduced phosphate present in a superphosphate is estimated from its insolubility in water, but solubility in a solution of citrate of ammonium. Reduced phosphate has an agricultural value between soluble and undissolved phosphate.

The best mineral phosphate found in England is Cambridge coprolite. This is not at present much used, cheaper phosphates being imported. Immense quantities of mineral phosphates are imported from South Carolina, Belgium, Spain, and Canada, besides considerable quantities of phosphatic guano.

The superphosphates richest in soluble phosphate (40 to 45 per cent.) are prepared from phosphatic guanos. Bone ash, and some phosphorites, also yield high quality manures. The great bulk of our superphosphates is at present prepared from Carolina phosphate; such manure will contain 23 to 27 per cent. of soluble phosphate.

Superphosphates form the basis of almost all manufactured manures. By using bones, or ground horn, or by adding shoddy or crude ammonium salts, *turnip manures* are produced containing a small amount of nitrogen. By mixing with the superphosphate a larger amount of ammonium salts, and in some cases potassium salts, the articles sold as *corn, grass, mangel,* and *potato manures* are prepared. Superphosphate made largely from bones is known as *dissolved bones.*

When superphosphate is applied to a soil containing carbonate of calcium the soluble phosphate is speedily precipitated, but in a form easily taken up by the roots of plants. In most cases the phosphoric acid is finally converted into basic phosphate of iron, a substance less easily assimilated by the roots; fresh applications of phosphates are thus more effective than the residues of previous manuring.

Superphosphates are naturally more speedy in their effect than manures consisting of undissolved phosphate. A small quantity of phosphoric acid applied as superphosphate will generally have as great immediate effect as a considerable quantity applied as bones or ground phosphate.

Superphosphate is chiefly employed for turnips, for which it is invaluable; it is also of considerable use for corn crops, especially barley. Its use tends to early maturity in the crop.

Gypsum.—This manure consists of sulphate of calcium; it is of very limited value. Gypsum is most suitable for crops, such as clover and turnips, which require a considerable amount of sulphur. As superphosphate always contains much gypsum special applications of gypsum will be unnecessary where superphosphate is employed. Finely-powdered gypsum is sometimes employed in stables to hinder the volatilisation of ammonium carbonate. Crude potassium salts act in the same manner, owing to the magnesium salts which they contain.

Lime, Chalk, and Marl are frequently manures of the greatest importance. On soils naturally destitute of lime, as is the case with many clays and sandstones, these manures will supply an indispensable element of plant food. Some marls will also supply a notable quantity of phosphoric acid. In most cases, however, the beneficial influence of these manures is due to the chemical actions which lime performs in the soil; the chief of these have been already glanced at (see p. 19).

Burnt lime is much more powerful in its action on vegetable matter than chalk or marl; it should be used with discrimination, lest the humus of the soil be unduly diminished. Heavy clays, or soils rich in humus, are those most benefited by burnt lime. In reclaiming peat bogs lime is of the highest value. The acid humic matter of the peat is neutralised by the lime, and the conditions thus made suitable for the oxidation of the nitrogenous organic matter and the production of ammonia and nitrates.

The general effect of lime is to render available the plant food already in the soil, without itself supplying any significant amount; liming cannot, therefore, be successfully repeated except at considerable intervals.

Potassium Salts.—These salts are now obtained from Stassfurt and Leopoldshall in large quantities; they form a thick deposit overlying an enormous mass of rock salt. The commonest potassium salt employed as manure is *kainite*; it consists of chloride of potassium, sulphate of magnesium, and water, with the chlorides of sodium and magnesium in addition. Kainite will contain about 13 per cent. of potash.

Wood ashes may also be employed as a potash manure; they will contain between 5 and 10 per cent. of potash. The ash of young boughs is richer than that from full-sized timber.

Potash manures produce their greatest effect on pasture; clover, potatos, and root crops may also be benefited by their use. Many soils, especially clay soils, are naturally well furnished with potash; on these soils potash manures are almost without effect.

Common Salt.—Chloride of sodium supplies no essential ingredient of plant food. Salt is commonly used for mixing with nitrate of sodium, and as a manure for mangels. The little value which it possesses is probably due to its action in the soil, where it may help to set free more important constituents.

Application of Manures.—A manure can be efficacious only when its constituents are brought into contact with the roots of the crop. To obtain this contact to the fullest extent the manure must be thoroughly and evenly distributed throughout the depth of soil mainly occupied by the roots. Soluble manures—as nitrate of sodium, chloride of sodium, ammonium salts, potassium salts, and superphosphate—have the great advantage that they distribute themselves within the soil after the first heavy shower far more perfectly than can be done by any mode of sowing. Whenever possible, manure should be reduced to a fine powder before application. Artificial manures, if distributed by hand, should first be made up to a considerable bulk by mixing with fine dry soil or ashes. Manures containing ammonia must not be mixed with alkaline ashes or with Thomas' slag, else some of the ammonia will be lost. When manure is especially required by the plant in its earliest stages—as superphosphate for turnips—it may be drilled with the seed; but, as a rule, manure should be sown broadcast, and ploughed or harrowed in.

Top-dressing, that is, sowing manure on the surface of land already under crop, should generally be confined to manures that are soluble, or the principal constituents of which easily become soluble in the soil. Nitrate of sodium is sown with advantage in this manner if showery weather can be depended on to distribute the manure in the soil. On pasture all manures are necessarily applied as top-dressings.

Manures of little solubility, or those for which the soil has a great retentive power, may be applied to the land before the growing period of the crop commences. Diffusible manures, on the other hand, should be applied only when the crop is ready to make use of them, else serious waste may occur by drainage. Farmyard manure, seaweed, fish manure, blood, horn, wool, meat guano, oilcakes, bones, and ground phosphates, and to some extent superphosphate and potassium salts, belong to the former class; while nitrates, and all manures containing ammonia, belong to the latter class. It was formerly supposed that the great retentive power of fertile soils for ammonia would effectually prevent any loss by drainage; we know now that ammonia is speedily converted into nitrates after mixing with the soil, and that these nitrates are readily washed out by heavy rain.

Following these principles, an autumn manuring for wheat may consist of farmyard manure, blood, or shoddy, with or without superphosphate; but dressings of guano, ammonium salts, or nitrate of sodium should be deferred till the spring. The question is, however, clearly one of climate, and with a dry winter climate ammonium salts or guano may be applied with advantage in the autumn. In a wet spring loss may be avoided by applying ammonium salts, and especially nitrate of sodium, in small successive dressings instead of in one application. Late applications of nitrogenous manure are, however, apt to produce straw rather than corn.

On soils of open texture, and little retentive power, preference must often be given to manures of little solubility, in order to diminish the loss occasioned by heavy rain; organic manures, as farmyard manure, seaweed, or oil-cakes, are in such cases very suitable.

Return for Manure Applied.—No dressing of manure is completely taken up by the crop to which it is applied, dressings larger than the actual requirements of the crop must therefore be employed to obtain a given result. At Rothamsted, with a moderate dressing of nitrate of sodium to barley, together with a liberal supply of ash constituents, about 60 per cent. of the nitrogen has been on an average recovered in the increased produce. A much larger proportion is recovered in good seasons. With mangels, manured in a similar manner, about 62 per cent. of the nitrogen in the nitrate of sodium has been, on an average, recovered in the increased produce of roots obtained, the nitrogen in the leaves being not reckoned, as they are returned to the soil. In the absence of a full supply of ash constituents the amount of nitrogen recovered in the crop is seriously diminished. Ammonium salts, and rape-cake, applied as manures, have yielded a smaller return than nitrate of sodium.

Most soluble and active manures produce their principal effect at once, and are of little benefit to subsequent crops. Ammonium salts or nitrates give all their effect in the first year. Sparingly soluble manures, and those which must suffer decomposition in the soil before they are of service to the plant, as farmyard manure and bones, will on the contrary continue to produce an effect over many years. Farmers have a prejudice in favour of the latter class of manures, but it is clear that the quickest return for capital invested is afforded by the former class. In the case of farmyard manure, applied annually on the heavy land at Rothamsted to wheat and barley, only about 10 to 15 per cent. of the nitrogen has been recovered in the increase; but the effect on the barley has continued for many years after the application of the manure ceased. It is evident that a small quantity of an active manure will accomplish the same work as a large quantity of one less active.

The residues of phosphatic and potassic manures are available for subsequent crops, but are distinctly less effective than fresh applications of the same manures.

CHAPTER IV.

CROPS.

The dry matter, nitrogen, and ash constituents, in average crops. *Cereal Crops.*—Characteristic composition—Mode of feeding—Most suitable manuring. *Meadow Hay.*—Characteristic composition—Demand for ash constituents—Influence of manures on quantity and quality—Pastures especially adapted for obtaining nitrogen from the atmosphere. *Leguminous Crops.*—Characteristic composition—Special source of nitrogen—Clover-sickness. *Root Crops.*—Characteristic composition—Differences in the nutrition of turnips, mangels, and potatos. *Forest Growth.*—Large production of dry matter for small consumption of ash constituents and nitrogen. *Adaptation of Manures to Crops.*—The feeding power of each crop must be taken into account.—Economic distribution of manure in a rotation—The practical value of manures only known by experiments on each farm. *Influence of Climate and Season.*—Effect of excess or deficiency of water and heat—Influence of preceding Winter. *Crop Residues.*—Their action—Differences between different crops. *Weeds.*—Their beneficial and injurious actions.

To understand the chemistry of crops we must first inquire as to their composition. The following table gives the average composition of ordinary farm crops, and of the annual produce of three descriptions of forest. The quantities of carbon, hydrogen, and oxygen present are omitted, also some of the smaller ash constituents. By "pure ash" is understood the ash minus sand, charcoal, and carbonic acid.

The composition of grain is tolerably constant; but the composition of straw, leaves, roots, and tubers, will vary very considerably according to the character of the soil, the manuring, and the season. The composition of

THE WEIGHT AND AVERAGE COMPOSITION OF ORDINARY CROPS IN POUNDS PER ACRE.

——	Weight of crop. At Harvest.	Weight of crop. Dry.	Total pure ash.	Nitrogen.	Sulphur.	Potash.	Soda.	Lime.	Magnesia.	Phosphoric Acid.	Chlorine.	Silica.
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
WHEAT, grain, 30 bushels . .	1,800	1,530	30	33	2·7	9·3	0·6	1·0	3·6	14·2	0·1	0·6
,, straw	3,158	2,653	142	15	5·1	19·5	2·0	8·2	3·5	6·9	2·4	96·3
Total crop . . .	4,958	4,183	172	48	7·8	28·8	2·6	9·2	7·1	21·1	2·5	96·9
BARLEY, grain, 40 bushels . .	2,080	1,747	46	35	2·9	9·8	1·1	1·2	4·0	16·0	0·5	11·8
,, straw	2,447	2,080	111	13	3·2	25·9	3·9	8·0	2·9	4·7	3·6	56·8
Total crop . . .	4,527	3,827	157	48	6·1	35·7	5·0	9·2	6·9	20·7	4·1	68·6
OATS, grain, 45 bushels . . .	1,890	1,625	51	38	3·2	9·1	0·8	1·8	3·6	13·0	0·5	19·9
,, straw	2,835	2,353	140	17	4·8	37·0	4·6	9·8	5·1	6·4	6·1	65·4
Total crop . . .	4,725	3,978	191	55	8·0	46·1	5·4	11·6	8·7	19·4	6·6	85·3
MAIZE, grain, 30 bushels . .	1,680	1,500	22	28	1·8	6·5	0·2	0·5	3·4	10·0	0·2	0·5
,, stalks, etc.	2,208	1,877	99	15	. .	29·8	. .	. .	. .	8·0	. .	. .
Total crop . . .	3,888	3,377	121	43	. .	36·3	. .	. .	. .	18·0	. .	. .
MEADOW HAY, 1½ ton . . .	3,360	2,822	203	49	5·7	50·9	9·2	32·1	14·4	12·3	14·6	56·9
RED CLOVER HAY, 2 tons . .	4,480	3,763	258	102	9·4	83·4	5·1	90·1	28·2	24·9	9·8	7·0
BEANS, grain, 30 bushels . .	1,920	1,613	58	77	4·4	24·3	0·6	2·9	4·2	22·8	1·1	0·4
,, straw ,, . . .	2,240	1,848	99	29	4·9	42.8	1·7	26·3	5·7	6·3	4·3	6·9
Total crop . . .	4,160	3,461	157	106	9·3	67·1	2·3	29·2	9·9	29·1	5·4	7·3

—	Weight of crop. At Harvest.	Weight of crop. Dry.	Total pure ash.	Nitrogen.	Sulphur.	Potash.	Soda.	Lime.	Magnesia.	Phosphoric Acid.	Chlorine.	Silica.
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
TURNIPS, root, 17 tons . . .	38,080	3,126	218	63	15·2	108·6	17·0	25·5	5·7	22·4	10·9	2·6
„ leaf „ . . .	11,424	1,531	146	49	5·7	40·2	7·5	48·5	3·8	10·7	11·2	5·1
Total crop . . .	49,504	4,657	364	112	20·9	148·8	24·5	74·0	9·5	33·1	22·1	7·7
SWEDES, root, 14 tons . . .	31,360	3,349	163	70	14·6	63·3	22·8	19·7	6·8	16·9	6.8	3·1
„ leaf „ . . .	4,704	706	75	28	3·2	16·4	9·2	22·7	2·4	4·8	8·3	3·6
Total crop . . .	36,064	4,055	238	98	17·8*	79·7	32·0	42·4	9·2	21·7	15·1	6.7
MANGELS, root, 22 tons . . .	49,280	5,914	426	87	4·9	222·8	69·4	15·9	18·3	36·4	42·5	8·7
„ leaf	18,233	1,654	254	51	9·1	77·9	49·3	27·0	24·2	16·5	40·6	9·2
Total crop . . .	67,513	7,568	680	138	14·0	300·7	118·7	42·9	42·5	52·9	83·1	17·9
POTATOS, tubers, 6 tons . .	13,440	3,360	127	47	2·7	76·5	3·8	3·4	6·3	21·5	4·4	2·6
BEECH, wood	. .	2,822	26	10	. .	4·2	0·8	12·9	3·4	1·5	. .	2·2
„ leaf litter	. .	2,975	166	39	. .	8·8	1·6	73·1	10·9	9·3	. .	53·9
Total produce . .	. .	5,797	192	49	. .	13·0	2·4	86·0	14·3	10·8	. .	56·1
SPRUCE FIR, wood	. .	3,064	20	. .	. .	3·6	0·4	8·2	1·8	1·3	. .	2·9
„ leaf litter . . .	. .	2‘683	121	. .	. .	4·3	1·5	54·4	6·2	5·7	. .	44·3
Total producè . .	. .	5,747	141	. .	. .	7·9	1·9	62·6	8·0	7·0	. .	47.2
SCOTCH PINE, wood	. .	2,884	15	. .	. .	2·3	0·2	9·0	1·5	1·0	. .	0·5
„ leaf litter . . .	. .	2,845	42	. .	. .	4·3	1·7	16·8	4·3	3·3	. .	5·8
Total produce . .	. .	5,729	57	. .	. .	6·6	1·9	25·8	5·8	4·3	. .	6·3

* Calculated from a single analysis only.

fodder and root crops is thus especially liable to variation. This subject is discussed on page 92.

Cereal Crops.—These contain much less nitrogen than either leguminous or root crops; about three-quarters of the nitrogen is in the corn, and only one quarter in the straw. The amount of phosphoric acid is not very different from that found in other crops; this ingredient is, in fact, the most constant in quantity of all the constituents of crops. The phosphoric acid is chiefly concentrated in the corn. Potash and lime are present in much smaller quantity than in other crops; they are chiefly found in the straw.

The presence of a large amount of silica is characteristic of the cereal crops; they possess apparently a capacity for feeding on silicates not enjoyed by other crops. The base of the silicate is made use of by the plant, while the silica itself is excreted upon the surface of the leaves and straw. It has been shown that silica is by no means essential for the growth of cereals: they take it up freely, but can also do without it.

Owing to their small demands upon the soil, and possibly also to their capacity for assimilating silicates, cereal crops will for a long time continue to yield a moderate produce upon exhausted unmanured land; a fact of great importance to the human race.

The autumn-sown cereals (wheat and rye) have both deeper roots and a longer period of growth than the spring-sown cereals (barley and oats), and are consequently better able than the latter to supply themselves with the necessary ash constituents from the soil. Barley possesses a considerable development of root near the surface and is apparently more capable of obtaining nitrogen from the soil than wheat. Maize has a later period of growth than the cereals already mentioned and will thus have a greater command of the nitrates produced in summer. Owing probably to this fact it is a crop less dependent on nitrogenous manure than wheat.

Cereal crops derive their nitrogen almost exclusively from nitrates; the form of organic combination in which the great bulk of the nitrogen is present in the soil is not suited for their assimilation. Notwithstanding, therefore, the small amount of nitrogen contained in cereal crops, they rank among those most benefited by nitrogenous manures. Phosphates, though generally of little use by themselves, are also beneficial (especially in the case of spring-sown crops) when applied with nitrogenous manure. A nitrogenous guano, or a spring dressing of nitrate of sodium and phosphatic slag, or sulphate of ammonia with superphosphate, is generally the most effective manuring for a cereal crop. When malting barley of high quality is to be produced the supply of nitrogenous manure must be carefully limited. Nitrate of sodium always gives a larger return in straw than sulphate of ammonium.

Meadow-Hay.—The grasses which form the main bulk of hay belong to the same family of plants as the cereal crops; the seed, however, in grass bears such a small proportion to the stem and leaf that meadow hay may be regarded as a straw crop. In accordance with this character hay is found to contain a much larger proportion of potash and lime than cereal crops, and a much smaller amount of phosphoric acid.

The roots of grass being far shorter than those of the cereals are less able to collect ash constituents from the soil; if, therefore, grass is mown for hay, manures containing potash, lime, and phosphoric acid will generally be required. Like the cereal crops, grass is greatly increased in luxuriance by the application of soluble nitrogenous manures.

Farmyard manure, or the feeding of cake, corn, or roots on the land, is the most appropriate manuring for permanent pasture, if a high quality as well as quantity of produce is desired. Large crops of hay may be obtained by manuring with nitrate of sodium, together with kainite and superphosphate; but a continuance of such treatment promotes a coarse herbage.

The natural clovers of a meadow are destroyed by the continued application of highly nitrogenous manures, a hay consisting almost exclusively of grass being produced. The clovers are developed by the application of manures supplying potash or lime without nitrogen. The effect of pasturing is to check the development of coarse herbage, and to promote the growth of the finer grasses and clover.

The perennial character of meadow herbage, which usually includes a variety of leguminous plants, presents favourable conditions for the collection of nitrogen from the atmosphere: see pp. 65,66.

Leguminous Crops.—Some of these are grain crops, as beans and peas; others are fodder crops, as red clover, sainfoin and lucerne. A striking characteristic of all these crops is the large amount of nitrogen which they contain, the quantity being about twice as great as that found in cereal crops of the same weight. The quantity of potash and lime in leguminous crops is also very large. The relative proportion of these two bases varies much in crops grown on different soils; upon a calcareous soil lime will preponderate in the crop, but on a clay soil potash. The lime is found chiefly in the leaf. Silica is nearly absent in leguminous crops.

The amount of nitrogen collected by leguminous crops is very remarkable. A good crop of red clover, when cut for hay, removes a large quantity of nitrogen from the land, but it nevertheless leaves the surface soil actually richer in nitrogen than it was before, from the residue of roots and stubble left in the soil. From whence is this large quantity of nitrogen obtained? It must be procured either from the subsoil or the atmosphere. The question is made more puzzling by the fact that nitrogenous manures generally produce but little effect upon leguminous crops. It seems now quite certain that leguminous crops possess in their root tubercles an apparatus capable of bringing the nitrogen of the atmosphere into combination (see p. 10). The special agent residing in these tubercles is a micro-organism derived from the soil. In the case of a poor soil the presence or absence of the necessary organism in the soil may determine its fertility or barrenness for a leguminous plant. It must, however, be recollected that, apart from the tubercles, leguminous plants are nourished in an ordinary way through their root-hairs, and that a deeply-rooted plant, like red clover or lucerne, obtains considerable food supplies from the subsoil.

Except in the case of extraordinary rich soils, land loses the power of growing most leguminous plants by repeated cropping with them, and is said to be "clover sick" or "bean sick." The origin of this barrenness has not yet been satisfactorily explained; it is generally intensified by an attack from insects on the weakened plant. No means of remedying this condition is known save by the growth of other crops for a series of years.

Potash manures have generally a very beneficial effect upon leguminous crops; they fail, however, to cure clover sickness. Farmyard manure, phosphates, gypsum and lime are also serviceable.

Root Crops.—All these crops contain a large amount both of nitrogen and ash constituents; among the latter potash greatly preponderates. Turnips contain more sulphur than any other farm crop.

Turnips and *swedes* draw their food chiefly from the surface soil. Their power of taking up nitrogen from the soil is distinctly greater than that of the cereal crops. Turnips are also well able to supply themselves with potash when growing in a fertile soil, but they have singularly little power of appropriating the combined phosphoric acid of the soil. On exhausted land it is generally impossible to obtain a crop without a supply of phosphates.

Mangels have far deeper roots than turnips, and also a longer period of growth. They have a great capacity for drawing food from the soil, including both nitrogen, potash, and phosphoric acid. When carted off the land they are probably the most exhaustive crop that a farmer can grow. As mangels have not the same difficulty that turnips have of attacking the combined phosphoric acid of the soil, phosphatic manures are, in their case, of much less importance. Nitrate of sodium, when applied alone to mangels, generally produces a great effect on the crop; this is not the case with turnips, which require phosphates as well as nitrogen in their manure.

As both turnips and mangels consume extremely large amounts of plant food, a liberal general manuring with farmyard manure is in most cases essential for the production of a full crop; but the special characteristic of the manure for turnips should be phosphatic, and of that for mangels nitrogenous. With an abundant supply of nitrogenous manure the proportion of leaf is increased, and the maturity of the root delayed. A heavily manured crop should be sown early. Late-sown crops of turnips or swedes should receive a smaller proportion of nitrogen, and a larger proportion of phosphates in their manure.

When *beetroot* is grown for sugar it is essential to produce small roots; heavy manuring is therefore avoided, and the roots grown near together.

Potatos are surface feeders, and require a liberal general manuring to ensure an abundant crop.

As both root crops and potatos require large supplies of potash, kainite will be found of service on land naturally poor in that ingredient. It will be chiefly required when the crops are raised with artificial manures only, as farmyard manure will always supply a considerable amount of potash.

Forest Growth.—The figures given in the table represent the composition of the produce of beech, spruce fir, and Scotch pine forests felled for timber, and are the results of extensive investigations made in Bavaria.

The amount of dry matter in the annual forest growth is in excess of that yielded by any of the cultivated crops given in the table, excepting mangels. This large produce is obtained by a very small consumption of soil food; the amounts of potash and phosphoric acid required are especially far less than in the case of any farm crop. The greater part both of the ash constituents and nitrogen is found in the fallen leaves; if these are left undisturbed, and allowed to manure the ground, the requirements of the forest become extremely small, far smaller than in ordinary farm culture. It appears that about 3000 lbs. of perfectly dry pine timber are produced with a consumption of only 2½ lbs. of potash, and 1 lb. of phosphoric acid per acre per annum: with beech timber the quantities required are rather larger. The amount of nitrogen in timber is very small; the annual growth of beech wood contains on an average about 10 lbs. per acre. The amount in the leaves and seeds is much more considerable. Forest trees do not produce seed till they are of mature age; the seed is formed at the expense of matter previously stored in the tree. When the litter is not removed, the surface soil will gain considerably in organic matter (containing both ash constituents and nitrogen) during the earlier years of forest growth, and thus greatly improve in value.

Adaptation of Manures to Crops.—The true economy of manure can be understood only when we are acquainted with the special characters of the crops we cultivate. The composition of a crop is no sufficient guide to the character of the manure appropriate to it, even when we possess in addition the composition of the soil on which it is to be grown. It is not only the materials required to form a crop, but the power of the crop to assimilate these materials, which must form the basis of our judgment. This fact has been much overlooked by many scientific writers, who have counselled farmers to manure their land in every case with all the constituents required by the crop, a proceeding both impracticable and unnecessary. In the case of a barren sand it may indeed be requisite to supply all the constituents of plant food before a crop can be grown, but such a case is far removed from the circumstances of ordinary agriculture.

When land is in a fertile condition the total amount of plant food available for crops is very considerable, and luxuriant growth may be obtained by supplementing the stores of the soil with the few particular elements of food which the crop it is wished to grow has most difficulty in obtaining. Thus, in a large majority of cases, a dressing of nitrate of sodium and phosphates will ensure a full crop of wheat, barley, or oats, and in many cases nitrate of sodium alone will prove very effective. These cereal crops generally find the supply of nitrates in the soil insufficient for their full growth, and the supply of phosphates more or less inadequate; but in a majority of cases they are well able to obtain a sufficient supply of potash and other essential elements of plant-food. We are thus able, by supplying one or two constituents of the crop, to obtain a luxuriant harvest. In the same way nitrate of sodium employed alone will, in most cases, produce a large crop of mangels; superphosphate alone, a large crop of turnips; while potassium salts alone may be strikingly effective with pasture and clovers.

This special manuring for each crop is no strain on the capabilities of the soil if a rotation of crops be followed. If superphosphate is applied for the turnips, potassium salts for the seeds, and a nitrogenous manure for the cereal crops, the more important elements of plant food contained in the soil will not be diminished at the end of the rotation. At the same time the most economic result will have been obtained from the manures employed, for each manure will have been supplied to that particular crop with which it yields the most remunerative result.

It is doubtless possible by means of rotations manured on the above principles to farm successfully with the sale of all the crops produced, and without the use of farmyard manure; this is possible at least so long as artificial manures can be obtained at a low price. In the majority of cases, however, the special manuring will only be required to supplement the general manuring by farmyard manure. Under these circumstances it would seem best, from a chemical point of view, to apply the farmyard manure to those crops which most require potash, or which stand most in need of a general manuring; such crops would be pasture, artificial grasses, turnips and potatos.

As the whole object of artificial manuring is to supplement the deficiencies of the soil, it is highly desirable that a farmer should ascertain by trials in the field what is the actual amount of increase which he obtains from the application of the manures he purchases. A few carefully made experiments will teach him what his land and crops are really in need of. Should he add superphosphate with the nitrate of sodium for his wheat? What dressing of the nitrate is most economical? Is superphosphate alone sufficient for his turnip crop, or should guano or nitrate be employed as well? What is the smallest quantity of superphosphate sufficient for the crop? Will it pay to use potassium salts for his seeds, his pasture, or his potato crop? These and many other questions can only be answered by trials on his own fields. On the farmer's knowledge of such facts will depend the economy with which he is able to use purchased manures, which are too often wastefully employed.

Influence of Climate and Season.—The influence of weather upon crops is far greater than the influence of manure.

As a plant contains water as its largest constituent, and as the whole of the plant food obtained from the soil is taken up through the medium of water, while the amount of water daily lost by the plant through evaporation is very large, the necessity of a large supply of water in the soil during the growing period of a crop is very evident. On the other hand, an excess of water in the soil prevents root development, and causes a loss of nitrates and other soluble plant foods in the drainage water. Deeply-rooted crops, as wheat, red clover, lucerne, sainfoin, and mangel, are those best fitted to resist drought; while shallow-rooted crops, as grass and turnips, are those which suffer most from it.

We have already seen that carbon, which forms the largest ingredient of all vegetable substances, is obtained by plants from the atmosphere under the influence of light, and that a certain temperature is necessary for this assimilation of carbon and for the other chemical processes which proceed in a growing plant; a sufficient supply of light and heat is therefore required for the production of a crop. In a season of deficient light and heat the harvest is always late, growth having taken place more slowly than in an average season. In the case of extremely cold and cloudy summers the whole season may be too short for maturing the crop, and the seed in consequence may never be fully ripened. Early sowing is generally advisable, as a longer period for growth is thus afforded to the crop.

As the character of the season determines the degree of maturity reached at harvest, it has a great influence both on the composition and quality of the crop. A fine malting barley, rich in starch, can only be produced in a fine season; any imperfect ripening, produced either by cold, wet weather, or by the premature drying of the grain during severe drought, will result in the production of grain poor in starch and relatively rich in nitrogenous matter. The effect of season on the composition of a crop will be found further discussed on pp. 14, and 92-94.

Each crop requires more or less a different climate for its perfect development; a knowledge of the kind of climate best suited to each crop is of great service in selecting crops for any particular district. Thus wheat requires hot and dry weather for its ripening period, while oats will ripen in a moist atmosphere. Mangels require heat, and can resist drought, while turnips develop best in a cool, moist air. Oats and turnips thus best suit the Scotch climate, while wheat and mangels are better fitted for the south-east of England.

The soil best furnished with plant food is the one which will yield the best results in adverse seasons, the crop having a greater amount of vitality and being able to turn to the best advantage the short periods of favourable weather that may occur. Poor soils yield their best results in seasons of slow but continued growth, the crop having a longer time to collect the scanty supply of food which the soil contains. In hot seasons, with an early harvest, only soils well supplied with food can produce full crops.

The character of the winter has a considerable influence on that of the following season. In a wet winter the soil may lose nitrates by drainage to a large extent. Root development will also be prevented by excessive wet. After such a winter the wheat crop generally is in a backward condition, and finds itself in an impoverished soil. In climates having a very severe winter the nitrates are preserved from loss by the frozen condition of the soil. In spring the melted snow is removed mostly by surface drainage, the soil beneath being still frozen; the water produced by the snow consequently does not remove the soluble matter of the soil.

Crop Residues.—The portion of the crop left in the soil after harvest serves most important functions; on this residue (apart from actual applications of organic manure) the maintenance of the humus, and consequently of the nitrogen of the soil, depends. The quantity of residue left by different crops is very different. From a crop of turnips, mangels, or potatos, practically no root residue remains in the soil; the residue, in the case of root crops, is limited to the leaves which may remain uneaten by the stock. The residue of roots and stubble left by an annual cereal crop is rather considerable, but poor in nitrogen. The residues from deeply-rooted crops, which have long held possession of the soil, as sainfoin and red clover, but especially lucerne, are very large, amounting to many tons of dry matter, and containing

100—200 lbs., or even more, of nitrogen per acre. In the case of permanent pasture the effect of long-continued crop residues is strikingly manifest, the surface soil containing twice as much nitrogen, and more than twice as much carbon, as ordinary arable land. In the case of pine forests, the accumulated residues of dead leaves, &c., are also very large: chiefly by their means bare rock is often transformed into fertile soil. It is obvious that the more luxuriant a crop the greater will be the crop residue: a series of good crops thus tends to enrich the soil with nitrogenous humus, while under a series of bad crops the soil will diminish in fertility.

Weeds.—The weeds of a farm form a natural crop; their influence is at times beneficial and at times injurious to the farmer. That some vegetation should grow on the land in the absence of a regular crop is most desirable. The rapid growth of weeds after harvest will greatly diminish the loss of nitrogen by drainage and be of use in other ways as a green crop. When the weeds are ploughed-in in the spring the valuable matter stored up by them again becomes available as plant food. On the other hand, it is obvious that a crop will have little chance of obtaining plant food if it has to compete with growing weeds which have obtained earlier possession of the soil. The best plan is apparently to destroy weeds, and to obtain the important benefits they yield by a judicious use of green crops, sown so as to occupy the land after harvest.

CHAPTER V.

ROTATION OF CROPS.

The aim of rotations. *Bare Fallow.*—Effects on the soil—Production of nitrates. *Green Crops.*—Effects of feeding on the land, or ploughing in—Gain of nitrogen to the soil by laying down land in pasture, or in leguminous crops—Advantages of green manuring. *Distinctive characteristics of Crops.*—Differences in periods of growth, range of roots, powers of assimilation, and quantity of food demanded. *Losses to the land during rotation.*—Losses in an assumed four-course rotation, how replaced—Losses of nitrates, how prevented—Gain of nitrogen from the atmosphere—Economical rotations—Sale of produce other than corn and meat.

It is by no means impossible to grow the same crop with success year after year on the same land; ordinary pasture is indeed an example of continuous cropping. The Rothamsted experiments show that excellent crops of wheat, barley, and mangel may be continuously obtained if appropriate manure is annually applied, and the land kept free from weeds. A rotation of crops is resorted to in ordinary practice in consequence of the facilities which such a plan affords for cleaning the land, and from the greater economy of manure which results from this practice. One of the principal aims of a rotation is to bring the land from time to time into a condition suitable for growing cereal crops; this suitable condition consists mainly in the accumulation of nitrogenous plant food in the surface soil.

Bare Fallow.—A bare fallow is one of the oldest modes of preparing soil for wheat. The soil is ploughed, and exposed a whole year to atmospheric influences, and finally sown with wheat. In the case of a clay soil this treatment would probably lead to the following results :—1. An improvement in the mechanical texture of the soil. 2. The disintegration of some of the mineral silicates, whereby potash and other necessary ash constituents of plants would be liberated and made available for vegetation. 3. The absorption of ammonia from the atmosphere by the soil. 4. The receipt of both ammonia and nitric acid from the air in the form of rain. 5. The oxidation of ammonia, and of the vegetable and animal remains in the soil, carbonic and nitric acids being produced.

The production of nitric acid is probably the most important result of a bare fallow. In ordinary farm soils at Rothamsted left as bare fallow, there has been found at the end of the summer 34—55 lbs. of nitrogen per acre in the form of nitric acid in the first 20 inches from the surface, the quantity depending on the richness of the soil in nitrogenous matter and the character of the season. The whole amount of nitrates produced during the 15 months that the land remains without a crop has been estimated at not less than 80 lbs. of nitrogen per acre for the fields under ordinary cultivation at Rothamsted. Supposing the season of fallow, and the following winter, are fairly dry, this increase in the available nitrogenous food will probably enable the soil to produce twice as much wheat as it could do without a fallow. If, however, the soil is exposed to heavy rain, the nitrates produced will be more or less washed out, and the benefit of the fallow greatly diminished. A mass of soil at Rothamsted, 5 feet deep, left for 20 years uncultivated, unmanured, and kept free from weeds, has lost by drainage in the last 13 years from 28 to 47 lbs. of nitrogen in the form of nitrates per annum. Bare fallow can be used with advantage only on clay soils, and in a tolerably dry climate; under other circumstances the practice must result in a serious loss of soil nitrogen.

Green Crops.—The most usual plan for bringing land into condition for the growth of cereals is the cultivation of green crops. These may be ploughed in, forming what is termed green manuring; or consumed on the land by the farm stock; or the crop may be removed, consumed in cattle-sheds or in the farmyard, and the resulting manure brought on to the land. The principle in every case is that the constituents of the crop shall be returned to the soil.

Let us suppose that land is laid down with grass and clover seeds, and after two or three years is ploughed up and a cereal crop taken. Whilst the land is continuously covered by vegetation the loss of nitric acid by drainage will be reduced to a minimum. If the grass is fed off on the land the surface soil will at the end of the three years be considerably enriched both with ash constituents and nitrogen. The former have been collected from the subsoil by the roots of the crop and returned to the surface soil as animal manure. The latter includes the accumulated receipts from the atmosphere and subsoil during the three years, minus the quantity lost by drainage and that assimilated by the animals. The accumulated nitrogen will be chiefly in the form of grass roots, stems, and humus. When such land is ploughed up the vegetable matter and humus are oxidised, and gradually yield their nitrogen as nitric acid.

Such a mode of cropping has several advantages over a bare fallow:—1. The land is turned to profitable use, food being produced for the farm stock. 2. Both ash constituents and nitrates are collected from the subsoil and brought to the surface. 3. Nitrogen is acquired from the atmosphere by the crop, as well as by the soil. This is especially true if leguminous plants are grown. 4. The nitrogen collected is kept in an insoluble form, as vegetable matter, and consequently cannot be washed away, but accumulates in the surface soil to a greater extent than is possible in a bare fallow. 5. Humus is produced in considerable quantity, the beneficial actions of which have already been noticed.

As an illustration of the accumulation of nitrogen in the surface soil when land is laid down permanently in pasture, we may refer to the arable land laid down to grass at Rothamsted, which gained nitrogen during 33 years at the rate of about 52 lbs. per acre per annum. Taking into account the quantity of hay removed, the greater part of this increase of nitrogen in the soil could not be accounted for by the quantity applied as manure; it was probably to a considerable extent derived from the atmosphere.

Leguminous crops, as already mentioned, have a special power of acquiring nitrogen from the atmosphere by means of their root tubercles, and are hence of the greatest value in a rotation. The accumulation of nitrogen in the surface soil in the form of roots, stubble, and decayed vegetable matter, is in the case of a good crop of clover so considerable that the whole of the above ground growth may be removed as hay, and the land yet remain greatly enriched with nitrogen and in an excellent condition for producing a crop of wheat. The growth of leguminous crops is the most important means which a farmer possesses for enriching his arable land with nitrogen.

The ploughing in of green crops has some advantages over the feeding of crops on the land. By this mode of proceeding the whole of the crop is returned to the soil, whereas in feeding a small part of the nitrogen and ash constituents is retained by the animal. The characteristic advantage of green manuring lies, however, in the large amount of humus which the soil acquires. All the carbon which the crop has obtained from the atmosphere is in this case incorporated with the soil, instead of being consumed by the animal. Green manuring is thus especially adapted for light sandy soils which need humus to increase their retentive power. It is employed with great advantage to fertilise barren soils in hot climates.

Having glanced at the general advantages to be derived from alternating green crops with cereals, we will consider next the characteristics of different crops which specially fit them to succeed or prepare for each other.

Distinctive Characteristics of Crops.—Differences in their periods of growth occasion a marked distinction in the relation of different crops to soil nitrogen. Thus the fact that the active growth of the cereals commences in spring, and concludes at their time of blooming towards the end of June, places these crops at a disadvantage as to the supply of nitrates from the soil. The autumn and winter rains have frequently washed out the greater part of the nitrates contained in the soil before the growth of the cereal crop commences, and nitrification in the soil has not long recommenced its activity in the summer months when the crop becomes too mature to appropriate fresh supplies of nitrogen. Continuous wheat cropping thus results in a gradual impoverishment of soil nitrogen by autumn and winter drainage, over and above the nitrogen actually removed in the crops, and thus necessitates a considerable application of nitrogenous manure if fertility is to be maintained. Maize, with its later period of growth, is better able to supply itself with nitrogen from the soil.

A root crop sown in early summer, on the other hand, has at its disposal all the nitrates that would be available for wheat or barley, and in addition the large supply of nitrates formed in the soil during summer and early autumn. A great part of the nitrates which would be lost by drainage during cereal cultivation is thus assimilated and retained by a root crop, and such crops are found to stand in less need of nitrogenous manure than cereals. By consuming the roots on the land the nitrates collected by the crop are returned to the soil in the form of animal manure, and the land thus prepared to carry a cereal crop. Similar remarks might be made respecting other green crops whose active growth extends into the autumn.*

Another important difference between crops lies in their range of roots. Deeply-rooted crops, as lucerne, sainfoin, red clover, rape, and mangel, and among the cereals wheat and rye, are to a considerable extent subsoil feeders, and have a greater power of obtaining ash constituents from the soil than shallow-rooted crops, as white clover, potatos, turnips, and barley. In accordance

* The writer is indebted to Sir J. B. Lawes for the important ideas contained in the two preceding paragraphs.

with this we find that superphosphate is a very effective manure for the last three crops, but is much less required by such crops as mangel or wheat. By growing deeply-rooted crops as part of a rotation the subsoil is made to contribute to the general fertility. Shallow-rooted crops, on the other hand, have generally a special faculty for appropriating food accumulated at the surface, and are often of great use in this respect, as when barley is made to follow turnips fed off on the land.

Very little is definitely known as to the different capacity of different crops for assimilating various forms of plant food, but there can be no doubt that this forms one of the most important distinctions between various crops, and is one reason of the economy of a rotation. A very plainly marked distinction as to mode of feeding is afforded by the behaviour of various crops towards silica. Graminaceous crops, as the cereals and grasses, are apparently capable of assimilating certain of the silicates contained in the soil, while other crops exhibit no such capacity. In such a case it is easy to imagine that an alternation of cereals with crops of a different description may be for the benefit of both, each drawing to some extent upon distinct supplies of food. Again, leguminous crops are clearly able to assimilate nitrogen to a far greater extent than cereals, and from a different source. If crops of winter beans and winter wheat are grown on similar unmanured land the bean crop will generally contain twice as much nitrogen as the wheat. The land is not, however, impoverished for wheat by the growth of beans, for wheat after beans will be a far better crop than wheat after wheat, thus affording a striking example of the advantages of a rotation.

The quantities of plant food required by different crops are given in the table on pp. 48—49; these also furnish reasons for the alternation of crops. It will be seen, for instance, that the cereals require but little potash and lime, while root crops, beans, and clover demand a large supply; it is obvious, therefore, that the resources of the soil are husbanded by growing these two classes of crops in alternation, the greater demand for potash and lime thus falling every alternate year.

The net result of a judicious alternation of crops, in which the special characteristics of each are turned to good account, is the production of a maximum total yield of produce with a minimum amount of manure.

Losses to the Land during Rotation.—The table showing the composition of ordinary farm crops will supply the requisite information as to the loss which a farm may suffer by the sale of individual crops. We will now consider briefly the losses during a rotation.

The conservation of plant food on a farm is generally effected by confining the exports to corn and meat, the rest of the produce being consumed on the farm, and the manure returned to the land. Let us assume that a farm is managed on the four-course system, and that the average crops obtained per acre are—swedes, 14 tons; barley, 40 bushels; seeds (half clover, half grass), 3 tons of hay, and wheat, 30 bushels. Further, that nothing is sold save corn and meat; that 2 bushels both of wheat and barley are returned to the land as seed; that 700 lbs. of linseed cake are fed with each acre of swedes; that 110 lbs. of oats are purchased per acre per annum for the horses. Finally, that half a ton of straw is fed per acre in the course of the rotation, and the rest used as litter. If the whole of the manure is returned without loss to the land, the quantities of nitrogen, phosphoric acid, and potash lost during the four years' rotation, as excess of exports over imports, will be as follows:—

ESTIMATED LOSSES PER ACRE DURING A FOUR-COURSE ROTATION BY SALE OF CORN AND MEAT.*

	Nitrogen.	Phosphoric Acid.	Potash.
	lbs.	lbs.	lbs.
By feeding swedes, 14 tons .	6·8	4·03	0·51
By sale of barley, 38 bushels .	32·3	14·35	9·60
By feeding seeds, 3 tons hay .	10·9	6·51	0·82
By sale of wheat, 28 bushels .	30·8	13·35	9·05
By feeding straw, ½ ton . .	1·2	0·72	0·09
	82·0	38·96	20 07
Deduct manure from 440 lbs. oats, and 700 lbs. oilcake . .	36·5	12·74	10·70
Total loss in 4 years . . .	45·5	26·22	9·37
Average loss each year . .	11·4	6 56	2·34

The loss of potash is extremely small, and may generally be quite disregarded. If, however, no cake is used, and the land is poor in potash, the loss might be replaced by the use of 1½ cwt. of kainite for the seeds. The loss of potash will be greater than we have assumed if urine has been lost in the stables, or if the farmyard manure has suffered by rain and drainage.

The loss of phosphoric acid would be replaced, even

* The figures given in this table differ from those in former editions, more complete data being now available. It is now assumed that the crops are consumed by sheep and cattle of *all ages*, and not simply by fattening stock.

if no cake were employed, by the use of 2 cwts. of superphosphate for the swedes.

The loss of nitrogen is seen to be more considerable than the loss of phosphoric acid or potash. The figures given are also certainly below the truth, as they take no account either of loss of nitrogen in the manure, or of the nitrates lost to the soil by drainage.

If the losses of nitrogen in the stable and the manure heap amount to one half of the original nitrogen in the manure (a case which is by no means impossible), the annual loss of nitrogen will be raised to 42 lbs. per acre.

The average annual loss of nitrogen as nitrates by drainage from the soil (calculated from the composition of uncontaminated spring and well waters) is in England not less than 7 lbs. per acre. On arable land the loss, especially in wet seasons, will much exceed this figure. Much may be done by the farmer to diminish this loss. The early sowing of mustard, turnips, rape, or rye on stubbles which are to be followed by a spring-sown crop is most desirable; the green crops thus obtained to be fed, or ploughed in, before the spring sowing. In the case of a bare fallow it has been found advantageous to plant mustard early in August, and plough the crop in in October before wheat sowing. By such methods the nitrogen of the nitrates is converted into vegetable matter, and preserved from loss by drainage.

Against the losses of nitrogen we have enumerated we have to place the amount annually supplied to the land by the rainfall, say 4—5 lbs. per acre; and also the unknown and more considerable quantity absorbed as ammonia from the atmosphere by soil and plant. Of much greater importance is the supply of nitrogen obtained by the cultivation of leguminous crops. Where such crops can be successfully grown, and are consumed upon the farm, there should be little fear of a deterioration in the nitrogenous contents of the soil under the conditions of rotation we have supposed.

In the four-course manured rotation upon the heavy land at Rothamsted, the nitrogen annually removed in the crops, on an average of forty years, has exceeded by about 32 lbs. the quantity supplied in the manure. If the crops on this experimental rotation should be permanently maintained in quantity, of which at present we cannot be certain, we must conclude that these 32 lbs. of nitrogen, together with the unknown additional quantity lost as nitrate by drainage, have been annually derived from the atmosphere—partly as rain, but mostly by direct absorption by the crops or soil.

When it is desired to make the utmost use of the natural sources of fertility, the land is allowed to remain more than one year in grass seeds; or one green crop is followed by another, as *trifolium incarnatum* by turnips; or a perennial leguminous crop is grown for several years. The losses by sale of corn are thus diminished, and the land is kept for some time under conditions favourable to an accumulation of nitrogen in the surface soil.

We have supposed that only corn and meat are sold off the land during the rotation; it will often be economical to sell a larger part of the produce and to purchase manure in its place. The sale of straw will be attended with little practical loss on heavy land; but on light land both the loss of potash, and the diminution in the bulk of the manure will be more or less felt. The sale of hay or roots is far more exhaustive, and, except on the most fertile soils, must demand a considerable purchase of manure or cattle food to replenish the soil with plant nourishment.

CHAPTER VI.

ANIMAL NUTRITION.

The Constituents of the Animal Body.—Water, albuminoids, gelatinoids, horny matter, fat, and ash constituents—Composition of animals in various stages of growth and fattening—Composition of wool and milk—Loss to a farm by sale of milk, cheese, and butter—Proportion of carcase in different animals—Composition of increase whilst fattening. *The Processes of Nutrition.*—The constituents of food, their particular functions in the body and relative values—Digestion—Respiration—Excretion.

In order to understand the mode in which animals are nourished we must first obtain some acquaintance with the nature of the animal body, and understand the composition of the increase which takes place during growth and fattening.

The Constituents of Animals.—The elements composing the animal frame are the ten already named as forming the essential constituents of plants (pp. 2—3), with sodium and chlorine in addition. The two last-named elements are commonly present in the succulent parts of plants, but are apparently not essential to plant life; in the animal frame they are, however, indispensable. Fluorine and silicon are also always found in the animal body, but are not known to be essential for life or growth; fluorine occurs in small quantities in the teeth and bones, and silicon in hair, wool, and feathers.

The *combustible matter* of the animal body is mainly composed of nitrogenous substances, and of fat.

The nitrogenous substances constituting the animal frame may be generally classed as—(1) albuminoids (proteids); (2) gelatinoids; and (3) horny matter. These three groups are related in composition, though differing a good deal in their properties. The albuminoids form the substance of animal muscle and nerve, and the greater part of the solid matter of blood; they are, undoubtedly, of the first importance in the animal economy. The gelatinoids form the substance of skin and sinew, of all connective tissue, and also the combustible matter of cartilage and bone. Horny matter, named by chemists keratin, is the material of which horn, hair, wool, and feathers are constituted. Besides the nitrogenous matters constituting tissue, the animal juices contain a variety of nitrogenous substances, as sarcine, creatine, etc., with which we are not immediately concerned.

The fats occurring in the animal body are principally stearin, palmitin, and olein. Stearin preponderates in hard fats, and olein in fluid fats.

Of the *incombustible constituents* by far the largest part is contained in the bones. In fat animals 75 to 85 per cent. of the total ash constituents are found in the bones. Bone ash chiefly consists of phosphate of calcium, with a small quantity of carbonate of calcium and phosphate of magnesium. In muscle by far the most abundant ash constituent is phosphate of potassium. Potassium salts are also abundant in the "yolk" of unwashed wool. Blood, on the other hand, always contains a considerable quantity of sodium salts.

The amounts of water, nitrogenous matter, fat, and ash constituents present in a large number of animals have been determined at Rothamsted. The following table shows the percentage composition of eight animals, after deducting the contents of the stomachs and intestines. The fat pig was one grown for fresh pork, not for bacon.

PERCENTAGE COMPOSITION OF WHOLE BODIES OF ANIMALS.

	Fat calf.	Half fat ox.	Fat ox.	Fat lamb.	Store sheep.	Fat sheep.	Extra fat sheep.	Store pig.	Fat pig.
Water . .	65·1	56·0	48·4	52·2	61·0	46·1	37·1	58·1	43·0
Nitrogenous matter .	15·7	18·1	15·4	13·5	15·8	13·0	11·5	14·5	11·4
Fat . .	15·3	20·8	32·0	31·1	19·9	37·9	48·3	24·6	43·9
Ash . .	3·9	5·1	4·2	3·2	3·3	3·0	3·1	2·8	1·7

Water is in nearly every case the largest ingredient of the animal body; the proportion of water diminishes with the growth of the animal, and especially during fattening. Fat forms in most cases the principal solid ingredient of well-fed animals, its proportion increases very largely during fattening. The proportion of nitrogenous matter and ash tends to increase from youth to maturity, but diminishes during fattening.

The largest proportion of nitrogenous matter and of ash are found in the ox, the smallest in the pig. The difference in the proportion of ash is chiefly due to the wide difference in the proportion of bone in these two animals. Fat is found in greatest quantity in the pig, and is least in the ox.

The following table shows the quantity of nitrogen, and of the principal ash constituents, in the fasted live weight of the animals analysed at Rothamsted. For convenience of comparison each animal is assumed to weigh 1000 lbs. The table also gives the nitrogen and ash constituents in wool and milk; it thus supplies full information as to the loss which a farm will sustain by the sale of animal produce. The composition of wool is deduced from foreign analyses.

ASH CONSTITUENTS AND NITROGEN IN 1000 POUNDS OF VARIOUS ANIMALS AND THEIR PRODUCTS.*

	Nitrogen.	Phosphoric Acid.	Potash.	Lime.	Magnesia.
	lbs.	lbs.	lbs.	lbs.	lbs.
Fat calf . . .	24·64	15.35	2·06	16·46	0·79
Half-fat ox . .	27·45	18.39	2·05	21·11	0·85
Fat ox . . .	23·26	15·51	1·76	17·92	0·61
Fat lamb . .	19·71	11·26	1·66	12·81	0·52
Store sheep . .	23·77	11·88	1·74	13·21	0·56
Fat sheep . .	19·76	10·40	1·48	11·84	0·48
Store pig . .	22·08	10·66	1·96	10·79	0·53
Fat pig . . .	17·65	6·54	1·38	6·36	0·32
Wool, unwashed .	54·00	0·70	56·20	1·80	0·40
,, washed . .	94·40	1·80	1·90	2·40	0·60
Milk . . .	5·92	2·00	1·70	1·70	0.20

* The constituents of animals are reckoned in this table on a fasted live weight including contents of stomachs and intestines.

These figures show that the ox contains in proportion to its weight a larger amount of nitrogen, and a much larger amount of phosphoric acid and lime, than either the sheep or pig. Of all the animals raised on a farm the pig contains least of all the important ash constituents.

The large amount of potash in unwashed wool is very remarkable; a fleece must sometimes contain more potash than the whole body of the shorn sheep.

If we assume a cow to yield 600 gallons of milk in the year, and the milk to be sold, the loss to the farm will be about 36 lbs. of nitrogen, 12 lbs. of phosphoric acid, and 10 lbs. of potash. If the milk is made into cheese the annual loss will be about 28 lbs of nitrogen, 7 lbs. of phosphoric acid, and 1 lb. of potash. If only butter is sold the loss of nitrogen and ash constituents will be quite insignificant.

In a fat ox about 60 per cent. of the fasted live weight will be butchers' carcase; in a fat sheep about 58 per cent.; in a fat pig (fatted for pork) 83 per cent. The proportion of carcase increases considerably during fattening. Thus the carcase in the store sheep killed at Rothamsted averaged 53·4, in the fat sheep 58·6, and in the very fat sheep 64·1 per cent. of the fasted live weight.

When a lean animal is fattened the larger part of the increase in live weight is carcase. It was found at Rothamsted that in the case of sheep passing from the "store" to the "fat" condition, increasing in weight from 102 lbs. to 155 lbs., about 68 per cent. of the increase was carcase. With "fat" sheep passing into the "very fat" state, increasing from 144 lbs. to 202 lbs. live weight, the proportion of carcase in the increase was about 77 per cent. With a fattening pig, increasing from 103 lbs. to 191 lbs. live weight, the proportion of carcase in the increase was found to be 91 per cent.

The percentage composition of the increase of sheep and pigs when passing from the "store" to the "fat" condition is about as follows. The increase of fattening oxen will have a similar composition.

PERCENTAGE COMPOSITION OF THE INCREASE WHILST FATTENING.

	Water.	Nitrogenous matter.	Fat.	Ash.
Sheep . . .	22·0	7·2	68·8	2·0
Pigs . . .	28·6	7·8	63·1	0·5

The increase during the fattening stage of growth is seen to be chiefly an increase in fat, eight to nine parts of fat being laid on for one of nitrogenous matter. The proportion of fat would be somewhat greater still in the increase of highly fattened animals, as, for instance, of pigs fed for bacon.

The Processes of Nutrition.—We have already seen that the food of plants is of the simplest character. From such simple substances as carbonic acid, nitric acid, water, and a few salts, a plant is able to construct a great variety of elaborate compounds. It accomplishes these surprising transformations by a consumption of force (sunlight) external to itself. An animal has no such constructive power. The animal frame is built up of substances existing ready formed in the food, or produced by the splitting up or partial combustion of some of the food constituents in the body. The animal derives no aid from external force. The temperature of the animal (about 100° Fahr.) is maintained by heat generated within the body by the combustion of the materials consumed as food. The force by which all the mechanical work of the animal is performed is also derived from the same source. The source of heat and force in the animal is thus purely internal.

It is evident from what has just been said that the food of animals has duties to perform which are not demanded of the food of plants. In plants the food merely provides the matter for building up the vegetable tissues. In the animal, besides constructing tissue, the food has to furnish the means of producing heat, and executing mechanical work.

1. *Food Constituents and their Functions.*—The solid ingredients of vegetable food may be classed generally as—(1) albuminoids (proteids); (2) fat; (3) carbohydrates; (4) salts. Besides these general ingredients of food we have in immature vegetable products a fifth class — the amides, which also takes part in animal nutrition. The albuminoids and amides are nitrogenous substances, the other ingredients of food are non-nitrogenous.

The albuminoids occurring in corn, roots, and other forms of vegetable food, are quite similar in composition to those found in milk, blood, and flesh. From the albuminoids of the food are formed not only the albuminoids of the animal frame, but also the gelatinoids, the hair, wool, horn, &c., and to some extent the fat. By the combustion of albuminoids in the body heat and mechanical force will also be developed. Albuminoids thus supply in themselves most of the requirements of the animal—a statement which can be made of no other food constituent. The albuminoids of food are frequently described as "flesh-formers."

An animal, even when not increasing in weight, will always require a certain constant supply of albuminoid in its food to replace the waste of nitrogenous tissue which is always going on. The amount of digestible albuminoid required for this purpose is but small; in the case of an adult man it is not more than forty grams (1·4 oz.) per day. For the requirements of animals see p. 120.

When the nitrogenous tissues, or the albuminoids consumed as food, are oxidised in the body, the nitrogen they contain is not burnt, but excreted in the form of urea. The urea produced is one-third the weight of

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the albumin oxidised.* When the albuminoids, either of the food or of the wasting tissues, are only partially oxidised, fat as well as urea may be produced. According to the new determinations of the heat evolved on combustion, 100 parts of albumin must yield less than 47 parts of fat.

The amides consumed as food are burnt in the system, and their nitrogen excreted as urea. Amides cannot supply the place of albuminoids as muscle-formers, but by combustion they serve for the production of heat and force.

The fats contained in food are similar to those found in the animal body, but an animal is apparently capable of transforming one kind of fat into another. The fat of the food is either burnt in the animal system to furnish heat and mechanical energy, or it is stored up as reserve matter. Fat has a greater value as a heat and force producer than any other ingredient of food.

The carbo-hydrates of the food are chiefly starch, sugar, and cellulose; these substances consist of carbon, hydrogen, and oxygen, the last two elements being in the proportion to form water—hence the name. Various other non-nitrogenous constituents of food, as pectin, lignin, and vegetable acids, are also generally included under this title, though not, strictly speaking, carbo-hydrates. Carbo-hydrates form the largest part of all vegetable foods. They are not permanently stored up in the animal body, but serve, when burnt in the system, for the production of heat and mechanical work. They are also capable, when consumed in excess of immediate requirements, of conversion into fat.

* There are small quantities of other nitrogenous products, as uric and (in the case of herbivorous animals) hippuric acid, voided in the urine, but they do not in this place require our attention.

The carbo-hydrates and fat are quite incapable of adding to the nitrogenous tissues of the body. They may, however, have this effect indirectly by protecting the albuminoids of the food from oxidation. A moderate quantity of albuminoids supplied to a growing animal will thus produce a larger increase of muscle when accompanied by a supply of carbo-hydrates or fat than if consumed alone. In the former case the non-nitrogenous ingredients of the food supply the heat and force demanded by the animal body, in the latter case the albuminoids have to meet every requirement.

If an adult animal receives the small quantity of albuminoids and salts necessary to supply the waste of tissue, the whole of its remaining wants may be met by supplies of carbo-hydrates and of fat.

The relative value of food constituents for the production of heat and force depends on the amount of heat evolved during their oxidation. It has been found that 100 parts of fat when burnt give the same amount of heat as 213 parts of the albuminoids of muscle, 469 parts of asparagine (the heat yielded by the matter excreted as urine when these substances are consumed in the body is in both cases deducted), 229 parts of starch, 235 parts of cane sugar, or arabic acid (gum), and 255 parts of glucose, or crystallised milk sugar. Digested cellulose has a smaller value than the carbo-hydrates just named, 267 parts are probably equivalent to 100 of fat.

The ash constituents present in the food are the same as those found in the animal body; all that is accomplished by the animal is to select from the supply those of which it is in want.

2. *Digestion.*—The object of digestion is to bring

the solid constituents of the food into a form suitable for absorption into the blood. Of the *carbo-hydrates* of the food some, as sugar, are already soluble and diffusible, and need no digestion; others, as starch and cellulose, are naturally insoluble. The digestion of carbo-hydrates commences with the action of the saliva, which has the property of converting starch into sugar (maltose). This action, in the case of ruminants, is prolonged by the temporary sojourn of the food in the first two stomachs, and its return to the mouth in chewing the cud. The digestion of the cellulose by a fermentive process commences in the paunch. The further solution of starch and cellulose is effected in the intestines. The pancreatic juice has a powerful action on starch. In the intestines maltose is converted into dextrose. The cellulose is dissolved in the colon by a fermentive process, due apparently to bacteria, in which acetic and butyric acids, carbonic acid, and a little marsh gas are the products.

The *albuminoids* of the food are attacked by the gastric juice of the stomach (the fourth stomach of ruminants), and converted into peptones, bodies similar to albuminoids in composition, but which, unlike them, are diffusible through a membrane. The pancreatic juice of the small intestines also converts albuminoids into peptones, and partly into amides, leucine and tyrosine.

The digestive agents in saliva, gastric juice, and pancreatic juice, are unorganised ferments (enzymes), known respectively as ptyalin, pepsin, and trypsin.

Fat, liquefied by the heat of the body, is probably capable of absorption without change. The digestion of fat in large quantities is greatly assisted by the bile and pancreatic juice.

The absorption of the dissolved constituents of the food takes place more or less in all parts of the alimentary canal, but chiefly in the small intestines. The absorbed matters pass into the blood.

The blood of an animal is the source of nourishment to the whole body; out of its ingredients all the tissues are formed. The blood is also the means of conveying to the tissues the oxygen which is essential to their vitality, and of removing from them carbonic acid, and the other products of their metamorphosis.

3. *Respiration.*—The blood is supplied with oxygen during its passage through the lungs, where it is brought into contact with air. The oxygen is absorbed by the hæmoglobin, which forms the chief constituent of the red blood corpuscles. The scarlet blood thus produced is circulated through the whole body by the arteries; the oxygen it supplies is consumed in the tissues, producing, among other results, heat and mechanical work. The blood finally returns from the tissues by the veins. The hæmoglobin has then lost its oxygen, and has assumed a purple colour; the blood serum also contains carbonic acid gas in solution, and many other products of decomposition. By passing again through the lungs the carbonic acid is more or less completely discharged, and a fresh supply of oxygen obtained.

4. *Excretion.*—The products which result from the oxidation of tissue, or of the food consumed, are removed from the body by the lungs, the kidneys, or the skin. The chief products of oxidation in the body are carbonic acid, water, urea, and salts. Carbonic acid is removed through the lungs, and to a smaller extent by the skin;

urea and salts by the kidneys; water by all the organs of excretion.

Non-nitrogenous substances, as fat and sugar, when oxidised in the body, yield simply water and carbonic acid. The nitrogen of the albuminoids, gelatinoids, and amides, is not oxidised, but is excreted in the form of urea. The sulphur of the albuminoids is in part oxidised to sulphuric acid.

The quantity of nitrogen in the urine is a measure of the albuminoids, gelatinoids, and amides oxidised in the body. In the urine, and in the perspiration of the skin, are also removed all the salts not required for the animal economy. Sodium and potassium salts are generally abundant in the urine.

The solid excrement contains the undigested part of the food, with the residues of the bile and other secretions of the alimentary canal.

CHAPTER VII.

FOODS.

The Composition of Foods.—Detailed composition—Proportion of nitrogen existing as true albuminoids—Comparison of foods. *Circumstances producing Variation.*—Influence of age and manuring—Changes during haymaking and ensilage. *Digestibility of Foods.*—Method of determination—Experiments with ruminants—Experiments with horses—Experiments with pigs—Experiments with geese and fowls. *Circumstances affecting Digestibility.*—Influence of age of animal, daily ration, and labour — Influence of cooking on digestibility—Influence of the maturity of fodder crops on their digestibility—Influence of one food on the digestibility of another—Common salt. *Comparative Nutritive Value of Foods.* — Comparative power of producing heat and work — Proportion of albuminoids to non-albuminoids—Influence of proportion of water—General conclusions.

In the preceding chapter we have enumerated the chief constituents of food, and described their functions in the animal body; we may now proceed a step further, and consider the detailed composition and feeding value of the foods actually employed on the farm.

The nourishing value of a food is plainly fixed by two factors:—1. Its composition. 2. Its digestibility. The first of these determines the richness of the food in albuminoids, fat, carbo-hydrates, and ash constituents. The second determines the extent to which these various constituents are made use of in the animal body.

Composition of Foods.—The average percentage composition of the foods commonly given to farm animals is shown in the following table. The figures given are in every case the mean of a large number of analyses.

PERCENTAGE COMPOSITION OF ORDINARY FOODS.

Food.	Water.	Nitrogenous substance.	Fat.	Soluble carbo-hydrates.	Fibre.	Ash.	Albu-minoids.
Cotton cake (decorticated)	8·2	44·0	13·5*	21·5	6·0	6·8	40·9
Cotton cake (undecorticated) . . .	12·2	20·8	5·4	35·6	20·8	5·2	19·3
Linseed cake . .	11·7	27·0	11·4†	34·2	9·0	6·7	25·4
Beans	14·5	25·5	1·6	45·9	9·4	3·1	22·4
Peas	14·3	22·4	2·0	52·5	6·4	2·4	19·7
Oats	13·0	12·9	6·0	55·4	10·0	2·7	11·9
Wheat	12·3	11·7	1·8	70·0	2·4	1·7	10·2
Rye	14·0	11·0	2·0	67·4	3·5	1·8	?
Barley	14·0	10·6	2·0	64·1	7·1	2·2	10·0
Maize	11·0	10·4	5·1	70·0	2·0	1·5	9·7
Malt dust . . .	10·0	23·7	2·2	43·8	13·5	6·8	17·3
Wheat bran . . .	14·0	14·5	4·0	51·3	10·1	6·1	12·3
Brewers' grains . .	76·6	4·9	1·1	11·0	5·2	1·2	4·8
Brewers' grains (dried)	9·3	20·2	7·7	43·6	15·0	4·2	19·8
Rice meal . . .	10·0	11·9	12·1	47·0	9·0	10·0	11·1
Clover hay (medium) .	16·0	12·3	2·2	38·2	26·0	5·3	10·2
Meadow hay (medium)	14·3	9·7	2·5	41·0	26·3	6·2	8·3
Bean straw . . .	16·0	8·1	1·0	35·3	35·0	4·6	?
Oat straw . . .	14·3	4·0	2·0	36·2	39·5	4·0	3·8
Barley straw . .	14·3	3·5	1·4	36·7	40·0	4·1	3·2
Wheat straw . .	14·3	3·0	1·2	36·9	40·0	4·6	2·9 ?
Pasture grass . .	80·0	3·5	0·8	9·7	4·0	2·0	2·6
Red clover (before bloom)	83·0	3·3	0·7	7·0	4·5	1·5	2·5 ?
Potatos . . .	75·0	2·1	0·2	20·7	1·1	0·9	1·3
Carrots . . .	86·0	1·3	0·2	10·0	1·6	0·9	0·7
Mangels . . .	88·0	1·1	0·1	8·9	1·0	0·9	0·4
Swedes . . .	89·3	1·4	0·2	7·4	1·1	0·6	0·7
Turnips . . .	92·0	1·0	0·2	5·2	0·9	0·7	0·5

* The cake lately imported contains often only 8—10 per cent. of oil.

† Hard-pressed linseed cakes contain 7—10 per cent. of oil; lightly-pressed cakes. 11—13 per cent. Some Russian cakes contain 14—20 per cent.

The "soluble carbo-hydrates" in the above table include starch, pectin, and the finer parts of the fibre; these are not soluble in water, but are dissolved by the weak acid and alkali employed by the analyst to separate the coarse fibre. In the straw of cereals nearly the whole of the "soluble carbo-hydrate" is cellulose.

The "nitrogenous substance" in the table is obtained by multiplying the percentage of nitrogen by 6·25, it thus represents the amount of albuminoids present, *if we assume that the whole of the nitrogen exists in this form.* It has however been shown during the last few years that a part of the nitrogen of vegetable foods exists, not as albuminoids, but as amides (asparagine, glutamine, leucine, tyrosine, &c.), and in some cases as nitrates. The following table shows the average proportion of the nitrogen which exists in the form of albuminoids in various foods, according to the analyses at present published; numbers marked with an asterisk are the mean of few analyses.

PROPORTION OF ALBUMINOID NITROGEN IN VARIOUS FOODS PER 100 OF TOTAL NITROGEN.

Cotton cake	93	Malt dust	72
Linseed cake	94	Brewers' grains	98*
Beans	88	Oat straw	80*
Peas	88	Barley straw	90*
Oats	94	Meadow hay	85
Wheat	90*	Clover hay	83
Barley	94	Grass (young)	75
Maize	93	Potatos	60
Rice meal	94*	Carrots	52
Wheat bran	85	Turnips	49
Malt	79	Mangels	37

It appears from these numbers that the greater part of the nitrogen in ripe seeds exists as albuminoids. In wheat grain the proportion of albuminoid nitrogen is rather low, owing to the considerable proportion of non-albuminoid nitrogen contained in the bran; on this point, however, further analyses are needed. In germinated grain, as malt, a considerable part of the albuminoids is replaced by amides. The few analyses of ripe straw show that the nitrogen present is chiefly albuminoid. In immature produce the proportion of non-albuminoid nitrogen is much more considerable. The albuminoids are in largest proportion in hay, in smaller proportion in green fodder, and in still smaller proportion in roots and tubers. In mangels a considerable part of the non-albuminoid nitrogen exists as nitrates. The circumstances producing variation in the proportion of albuminoids will be considered presently.

We may now consider the average composition of the various foods mentioned in the table.

The amount of total *dry matter* is seen to be tolerably uniform throughout the various classes of dry foods, the foods richest in fat being generally the driest. Corn and straw in bulk will frequently contain a somewhat larger amount of water than that mentioned in the table. In green fodder and roots the proportion of water reaches its maximum. Of the roots and tubers, potatos contain the largest, and white turnips the least proportion of dry matter.

We have already seen that *albuminoids* and *fat* are the most concentrated forms of food which an animal can consume; those foods which are rich in albuminoids and fat have therefore, if digestible, the highest nourishing value. At the head of all foods in this respect stand the various descriptions of oilcake; they are, without doubt, among the most concentrated foods at the farmer's disposal. The leguminous seeds, as beans, peas, and lentils, are rich in albuminoids, but not in fat. The cereal grains are much poorer in albuminoids, containing only about one half the proportion found in leguminous seeds. Of the common cereals, oats are generally the most nitrogenous, and maize the least. Oats and maize are characterised by containing more fat than the other cereal grains. The special characteristic of all the cereal grains is their richness in an easily-digested carbo-hydrate, starch.

Of the cereal products mentioned in the table, the bran, brewers' grains, and rice meal, represent respectively the external covering of wheat, barley, and rice. These foods are richer both in nitrogenous matter and fat, but contain a much more considerable proportion of fibre than the whole grain. Malt-dust (known also as malt combs) consists of the radicles of the germinated barley, which are removed after the malt has been dried. This material is very rich in nitrogenous matter, a considerable proportion of which, however, is in the form of amides.

In the case of hay, straw, green fodder, silage, and roots, the general composition is a less safe guide to the nourishing value. The nitrogen is here no certain measure of the proportion of albuminoids present. The fat credited to these foods includes indigestible waxy matter; in the case of green fodders, chlorophyll; and in the case of silage, lactic acid; these substances being all equally dissolved by the ether used to separate the fat. The carbo-hydrates also include various substances of little feeding value. The same weight of dry matter in crude foods of this class has thus a decidedly less nourishing value than in foods consisting entirely of matured grain. Foods belonging to different classes cannot safely be compared on the basis of their composition.

Most foods supply a sufficient quantity of the *ash constituents* which are required for the formation of bone and muscle; the chief of these are phosphoric acid, lime, and potash. The oilcakes and bran are the foods richest in phosphoric acid; straw and meadow hay are the foods poorest in this constituent. Lime is most abundant in clover hay, bean straw, and turnips, and occurs in least quantity in the cereal grains and in potatos. Potash is abundant in roots, hay, bean straw, bran, and oilcake, and is found in smallest quantity in the cereal grains. The proportion of phosphoric acid and potash in various foods is shown in the table on page 139.

Of all the ash constituents lime and soda are probably the most generally deficient. Maize is of all ordinary foods (rice excepted) the poorest in lime; it certainly contains too small an amount for a rapidly growing animal. At Rothamsted a mixture of coal ashes, common salt, and superphosphate was used with advantage in the case of young pigs fed solely on maize. It must be recollected, however, that animals will generally receive no inconsiderable amounts of lime in their drinking water.

Circumstances producing Variation in Composition.— The composition of all vegetable foods is liable to variation, depending on the state of maturity of the plant, and the character of the soil and season. In the case of perfectly *matured* produce, as, for instance, ripe seed, the variations in composition are not generally considerable, and an average composition, such as is given in the table, will be found in most cases pretty correct. But in the case of immature produce, such as meadow grass, turnips, or mangels, the composition largely depends on the stage of growth in which the plant is taken, and is also greatly affected by the character of the manuring. It may be generally stated that as a plant matures the proportion of water, nitrogenous matter, and ash constituents diminishes, while the proportion of carbo-hydrates largely increases. At the same time the amides become more or less converted into albuminoids.

The following table shows the percentage composition of meadow grass cut at three different dates in the same field. The first cutting will represent pasture grass fed off in the green state by stock; the second cutting is good ordinary hay; the third cutting is an over-ripe hay, somewhat coarse and stemmy, but well harvested. The composition given in every case is that of the dry substance:—

COMPOSITION OF HAY HARVESTED AT DIFFERENT DATES.

Date of Cutting.	Nitrogenous substance.	Fat.	Soluble carbo-hydrates.	Fibre.	Ash.
May 14 . .	17·65	3·19	40·86	22·97	15·33
June 9 . .	11·16	2·74	43·27	34·88	7·95
June 26 . .	8·46	2·71	43·34	38·15	7·34

Young grass is thus much richer in nitrogenous substance, and contains a smaller proportion of indigestible fibre than older grass, and is consequently more nourishing. The same comparison may be made between young clover and that which is allowed to mature for hay. Fodder crops should be cut for hay immediately full bloom is reached; after this point the quality of the hay will considerably deteriorate.

While fodder crops deteriorate towards maturity, from the conversion of soluble carbo-hydrates into fibre, crops such as potatos and mangel improve, the carbo-hydrates produced in their case being respectively starch and sugar, both of them substances of great feeding value.

The influence of *high manuring* on the composition of a crop is generally considerable. A luxuriant crop will always contain more water than one in less active growth. Very large mangels often contain only 6 per cent. of dry matter, while in quite small roots the proportion may be as high as 15 per cent. Luxuriance also retards maturity. A heavily manured mangel will contain, at the same date, a much smaller proportion of sugar than a similar mangel grown on poorer soil. The result of liberal nitrogenous manuring is thus not only to increase the bulk of the crop, but also generally to diminish the proportion of carbo-hydrates, and increase the nitrogen, ash constituents, and water. In highly manured crops a smaller proportion of the nitrogen will exist as albuminoids than in crops less heavily manured and more mature. Thus, in a crop of mangels of 18 tons per acre, manured with farmyard manure, the albuminoid nitrogen amounted to 38 per cent. of the total nitrogen; while in a crop of 28 tons, receiving nitrate of soda and superphosphate in addition to the dung, the albuminoid nitrogen was only 29 per cent. of the total. It is evident that large mangels or turnips, produced by liberal manuring, are less nutritious than smaller roots. Potatos do not deteriorate in quality as they increase in size.

In the case of hay the composition is further affected by the *conditions of haymaking,* and by the subsequent changes in the rick. Grass that has suffered from rain during haymaking will contain less soluble matter (carbohydrates and albuminoids) than well-made hay; this loss will be greatly increased if the hay has been long in the field, and undergone fermentation as well as washing. The changes which take place in the rick are seen on a larger scale in the process of ensilage.

When green fodder is stored in a *silo* the mass becomes hot from oxidation, a loss both of water and solid matter takes place, carbonic acid and other gases being evolved. If the green fodder has been cut small, and compressed by weights as soon as it was placed in the silo, oxidation is at a minimum; under these circumstances alcoholic, lactic, and butyric fermentation sets in more or less strongly, and "sour silage" is produced. If, on the other hand, the silo is filled gradually, and a few days elapse before the weights are applied, the temperature rises much higher, owing to the greater bulk of air enclosed. If the mass is weighted as soon as 140°—160° Fahr. is reached, "sweet silage" will result, the high temperature having been fatal to the living organisms which produce an acid fermentation. In making silage the loss of solid matter falls chiefly on the carbohydrates. The total nitrogen is scarcely altered in quantity, but a considerable part of the albuminoids is destroyed, the nitrogen being found in the silage as amides, or as ammonium salts. In the case of "sour silage" one-third of the albuminoids is not unfrequently destroyed. In making sweet silage there is, apparently, a smaller destruction of albuminoids. The final product, in this case, contains a larger proportion of soluble carbohydrates, and little or no acid. The total loss of solid matter is probably greater in making sweet, than in making sour silage.

Digestibility of Foods.—Our knowledge concerning the digestion of food by farm animals is almost entirely derived from German investigations;* much information has already been obtained upon this subject, though a great deal yet remains to be accomplished. The general method of investigation has been to supply an animal with weighed quantities of food, the composition of which has been ascertained by chemical analysis. During this experimental diet the solid excrements are collected and weighed, and are finally analysed by the same chemical methods previously applied to the food. Subject, therefore, to certain small corrections for intestinal secretions, we obtain by this plan the amount of each constituent of the food which has passed through the animal unabsorbed, and by difference the amount digested. The proportion of each constituent digested for 100 supplied in the food is known as its "digestion coefficient."

1. *Experiments with Ruminants.*—Ruminating animals possess an extensive digesting apparatus, consisting of the well-known four stomachs, in addition to the intestinal organs. Food takes a considerable time in passing

* The information given in this section is taken to a great extent from the admirable work of Dr. E. Wolff, "Die Ernährung der Landwirthschaftlichen Nutzthiere," and its valuable Supplement.

through this system. In changing the diet of an ox, five days will generally elapse before the remains of the preceding diet are entirely expelled by the animal. Animals of this class are specially adapted for the digestion of bulky foods containing much fibre.

Experiments have been made with oxen, cows, sheep, and goats. The power of these different animals for digesting food is apparently very similar, but no accurate comparisons have as yet been made. The following table shows the average results obtained with ruminating animals fed on the foods respectively mentioned. The figures given represent the "digestion coefficients" found for each constituent of the food consumed.

EXPERIMENTS WITH CATTLE, SHEEP, AND GOATS.

Food.	Digested for 100 of each constituent supplied.				
	Total organic matter.	Nitrogenous substance.	Fat.	Soluble carbo-hydrates.	Fibre.
Meadow hay (medium)	60	57	48	62	58
Clover hay (medium)	57	55	51	65	45
Lucerne hay (very good)	60	74	39	66	43
Oat straw	50	35	35	45	57
*Barley straw	53	20	42	54	56
*Wheat straw	46	17	36	39	56
*Bean straw	51	49	56	64	39
*Cotton cake (decorticated)	80	85	88	84	?
*Cotton cake (undecorticated)	52	74	91	50	16
*Linseed cake	81	86	90	80	44
*Peas	90	89	75	93	66 ?
Beans	89	88	87	92	72 ?
Oats	71	79	84	76	24
*Barley	81	77	100	87	?
*Maize	89	79	85	91	?
*Rice meal	89	77	88	100	67
Wheat bran	72	78	69	77	33
*Malt dust	84	82	49	88	95
*Brewers' grains	63	73	84	64	39

* These results are derived from a few experiments.

The digestibility of the foods in the upper division of the table has been for the most part determined by feeding the animals on these foods alone; the digestibility of the foods in the lower division of the table, and also of roots, has been found by supplying these foods in various proportions along with hay, the digestibility of which had been already ascertained with the same animal.

In the case of ordinary meadow and clover hay the total organic matter digested is but 55 to 60 per cent. of that supplied; with hay of exceptional quality the proportion digested may rise to 70 per cent. With straw only 45 to 50 per cent. of the organic matter is generally digested, the minimum occurring with wheat straw.

The digestibility of the nitrogenous matter in hay and straw appears to increase as its proportion rises. A sample of wheat straw experimented with contained 4·8 per cent. of nitrogenous matter in its dry substance, of which only one-fifth, or 20 per cent., was digested; while good lucerne hay with 19·3 per cent. of nitrogenous matter had 76 per cent. of this in a digestible form. The precise nature of the digested and undigested nitrogenous matter has not yet been ascertained; amides being soluble bodies have undoubtedly been usually reckoned as digestible albumin.

Of the fibre in hay and straw about 40 to 60 per cent. is generally digested by ruminant animals. The fibre of leguminous hay and straw (clover and lucerne hay, and bean straw) is less digestible than the fibre of similar graminaceous foods (grass hay, oat and wheat straw). It has been shown that both in the case of the soluble carbohydrates, and of the fibre, the portion digested has always the general formula of starch or cellulose, $C_6H_{10}O_5$, while the portion left undigested is much richer in carbon. It appears, therefore, that while cellulose is digested to a considerable extent, the lignin which is deposited on the tissues as the plant increases in age, and which contains a larger proportion of carbon, is much less digestible. Chemical analysis shows that the fibre of leguminous hay and straw is richer in carbon, and consequently in lignin, than the fibre of grass hay or cereal straw.

The concentrated foods placed in the lower section of the table are seen to be far more thoroughly digested than is the case with hay or straw. When of good quality, 80 to 90 per cent. of the organic matter of these foods will be assimilated by the animal, except in those cases where much fibre is present. The albuminoids and fat in these foods have especially a greater digestibility than the same ingredients in hay and straw. The amount of fibre is usually too small for its digestibility to be determined with certainty. The hard fibre forming the husk of seeds is apparently but little digested. The oats employed were of somewhat inferior quality.

Roots and potatos are not mentioned in the table; they are apparently very thoroughly digested.

2. *Experiments with Horses.*—In experiments conducted by Wolff the digestive powers of the horse and sheep have been accurately compared, the same food having been supplied to each animal.

The principal results were as follows :—

EXPERIMENTS WITH HORSES.

Food.	Proportion of each constituent digested for 100 supplied.				
	Total organic matter.	Nitro-genous substance.	Fat.	Soluble carbo-hydrates.	Fibre.
*Pasture grass	62	69	13	66	57
Meadow hay (very good) .	51	62	20	57	42
Meadow hay (ordinary) . .	48	57	24	55	36
Red clover hay	51	56	29	64	37
Lucerne hay (very good) .	58	73	16	70	40
*Oats	68	86	71	74	21
*Beans	87	86	8	93	69
*Maize	91	78	63	94	100

EXPERIMENTS WITH SHEEP.

*Pasture grass	75	73	65	76	80
Meadow hay (very good) .	64	65	54	65	63
Meadow hay (ordinary) . .	59	57	51	62	56
Red clover hay	56	56	58	61	49
Lucerne hay (very good) .	59	71	41	66	45
*Oats	71	80	83	76	30
*Beans	90	87	84	91	79
*Maize	89	79	85	91	62

On comparing these figures it is evident that a horse digests meadow grass and hay less perfectly than a sheep, and the difference between them is apparently as great when the food is young grass as when ordinary hay is employed. There is little difference in the proportion of albuminoids assimilated by the two animals, but the divergence becomes considerable when we come to the carbo-hydrates, fibre, and fat. Of the carbo-hydrates the horse digests 7—10 per cent., of the fibre 21 per cent., and of the fat and waxy matter 24—52 per cent. less than the sheep. On the whole, the horse digests about 12 per cent. less of the total organic matter of grass hay than the sheep. With red clover hay the results with the horse are better. With lucerne hay of good quality the digestion by the horse is still better, and (save as regards the fat) practically equals that of the sheep.

The smaller digestive power of the horse for vegetable fibre is plainly connected with the fact that it is not like the sheep a ruminant animal, and is thus unprovided with the same means of attacking an insoluble food. In a trial with wheat-straw chaff the horse digested 22·5, and the sheep 47·6 per cent. of the total organic matter.

With corn the digestion of the horse is apparently quite equal to that of the sheep. No stress must, of course, be laid on the digestion coefficients found for ingredients of the food present in small quantity, as the fat and fibre of beans, and the fibre of maize. In French experiments on horses, in which maize or beans were consumed alone, without the addition of hay, it was found that with maize 94·5 per cent. of the total organic matter, and 87·1 per cent. of the nitrogenous substance, and with beans 90·4 per cent. and 89·3 per cent. respectively, were digested.

Of potatos 93 per cent., and of carrots 87 per cent. of the organic matter were digested by the horse.

3. *Experiments with Pigs.*—These have not been so numerous as those with ruminant animals. The following table shows the digestibility ascertained for some of the common pig foods :—

EXPERIMENTS WITH PIGS.

Food.	Digested for 100 supplied.			
	Total organic matter.	Nitrogenous substance.	Fat.	Soluble carbohydrates.
*Sour milk	97	96	95	99
*Meat flour	95	97	87	—
Pea meal	91	88	49	96
*Bean meal	84	79	71	91
Barley meal	83	78	68	90
Maize meal	92	86	76	9
Rye bran	67	66	58	75
Potatos	94	81	—	98

The digestive power of the pig for the foods here mentioned is very considerable, and in cases admitting of comparison appears to be fully equal to that possessed by ruminant animals. Nor is the pig incapable of digesting vegetable fibre, when this is presented in a favourable condition. Two pigs fed on green oats and vetches digested 48·9 per cent. of the fibre supplied. The digestive apparatus of a pig is not, however, adapted for dealing successfully with bulky fodder. Pigs are very capable of digesting animal food, as will be seen from the results obtained with milk and meat flour quoted in the table.

4. *Experiments with Geese and Fowls.*—Birds have apparently no power of digesting vegetable fibre; the food passes too quickly through the system for the fibre to be attacked.

Circumstances affecting Digestibility.—The individual character of the animal undoubtedly affects the proportion digested. Of two animals supplied with the same food, one will often persistently digest a larger proportion than the other. In young animals the digestive

* The numbers in this case were obtained from a single sample of food.

power is apparently equal to that of animals of full age. Sheep from six to fourteen months old showed no distinct change in digestive capacity.

Differences in the quantity of the daily ration of hay do not sensibly affect the proportion digested; an animal will not digest more by being starved. Labour is also practically without influence; horses at rest and at work digest nearly the same proportion of their food. The cooking of food is generally of doubtful advantage; beans, maize, and bran are not better digested by horse or ox when previously soaked in water. Barley, maize and pea meal have been found more nourishing for pigs when fed dry than when previously cooked. Differences in the quality of a food may, however, exercise a great influence on its digestibility: the addition of another food may also considerably alter the rate of digestion of the first food.

The digestibility of fodder plants is mainly determined by their age; all the constituents of a young plant are more digestible than in the same plant of greater age. The composition of meadow grass cut at three different dates has been already given on page 93; the three cuttings were supplied to sheep in the form of hay, and the following digestion coefficients were obtained:—

DIGESTION OF HAY BY SHEEP.

Date of cutting.	Proportion of each constituent digested for 100 supplied.				
	Total organic matter.	Nitrogenous substance.	Fat.	Soluble carbohydrates.	Fibre.
May 14 . . .	75·8	73·3	65·4	75·7	79·5
June 9 . . .	64·3	72·1	51·6	61·9	65·7
„ 26 . . .	57·5	55·5	43·3	55·7	61·1

The diminution in digestibility with the increasing maturity of the grass is very striking, and is very equally spread over all the constituents. Experiments with clover cut at different stages of growth have yielded similar results.

It follows from what has now been stated that no fixed nutritive value can be ascribed to fodder crops, or to the hay made from them, as both their composition and digestibility are largely influenced by their age and condition when cut. The young plant is always the most nutritive. The superior fattening quality of a pasture, as compared with that of the hay made from it, is clearly due to the fact that on land continuously grazed the animal is entirely fed on young herbage, while hay will always consist of the fully grown plant. Further illustrations of the different digestibility of hay of various qualities have been already given on page 100.

Fodder crops do not sensibly diminish in digestibility by being made into hay, if haymaking is carefully carried out in good weather. But the loss of the finer parts of the plant by rough treatment, or the washing out of soluble matter by rain, may considerably diminish the digestibility. Hay appears to lose some of its digestibility by keeping.

Influence of one food on the digestion of another.—If to a diet of hay and straw, consumed by a ruminant animal, a pure *albuminoid,* as wheat gluten, be added, the added food is entirely digested without the rate of digestion of the original food being sensibly altered. The same result has been obtained in experiments with pigs fed on potatos, to which variable quantities of meat flour were afterwards added: the albuminoids of the meat were entirely digested, while the proportion of the potatos digested remained unchanged.

An addition of *oil* (olive, poppy, and rape oil) to a diet of hay and straw is also apparently without unfavourable influence on the rate of digestion; indeed some experiments with small quantities of oil (½lb. of oil per day per 1,000 lbs. live weight) show an improved digestion of the dry fodder. Oil supplied in moderate quantities is itself entirely digested.

An addition of *starch* or *sugar* to a diet of hay or straw will, on the contrary, diminish its digestibility, if the amount added exceeds 10 per cent. of the dry fodder. The albuminoids of the food suffer the greatest loss of digestibility under these circumstances; the fibre also suffers in digestibility if the amount of carbo-hydrate added is considerable. When starch has been added, it is itself completely digested, if the ratio of the nitrogenous to the non-nitrogenous constituents of the diet (see page 111) is not less than 1 : 8.

These facts are of considerable practical importance. Nitrogenous foods, as oilcake and bean meal, may be given with hay and straw chaff without affecting their digestibility; but foods rich in carbo-hydrates, as potatos and mangels, cannot be given in greater proportion than 15 per cent. of the fodder (both reckoned as dry food) without more or less diminishing the digestibility of the latter. This decrease in digestibility may, however, be counteracted in great measure by supplying with the potatos or mangels some nitrogenous food. When this is done the proportion of roots or potatos may be double that just mentioned without a serious loss of digestibility. Potatos exercise a greater depressing effect on the digestibility of hay than roots, starch being more potent in this respect than sugar. The cereal grains are rich in starch, but contain also a fair proportion of albuminoids; they may be added to dry fodder without seriously affecting its digestibility, if the ratio of the nitrogenous to the non-nitrogenous constituents of the diet does not fall below 1 : 8.

Common salt is well known to be a useful addition to the food of animals. It is stated to quicken the conversion of starch into sugar by the saliva and pancreatic juice. When sodium salts are deficient in the food, salt supplies the blood with a necessary constituent. Sodium salts are tolerably abundant in mangels, and small in quantity in hay; they are absent in potatos, and generally absent in grain of all kinds.

Comparative Nutritive Value of Foods.—Having made ourselves acquainted both with the composition, and the degree of digestibility of ordinary cattle foods, we are now in a position to enter on some general considerations as to their relative feeding value. The following table shows the quantity of digestible nutritive matter in 1000 lbs. of ordinary foods when supplied to sheep or oxen. The carbo-hydrates in the table include digestible cellulose. In calculating the amount of digestible albuminoids it has been assumed that in the original digestion experiment the amides and nitrates present, being soluble bodies, have been reckoned as digestible albumin.

DIGESTIBLE MATTER IN 1000 LBS. OF VARIOUS FOODS.

	Total organic matter.	Nitrogenous substance.	Fat.	Carbohydrates	Albuminoids.
	lbs.	lbs.	lbs.	lbs.	lbs.
Cotton cake (decorticated)	683	374	119	190	343
Linseed cake . . .	648	232	103	313	216
Peas	745	199	15	531	172
Beans	728	224	14	490	193
Oats	597	102	50	445	94
Barley	660	82	20 ?	558	75
Maize	774	82	43	649	75
Rice meal	712	92	106	476	84
Wheat bran . . .	569	113	28	428	91
Malt dust . . .	716	193	11	512	127
Brewers' grains . . .	136	36	9	91	35
Pasture grass . . .	137	26	5	106	17
Clover hay (medium) .	444	68	11	365	47
Meadow hay (medium) .	474	55	12	407	41
Barley straw . . .	435	7	6	422	4
Wheat straw . . .	377	5	4	368	—
Potatos	227	17	1	209	9
Carrots	131	13	2	116	7
Mangels	111	11	1	99	4
Swedes	101	14	2	85	7
Turnips	73	10	2	61	5

The figures in this table will be found useful in arranging the rations for farm animals; the figures can, however, only approximate to the truth, as with different qualities of the same food, and different animals, somewhat different quantities of matter will be digested. The figures given for carrots, mangels, swedes and turnips are rather too high, as they have been assumed to be entirely digested.

1. *Capacity of different Foods for producing Heat and Work.*—The only basis on which the nutritive value of foods of different composition can be compared is in respect to their capacity for producing heat. The pro-

duction of heat and mechanical work is the principal result which food accomplishes in the animal body; the capacity for producing heat is also intimately related to the capacity for producing fat. On the other hand, the amount of heat which any food is capable of producing stands in no relation to its power of increasing or renewing the nitrogenous tissues of the body. We may, however, safely assert that the amount of heat generated by the combustion of the digestible constituents of any food will be a fair guide to its nutritive value, when the diet of which it forms a part supplies a sufficient amount of digestible albuminoids, and this will be the case whenever foods are skilfully employed.

According to recent determinations of the heat-producing power of the various food constituents, their comparative values in this respect are:—

Fat	229
Albumin	107
Starch	100
Cane Sugar and Gum	97
Glucose and Milk Sugar	90
Cellulose (about)	86
Asparagine	49

The albumin and asparagine are here reckoned as minus the nitrogenous matter (urea) excreted by the kidneys.

If we take the quantities of digestible fat, albuminoids, amides, carbo-hydrates, and cellulose, supplied by any food, and multiply them by their respective heat coefficients, the sum of the products will represent the heat-producing capacity of the food when consumed in the animal body. Taking the heat-producing capacity of cotton cake, calculated in this manner, as 100, the values found for other foods will be as follows:—

COMPARATIVE HEAT-PRODUCING VALUE OF FOODS.

	Ordinary condition.	Perfectly dry.
Cotton cake (decorticated) . .	100	100
Maize	97	100
Rice meal	94	96
Linseed cake	93	97
Peas	90	96
Beans	87	93
Barley	80	85
Malt dust	80	81
Oats	78	83
Wheat bran	69	73
Meadow hay (medium) . . .	51	55
Clover hay (medium) . . .	48	53
Barley straw	46	49
Wheat straw	40	43
Potatos	26	95
Brewers' grains	16	64

The correctness of these figures mainly depends upon the digestibility of the respective foods being as shown in the experiments with ruminant animals described in the last section. Linseed cake, from the large proportion of fat and albuminoids which it contains, would be expected to occupy a higher position in the table than maize; its lower rank is due to its less perfect digestibility. The table on page 97 shows, that while 19 per cent. of the organic matter of linseed cake remain undigested, and therefore useless to the animal, only 11 per cent. of maize are thus wasted. If the linseed cake were richer in fatty matter it would occupy a higher place in the table.

We should conclude from these calculations that an equal weight of dry food, as maize, peas, or oil-cake will have a nearly similar feeding value if supplied to an animal receiving a sufficient amount of albuminoids in its diet, as, for example, if given to a sheep fed on good meadow or clover hay.

Many foods may, in fact, be substituted for each other without injury to the nutritive value of the whole diet. A farmer should thus be able to introduce economy into his feeding by watching the market, and making use of those foods which are cheapest. In making his selection, the manure value of the food must, however, be taken into account.

2. *Proportion of Albuminoids to Non-Albuminoids.*—A point of considerable importance in determining the suitability of a food as an article of diet is the proportion between the digestible albuminoid and the digestible non-albuminoid organic constituents: this relation is most conveniently termed the "albuminoid ratio" of the food. Before calculating this relation, the non-albuminoid ingredients of the food are first reduced to their equivalent in starch.* Taking the average composition of foods already given, and the digestibility of their constituents shown by the German experiments, the albuminoid ratios will be as follows:—

* It has been usual to multiply the fat by 2·5 to obtain its equivalent in starch and to add the product to the digested carbo-hydrates and fibre to obtain the total non-albuminoid nutritive matter. In the following table the fat has been multiplied by 2·3, and the carbo-hydrates (and in the second column the amides) reduced to their approximate equivalent in starch, according to the relations shown on p. 108.

RELATION OF NITROGENOUS TO NON-NITROGENOUS CONSTITUENTS IN THE DIGESTIBLE PART OF FOOD.

	Total nitrogenous substance to non-nitrogenous.	Albuminoids to non-albuminoids.
Cotton cake, decorticated	1 : 1·2	1 : 1·4
Cotton cake, undecorticated	1 : 2·1	1 : 2·4
Linseed cake	1 : 2·3	1 : 2·6
Beans	1 : 2·3	1 : 2·7
Brewers' grains	1 : 2·8	1 : 2·9
Peas	1 : 2·8	1 : 3·3
Malt dust	1 : 2·6	1 : 4·2
Wheat bran	1 : 4·2	1 : 5·3
Oats	1 : 5·4	1 : 5·9
Pasture grass	1 : 4·0	1 : 6·4
Clover hay (medium)	1 : 5·0	1 : 7·5
Barley	1 : 7·3	1 : 8·0
Rice meal	1 : 7·6	1 : 8·4
Meadow hay (medium)	1 : 6·9	1 : 9·5
Maize	1 : 9·0	1 : 9·9
*Swedes	1 : 5·4	1 : 11·5
*Turnips	1 : 5·8	1 : 12·1
*Carrots	1 : 8·6	1 : 16·5
†Potatos	1 : 12·2	1 : 23·5
*Mangels	1 : 8·6	1 : 24·1
Barley straw	1 : 53·8	1 : 108·0
Wheat straw	1 : 65·9	1 : ?

In the first column the whole of the nitrogen in the food is reckoned as existing as albuminoids; this supposition, though erroneous, is the one most usually made in calculating the albuminoid ratio. In the second column the true albuminoids only are taken account of; we shall employ these latter ratios in the present work. In this column the amides have been reckoned among the non-albuminous constituents.

* The whole of the root is here assumed to be digestible.

† The quantity of digestible constituents is taken from the experiments with pigs.

The figures show in a striking manner the wide differences that exist amongst foods as to the proportion of albuminoids which they supply. The differences are in fact far greater than was formerly supposed, when it was customary to assume that the whole of the nitrogen of food was albuminoid. Mangels now appear as a food very poor in albuminoids, whereas they were formerly supposed to contain a sufficient proportion. The poverty of a diet of roots and straw chaff in digestible albuminoids is the true reason of the excellent effects produced by the addition of oil-cake or leguminous corn. Oil-cake, peas, and beans, used under these circumstances, have an effect far above their own intrinsic feeding value, as their presence raises the character of the whole diet, and enables the carbo-hydrates of the roots and straw to contribute to the formation of carcase. If, on the other hand, an animal is at pasture, or fed with clover hay, and is thus receiving an abundance of albuminoids, the use of oil-cake or beans will be without especial advantage to the animal, and they may be economically replaced by maize or other cereal grains.

It should be recollected that the albuminoid ratio of a food may be different for different animals if their powers of digestion are unequal. Thus the same meadow hay supplied to sheep and horses had for the former an albuminoid ratio of 1 : 9·1, and for the latter a ratio of 1 : 6·7. The horse, as we have seen, digests the nitrogenous constituents of hay nearly as well as the sheep, but fails in digesting the non-nitrogenous constituents. Hay is thus a more nitrogenous food for horses than for sheep.

The proportion of albuminoids most suitable for various diets will come under consideration in the next chapter.

3. *Influence of proportion of Water.*—The feeding value of roots, and of other foods rich in water, is often diminished by the fact that a part of the heat they produce in the body is consumed in raising the water they supply to the temperature of the animal, and of vaporising a part of it as perspiration. With sheep the normal proportion of water to dry food is about 2 : 1; with horses 2—3 : 1; with cattle about 4 : 1. An excess of water produces a waste of food.

A sheep feeding on turnips in winter in the open field, consuming, say, 20 lbs. of roots per day, will receive in its food about 18 lbs. of water, of which 14 lbs. is beyond that necessary for nutrition. This 14 lbs. of water has to be raised from near the freezing point to the temperature of the animal body, a rise of at least 60° Fahr. To warm the water to this extent will require the combustion of about 51 grams of carbo-hydrates, (reckoned as starch,) equal to about 8 per cent. of the total food consumed. The actual waste of food will however greatly exceed this, as a part of the extra water will be exhaled as vapour in the breath and perspiration, and to vaporise 1 lb. of water at the temperature of the animal body requires the combustion of 64 grams of starch.

The consumption of an excess of water will also somewhat increase the amount of albuminoids oxidised in the animal body, and thus occasion a waste of the nitrogenous part of the food.

The economy of supplying sheep on roots or green fodder with dry food in addition, is obvious from the facts just stated; by so doing the quantity of water consumed by the animal is diminished, and its proportion in the diet brought more nearly to a normal ratio.

4. *General Conclusions.*—Attempts have often been made to affix a money value to each of the constituents of food, and having done this, to calculate the money value of any food on the basis of its composition. Calculations of this kind can at any time be made on the basis of the *market prices*, but values thus arrived at are naturally variable, and by no means necessarily represent the value of the food to the animal, or its value as a source of manure. The relative nutritive value of the various constituents of food can be estimated on scientific grounds only on the basis of their respective heat-producing powers (p. 109); from this point of view fat has more than twice the value of any other food constituent. If, however, the value of food constituents is to include (as it must in practice) their manure value, the nitrogenous substance will then become of greatest worth. The manure value is at present scarcely taken into account in determining the market price of food.

It is difficult, however, to affix a definite feeding value to any food, as its practical effect must depend in great measure on the conditions under which it is employed; more especially on the kind of animal consuming it, and the general character of the diet of which it forms a part. Thus the value of a bulky food, as hay or straw, is far greater when given to a ruminant animal than when consumed by a horse or pig. Concentrated, easily digestible foods, as corn and oil-cake, have clearly a value above their composition when added to a poor and bulky food, as straw chaff, or to a watery food like turnips, because they are the means of raising the quality of the diet to a point at which the animal will thrive. On the other hand, roots and green fodder, even when watery and poor in composition, may have a considerable effect when added in moderate proportion to dry food. The highest value is in short only obtained from food when it is skilfully employed.

There is finally a condition which we can never hope to express by figures, but which has a considerable influence on the effect of any diet; this is flavour. An agreeable flavour stimulates appetite, and probably promotes digestion. This part of the question belongs, however, rather to practice than science.

CHAPTER VIII.

RELATION OF FOOD TO ANIMAL REQUIREMENTS.

The Requirements of the Young Animal.—Composition of colostrum and milk—Suitable albuminoid ratio of the food—Importance of ash constituents. *The Adult Animal.*—Production of Heat—Production of Work—Maintenance diets—Labour diet. *The Fattening Animal.*—Conditions necessary for increase—Results obtained when fattening oxen, sheep, and pigs, on ordinary diets—Alterations in consumption of food, and rate of increase, as fattening proceeds—Albuminoid ratios for fattening animals. *Production of Wool.*—Composition of wool—Influence of diet. *Production of Milk.*—Influence of diet on the quantity of the milk—Albuminoid ratio for milk-cows—Comparative yield of nitrogenous produce by cow and ox—Influence of diet on the quality of milk and butter.

The Young Growing Animal.—The special character of the nutrition of young animals is the rapid formation of nitrogenous tissue and bone, for which purpose an abundant supply of albuminoids and ash constituents in the food is clearly requisite.

The kind of food most appropriate to the wants of a young animal is shown by the composition of milk. The milk supplied to the young immediately after birth (the colostrum) is of a very concentrated description. During the first week after birth the quantity of the milk greatly increases, and its composition gradually alters from that of colostrum to that of ordinary milk.

In the following table will be found the composition of the colostrum and milk yielded by various animals; the numbers given are the mean of many analyses.

COMPOSITION OF COLOSTRUM.

	Water.	Albuminoids.	Fat.	Sugar.	Ash.	Albuminoid ratio.
Ewe .	66·4	16·6	10·8	5·0	1·2	1 : 1·8
Sow .	70·1	15·6	9·5	3·8	0·9	1 : 1·6
Cow .	71·7	20·7	3·4	3·2	1·1	1 : 0·5

COMPOSITION OF MILK.

Ewe .	81·3	6·3	6·8	4·8	0·8	1 : 3·1
Sow .	84·6	6·3	4·8	3·4	0·9	1 : 2·2
Cow .	87·0	3·7	3·9	4·7	0·7	1 : 3·6
Human .	87·0	2·4	3·9	6·2	0·5	1 : 6·1
Goat .	87·3	3·5	3·9	4·5	0·8	1 : 3·7
Ass .	89·6	2·2	1·6	6·1	0·5	1 : 4·2
Mare .	90·2	1·9	1·1	6·4	0·4	1 : 4·4

The colostrum is characterised by an especially high percentage of albuminoids. In milk we find a smaller proportion of albuminoids and a much larger proportion of sugar.

The solid matter of milk has a very high feeding value, owing to the large proportion of fat and albuminoids present and its perfect digestibility. If we take, as before, the heat-producing capacity of dry cotton cake as 100, then the heat-producing capacity of dry cow's milk will be 143. Milk also supplies the ash constituents necessary for the formation of bone and tissue: 100 lbs. of cow's milk will supply about 0·20 lb. of phosphoric acid, 0·17 lb. of lime, and 0·17 lb. of potash.

The relation of the nitrogenous to the non-nitrogenous constituents of milk is much higher than in most vegetable foods; the analyses in the table show a relation varying from 1 : 2·2 to 1 : 6·1, and in colostrum the relation is still higher. In supplying very young animals with artificial food the above facts must be borne in mind; the food should clearly be of an easily digestible character, and contain a considerable proportion of albuminoids and fat. Instead of this, foods rich in starch are too often employed. Linseed is, of ordinary foods, the one most similar to milk in composition.

As the animal grows the quantity of food it requires increases, at the same time a larger proportion of the food is applied to the production of heat and mechanical work: the proportion of nitrogenous matter in the food may therefore gradually be diminished, carbo-hydrates and fat being quite as fit as albuminoids for producing heat and work. Under natural conditions this diminution in the nitrogenous character of the diet soon takes place, the animal daily taking more and more grass in addition to its mother's milk. The albuminoid ratio of the diet of young rapidly growing animals may vary from 1 : 5 to 1 : 7, the more nitrogenous diet being that most suitable for younger animals, or for the production of more rapid increase.

It is very important that the food supplied to young animals should contain a sufficient amount of ash constituents, and especially of lime: see p. 92.

The Adult Animal.—The food of an adult animal, not fattening, is employed for the renovation of the tissues, the formation of hair, wool, &c., and for the production of heat and mechanical work; by far the greater portion of the food is applied to the production of heat.

Production of Heat.—In the case of an animal at rest, not gaining in weight, the final results of the digested food will almost wholly appear as heat and excrementitious matter.

The smaller the animal the larger is the production of heat per unit of weight. Thus a full-grown dog, weighing 6 lbs., was found to produce twice as much heat per unit of weight as one weighing 40 lbs. This is due to the fact, that small bodies have, in proportion to their weight, a much greater surface than large bodies, and consequently suffer more by cooling. Small animals thus stand in special need of a liberal diet.

Production of Work.—The work performed by an animal is partly internal and partly external. The *internal* work consists in the muscular movements which produce circulation, respiration, and other vital processes; such work is carried on even when the animal is at rest. In man the whole of the blood is pumped through the heart every half minute. The daily work performed by the heart of an average man has been calculated as equal to 150—200 foot-tons; that is to say, the power exerted by the heart would raise 1 ton to the height of 150—200 feet. The work performed by other organs, and by the muscles when merely maintaining the body in an erect position, must be very considerable, but has not yet been satisfactorily measured. Nearly the whole of the internal work is finally resolved into heat.

As *external* work we may take as an example a walk of 20 miles on level ground; this to a man of 11 stone weight (154 lbs.) will represent an exertion equivalent to about 363 foot-tons. During hard work, about one-sixth of the total energy developed in a man's body may appear as external work, the rest will appear as heat.

It was formerly supposed that muscular force was produced by the oxidation of the nitrogenous constituents of muscle, and that a diet rich in albuminoids was necessary if hard labour was to be maintained. This idea is now known to be erroneous, it having been shown by repeated experiments that labour does not necessarily increase the production of urea, while it does in every case greatly augment the amount of carbonic acid exhaled.

The energy required for work may be produced in the body by the oxidation of albuminoids, but it may equally be generated by the oxidation of fat or carbohydrates. The animal body has been compared to a steam engine, in which food is burnt in place of coal.

When labour is demanded from an under-fed animal, the oxidation taking place may be in excess of the food supplied; in such a case the fat and albuminoids of the animal tissues are oxidised, and the excretion of urea becomes increased. A working animal ill supplied with food will thus suffer seriously in condition.

When an animal "out of training" is suddenly called upon to perform hard work, it will at first show an increased oxidation of albuminoids as the result of labour; but this will cease as the body becomes fit for work, if sufficient food is supplied. During training for increased work an albuminous diet will be necessary, as the muscular apparatus has to be built up.

Maintenance Diets.—In the case of an adult animal not increasing in weight, and performing a minimum amount of work, as, for instance, a horse or ox in a stable, the quantity of food required is reduced to its smallest limits. A horse of 1000 lbs. weight, at perfect rest, will require, according to the German experiments, 8·4 lbs. per day of digestible organic matter (reckoned as starch) to maintain its condition. The French experimenters found 7·2 lbs. sufficient. In their case 70 per cent. of the food was corn, while in the German experiments 42 per cent. was corn, and the rest hay and straw chaff. An ox of 1000 lbs. live weight, quiet in the stall, will require daily, according to the German experiments, about 0·5—0·6 lbs. of digestible albuminoids,* and 7·3—8·4 lbs. of digestible non-albuminous food, reckoned as starch, to preserve its condition.† With sheep the maintenance diet must be more liberal, as in their case the growth of wool, with its accompanying fat, is always in progress, and is practically independent of the abundance or poverty of the diet. For 1000 lbs. live weight (shorn), sheep fed on meadow hay will require about 1·0 lb. of digestible albuminoids,* and 10·8 lbs. of digestible non-albuminous food, or 16—17 lbs. of dry organic matter, per day, to preserve their condition. If fed on mangels and straw chaff the quantity of dry organic matter must be raised to 20—25 lbs. In these maintenance diets for adult animals the albuminoid ratio of the food is but

* These numbers represent true albuminoids, and are, therefore smaller than the German figures.

† In these experiments the food was chiefly hay or straw. By feeding with maize meal only, and keeping the cattle in a warm stable, the digested albuminoids have been reduced to 0·4 lb., and the non-albuminoids, reckoned as starch, to 3·7 lbs. per day. The economy of this American system probably depends on the much smaller amount of water drunk by the animal with this less bulky food.

1 : 14 in the case of the ox, 1 : 11 in the case of the sheep fed on hay, and the relation is wider still in the case of the sheep fed on straw and mangels. It is advisable that a minimum amount of nitrogenous matter should be given, as any excess over that absolutely demanded promotes waste in the system.

Labour Diet.—If external work is to be performed, the body weight remaining unaltered, the quantity of food must be considerably increased, and the food must be of such quality that it may be possible to digest a sufficient amount in the required time. A man doing a fair day's work was found to exhale one-third more carbonic acid than when at rest; a man doing such work would clearly require one-third more food to maintain the same condition of body. According to Wolff's experiments, 1251 foot-tons of work may be obtained from a horse, without altering its body weight, for each pound of digestible organic matter, reckoned as starch, consumed over and above the maintenance diet. Wolff found, as has been already mentioned, that it is indifferent whether this extra food is supplied by albuminoids or carbo-hydrates.

The relative value of the principal constituents of food for the production of heat and work will be found on p. 108, and the relative value of different foods on p. 109. The value of foods containing cellulose is for the horse somewhat less than that shown in the table.

In constructing a labour diet for horses it is well to combine bran with beans or oats, but not with maize, as both bran and maize are somewhat laxative.

The Fattening Animal.—For the body to increase in weight it is clear that the food supplied must be in excess of the quantity demanded for mere renovation of tissue, and for the production of heat and work. When such an excess of food is given, a part of the albuminoids and ash constituents is generally converted into new tissue, while a part of the fat, carbo-hydrates, and albuminoids is stored up in the form of fat.

As only the *excess* of the food is converted into increase, liberal feeding is, within certain limits, the most economical. If a lamb can be brought by liberal treatment to 150 lbs. live weight at one year old, the amount of food consumed will be far smaller than if two years are occupied in attaining the same weight, for the food required for animal heat and work during the second year is clearly saved.

Economy of food is also promoted by diminishing the demand for heat and work. An animal at rest in a stall will increase in weight far more than an animal taking active exercise on the same diet. In the same way the increase from a given weight of food will be less in winter than in spring or autumn, a far larger proportion of the food being consumed for the production of heat when the animal is living in a cold atmosphere. Hence the economy of feeding animals under cover during winter. If, however, the temperature becomes so high as to considerably increase the perspiration, waste of food again takes place, heat being consumed in the evaporation of water. The temperature most favourable for animal increase is apparently about 60° Fahr. Quietness, and freedom from excitement, are essential to rapid fattening; the absence of strong light is therefore desirable.

The capacity of an animal for fattening depends much on breed and temperament. A farmer learns to recognize the fattening disposition of an animal from the feel of its skin, etc.

The three animals with which the farmer is chiefly concerned have very different powers of consuming food, and yield different rates of increase. Lawes and Gilbert reckon that, on an average of the whole fattening period, an ox will produce 100 lbs. of live weight from the consumption of 250 lbs. oilcake, 600 lbs. clover hay, and 3500 lbs. swedes. Sheep will produce the same increase by the consumption of 250 lbs. oilcake, 300 lbs. clover hay, and 4000 lbs. swedes.* Pigs will require about 500 lbs. of barley meal to yield a similar result. Taking these data, the rate of food consumed, and of increase yielded, will be as follows:—

RESULTS OBTAINED WITH FATTENING ANIMALS

PER 100 LBS. LIVE WEIGHT PER WEEK.

	Received by the animal.		Results produced.		
	Total dry food.	Digestible organic matter.	Food consumed for heat and work.†	Dry Manure produced‡	Increase in live weight.
	lbs.	lbs.	lbs.	lbs.	lbs.
Oxen	12·5	8·9	6·86	4·56	1·13
Sheep . . .	16·0	12·3	9·06	5·10	1·76
Pigs	27·0	22·0	12·58	6·27	6·43

RESULTS OBTAINED IN RELATION TO FOOD CONSUMED.

	Increase in live weight.		On 100 lbs. of dry food.		
	Per 100 lbs. dry food.	Per 100 lbs. digested organic matter.	Consumed for heat and work.†	Dry Manure produced‡	Dry Increase yielded.
	lbs.	lbs	lbs.	lbs.	lbs.
Oxen	9·0	12·7	54·9	36·5	6·2
Sheep . . .	11·0	14·3	56·6	31·9	8·0
Pigs	23·8	29·2	46·6	23·2	17·6

It is evident from the upper division of the table that pigs are able to consume far more food in proportion to their weight than either sheep or oxen. This is due to the concentrated and digestible character of the food (corn meal) supplied to a fattening pig, and to the great capacity of this animal for assimilation. The proportion of stomach is greater in a fat ox or sheep than in a pig, being on 100 lbs. live weight, 3·2 for the ox, 2·5 for the sheep, and 0·7 for the pig. On the other hand, the proportion of the intestines is greater with the pig than with sheep or oxen. Ruminant animals are thus best fitted for dealing with food requiring a prolonged digestion, while the pig excels in the capacity for assimilation.

As a natural result of the larger consumption of food, the pig increases in weight much more speedily than either the sheep or ox; but not only is the rate of increase more rapid, the increase yielded by the pig is also far greater in proportion to the food received, as

*Since these estimates were made the fattening capacity of both sheep and oxen has apparently increased, owing to improvements in the breeds.

† In calculating the amount of food consumed for the production of heat and work, it has been assumed that the fat in the increase has been derived from the fat and carbo-hydrates supplied by the food.

‡ Dry matter of solid excrement and urine, exclusive of litter.

plainly appears from the lower division of the table. The pig, with its very large consumption of food, has, in fact, to spend a smaller proportion of it on heat and work, and has thus a larger surplus left to store up as increase. Of 100 lbs. digested organic matter, the fattening ox spends about 77 for heat and work, the sheep 74, and the pig 57. The upper division of the table shows, however, that in a given time and for the same body weight, the pig appropriates a larger amount of food to heat than the sheep, and the sheep more than the ox. This is probably due to the greater loss of heat from the bodies of small animals (see p. 119), which in the pig is intensified by the slight covering of hair upon its skin. The pig, with its rapid feeding, and high rate of increase, is undoubtedly the most economical meat-making machine at the farmer's disposal.

The results given by sheep are seen to lie in nearly every case between those given by oxen and pigs, being however much nearer to the former than to the latter. The German experiments place the sheep below the ox as an economic producer of increase, instead of above it, as in the Rothamsted statistics just quoted; the difference is probably due to the different breeds of animals experimented with. The results relating to manure will be discussed in the next chapter.

We have hitherto looked at the fattening period as a whole; the rates of consumption and of increase are, however, very different in different stages of this period.

As a fattening animal increases in size the quantity of food it consumes also somewhat increases, the stomach at the same time becomes larger. When the animal becomes very fat the consumption of food falls off again, and the rate of increase at this point is much diminished.

As fattening advances the daily increase in live weight becomes gradually smaller, and the same amount of food will produce a steadily diminishing amount of increase. This is partly because the increase during the later stages of fattening is drier, and contains a larger proportion of fat than in the earlier stages of the process. Partly also because the consumption of food for heat and work is increased with the increasing size of the body. More internal work must also be performed to add increase to a large animal than to a small one. These changes in the rates of consumption and increase are seen more strikingly in the case of pigs than with other animals, from the greater rapidity of the fattening process. The following table shows the average results obtained on sixteen pigs fattened at Rothamsted at the same time, the food being 7 lbs. of pea meal per head per week, with an unlimited supply of barley meal. The pigs had an average weight of 135·8 lbs. when put up to fatten: at the end of ten weeks their average weight had become 276·3 lbs.

FATTENING PIGS—WEEKLY CONSUMPTION OF FOOD AND RATE OF INCREASE.

	Food consumed.		Increase in live weight.		Food producing 100 lbs. of increase.
	Per head.	Per 100 lbs. live weight.	Per head.	Per 100 lbs. live weight.	
	lbs.	lbs.	lbs.	lbs.	lbs.
First fortnight . .	60·1	39·7	15·5	10·3	386
Second do. . . .	67·5	36·7	17·4	9·4	388
Third do. . .	66·4	30·9	13·2	6·2	502
Fourth do. . . .	66·0	27·4	12·9	5·4	511
Fifth do. . .	69·6	26·3	11·3	4·2	618
Mean	65·9	32·0	14·1	6·8	469

The figures in this table illustrate in a striking manner the alterations in the proportion of food consumed, and increase yielded, during the period of fattening. The weights of food refer to meal in its natural state, and do not represent dry substance. The irregularities in the progression of the figures are due to the variable appetite and condition of the animals. Animals when first confined, and supplied with fattening food, generally increase largely in weight during the first few weeks, after which the rate of increase diminishes to a considerable extent.

The composition of the animal increase accumulated during fattening has been already given on page 79. The proportion of nitrogenous matter in this increase is very small, the albuminoid ratio of the increase in the case of the pig being only 1 : 19, and in that of the sheep 1 : 22. For the purpose of rapid fattening we must not, however, provide food containing as low a proportion of albuminoids as is stored up in the increase; the animal body, in fact, requires a constant supply of albuminoids for the renovation as well as for the production of tissue. A diet tolerably rich in albuminoids is also both more digestible, and of greater feeding value, than a diet poor in this constituent.

Wolff recommends a more nitrogenous diet for fattening sheep than for oxen or pigs. The ratio of nitrogenous to non-nitrogenous substance which he recommends for fattening sheep is 1 : 5·5, concluding with 1 : 4·5. For pigs, 1 : 4—5 below 5 months, and 1 : 5.5—1 : 6·5, as the age and weight increases. For oxen 1 : 6·5 at the commencement of fattening, to be reduced to 1 : 5.5 when fattening in earnest has set in. In all these diets, however, the amides have been reckoned as albuminoids; the ratios are thus too narrow, the error falling chiefly on the diets of the sheep and oxen. Practical results show that very good rates of increase may be obtained with smaller proportions of albuminoids than those recommended by Wolff, if cereal grains form a considerable part of the diet. Thus, a three years' trial at Woburn proves that a daily ration of 20 lbs. swedes, ¼ lb. hay, and ¾ lb. wheat for sheep (nitrogenous substance to non-nitrogenous 1 : 6—7, albuminoid ratio about 1 : 11) yields excellent results, generally equal to those obtained when cake is substituted for wheat. The economy of any diet cannot, however, be decided without taking into account the value of the manure produced. From this point of view, fattening with cake or leguminous corn may be more to the farmer's advantage than the employment of cereal grains.

Fat, as we have already seen, is the most potent of the constituents of food; oil-cakes rich in oil have thus a special value for the production of concentrated diets, and are peculiarly adapted for winter feeding.

Young animals require a more nitrogenous diet during fattening than animals of maturer age, as growth, as well as fat, must be provided for.

Production of Wool.—Wool, besides the moisture and dirt which it naturally contains, is made up of three ingredients, suint, fat, and pure wool-hair. The suint is an excretion of the perspiration glands of the skin; it chiefly consists of a compound of potassium with an organic acid containing nitrogen, of which little is known. Suint is soluble in water, and is in great part removed when sheep are washed before shearing. In the case of Merino sheep the suint may amount to more than one-half the weight of the unwashed fleece; but in the case of ordinary sheep, freely exposed to weather, the quantity may be 15 per cent. or less. In a washed fleece the fat may vary from more than 30 per cent. to 8 per cent., or less. Short fine wool contains the largest proportion of fat. Pure wool-hair contains about 16 per cent. of nitrogen. The quantity of nitrogen and ash constituents, both in unwashed and in washed wool, has been already given on page 78.

The production of wool-hair and of wool-fat is practically no greater when sheep receive a liberal fattening diet, than when the diet only suffices to maintain the ordinary condition of the animal; indeed, under poor treatment, the carcase may lose weight to some extent without the production of wool being seriously altered. With starvation, however, the yield of wool is considerably diminished. If sheep are kept on a poor diet for the mere production of wool, the amount of albuminoids supplied must not fall too low, wool-hair being formed entirely from this part of the food.

Production of Milk.—The quantity of milk produced is largely determined by the individual character of the animal, and the length of time which has elapsed since birth; the quality of the milk is also affected by the same conditions. Subject to these natural limitations, both quantity and quality are greatly influenced by the character of the food supplied.

A liberal diet is essential for a full supply of milk. The milk yielded by each cow should be recorded, and the supply of concentrated food (cake, bean meal, bran, &c.) should rise and fall with the yield of milk, the object being to obtain as large a produce as can be reached without fattening the animal. The best feeding will not turn a badly milking cow into a good one, but it is possible by sustaining the cow with proper food at the period of her greatest milk production to prolong that profitable period very considerably. Green fodder is favourable to a large produce, so also are brewers' grains.

As milk is a highly nitrogenous product, the albuminoid ratio in cow's milk being 1 : 3·6, it is obvious that cows in full milk will require a nitrogenous diet. Such a diet is naturally provided when cows feed on young grass and clover; when hay, straw, and roots form the bulk of the food, it is imperative that cake or leguminous corn be also employed if abundance of milk is desired. Wheat bran, and brewers' grains, are generally recognized as good milk foods, and are shown by the table on page 111 to have a high albuminoid ratio. Wolff gives 1 : 5·4 as the ratio of nitrogenous to non-nitrogenous substance suitable for cows in full milk. Practice shows that an albuminoid ratio of 1 : 6—8 is sufficient, the higher ratio of albuminoids being reserved for cows yielding 40—50 lbs. of milk per day.

Milk is far more nitrogenous than the increase of carcase obtained when an animal is fattened. If a cow yields 21 gallons per week, the nitrogen in the milk will be about equal to that contained in 100 lbs. increase of fattening oxen. The saleable nitrogenous matter yielded by one cow will thus equal that produced in the same time by 6—10 oxen.

The quality of milk is considerably influenced by the richness of the diet. A diet of watery grass will probably yield a moderate quantity of poor milk; the addition of oil-cake will increase both the yield of milk and also its richness. The alteration in the composition of milk by poor or liberal feeding is chiefly an alteration in the percentage of solid matter; the relative proportions of casein and sugar are scarcely affected by the character of the diet, the butter-fat is more variable.

The quality of the butter is more or less influenced by the character of the food, some foods producing a hard, and others a soft butter. Rape-cake, oats, and wheat-bran are reckoned in Denmark as first-class butter-foods; cotton-cake, palm-nut cake, and barley as second-class foods; while linseed-cake, peas, and rye are placed in the third class. The first-class foods produce a soft butter, the third-class foods a hard butter. By the employment of first and second-class foods with straw, chaff, hay, and roots, an abundance of excellent butter may be produced throughout the winter. Turnips strongly flavour both milk and butter; carrots and mangels are a better food for milk-cows.

CHAPTER IX.

RELATION OF FOOD TO MANURE.

Quantity of the Manure—How calculated—Character of manure from horses, cattle, sheep, and pigs. *The Litter*—Its absorbent power and composition. *Composition of Manure*—Proportion of the ash constituents and nitrogen of the food which appears in the liquid and solid excrements—Composition of the excrements of sheep, oxen and cows. *Manure value of Foods*—The quantity of nitrogen and ash constituents contained in foods—Their value as compared with the same materials in artificial manures—Economic use of manure.

Quantity of the Manure.—This is very variable, depending largely on the amount of indigestible matter in the diet. Thus the quantity of manure credited to the fattening ox and sheep in the table on p. 124, would be greatly increased if a portion of the roots in their diet was replaced by straw-chaff. The manure credited to the pig would be much less if, instead of barley meal, it had received potatos and skim milk.

The quantity of dry matter in the solid excrement of an animal may be calculated from the digestion co-efficient of the diet. The quantity of dry matter in the urine is, according to Wolff, nearly 6 per cent. of the dry food consumed.

The mixed excrements of pigs and cattle are far more watery than those of sheep and horses, a larger proportion of litter has therefore to be used for the first-named animals. Pigs and cattle thus yield a bulky, watery manure, sheep and horses a drier and more concentrated product. Manure freshly made, with a minimum of litter, will contain 73—80 per cent. of water.

The Litter.—The worth of a litter depends partly on its power of retaining water, and partly upon the manurial constituents which it itself supplies.

WATER RETAINED BY 1 PART OF LITTER.

Dead leaves	2·0	Sawdust	4·2—4·4
Straw	2·2—3·0	Spent tan	4·0—5·0
Peat moss	3·8	Peat	5·0—8·0

MANURIAL CONSTITUENTS IN 100 PARTS OF LITTER.

	Nitrogen.	Phosphoric Acid.	Potash.
Dead leaves	0·8	0·3	0·3
Straw	0·4—0·6	0·2—0·3	0·6—1·6
Peat moss	0·8	trace	trace
Sawdust	0·2—0·7	0·3	0·7
Spent tan	0 5—1·0	—	—
Peat	1·0—2·0	—	—

Peat is thus, of all forms of litter, both the most efficient absorbent, and also the one supplying the largest amount of valuable matter.

Composition of Manure.—In the case of an adult animal, neither gaining nor losing weight—a working horse, for instance—the quantity of nitrogen and ash constituents voided in the manure will be nearly the same as that contained in the food consumed, the albuminoids and ash constituents of the food used for the renovation of tissue being in this case equivalent to the quantities yielded by the degradation of tissue. In cases where the animal is increasing in size, is producing young, or furnishing wool or milk, the amount of nitrogen and ash constituents in the manure will be less than that in the food in direct proportion to the quantity of these substances which has been converted into animal produce. The manure from animals of the latter description will thus be poorer than that obtained from the former class, supposing the same food to be given to each.

The proportion of the nitrogen in the food which will appear in the solid excrement is determined by the digestion co-efficient of the nitrogenous constituents. Thus 78 has been already given as the digestion co-efficient of the nitrogenous matter of barley meal when consumed by a pig; it follows that in this case for 100 of nitrogen consumed 22 will be voided in the solid excrement, and 78 pass into the blood. It has been already stated that 500 lbs. of barley meal, containing about 53 lbs. of nitrogenous substance, will in the case of a fattening pig produce 100 lbs. of animal increase, containing 7·8 lbs. of albuminoids. It follows from these data, that for 100 lbs. of nitrogen consumed, 14·7 are stored up as carcase, 22 appear in the solid excrement, and 63·3 as urea, &c., in the urine. In the same way, by deducting the ash constituents stored up from those present in the food, we can arrive at the quantity of ash constituents voided in the manure. The following table shows the results obtained by this mode of calculation in the case of the fattening ox, sheep, and pig receiving the diets mentioned on page 124. The relation of food to manure in the case of milking cows is calculated from recent Rothamsted experiments, in which cows receiving a liberal diet yielded an average of 27 lbs. of milk daily. The horse at rest is assumed to receive as a maintenance diet 19 lbs. of meadow hay; the horse at work, 15 lbs. of hay and 10 lbs. of oats daily.

NITROGEN IN ANIMAL PRODUCE, AND VOIDED, FOR 100 CONSUMED AS FOOD.

	Obtained as carcase or milk.	Voided as solid excrement.*	Voided as liquid excrement.	In total excrement
Horse, at rest . .	None.	43·0	57·0	100
,, at work . .	None.	29·4	70·6	100
Fattening oxen . .	3·9	22·6	73·5	96·1
Fattening sheep . .	4·3	16·7	79·0	95·7
Fattening pigs . .	14·7	22·0	63·3	85·3
Milking cows .	24·5	18·1	57·4	75·5

ASH CONSTITUENTS IN ANIMAL PRODUCE, AND VOIDED FOR 100 CONSUMED AS FOOD.

	Obtained as live weight or milk.	Voided in excrements and perspiration.
Horse	None.	100
Fattening oxen	2·3	97·7
Fattening sheep	3·8	96·2
Fattening pigs	4·0	9[illegible]·0
Milking cows	10·3	89·7

The proportion of the ash constituents and nitrogen of the food which is stored up in the body of an animal

* The quantities of nitrogen given in this column are a little below the truth, as, besides the undigested albuminoids, some nitrogenous biliary matter is present in the solid excrement. With oxen and sheep the amount of biliary matter in the excrement is very small; with pigs it is more considerable. In the case of the pig the nitrogen in the solid excrement should probably stand as 26·0, and that in the liquid as 59·3.

is generally very small. In the case of the fattening animals, 96 per cent., or more, of the ash constituents of the food find their way into the manure. With fattening oxen and sheep, and with horses, more than 95 per cent. of the nitrogen of the food are voided in the manure. The pig is seen to retain a much larger proportion of the nitrogen of its food, about 85 per cent. appearing in the manure. The milking cow gives the best return in saleable produce for the nitrogen which it receives, only about 75 per cent. appearing in the manure. With diets containing a smaller amount of albuminoids the proportion of nitrogen appearing as manure will of course be diminished.

The amount of nitrogen voided in the urine is seen to be always greater than the quantity contained in the solid excrement, and is generally three or four times as much. This relation will vary according to the character of the diet. If the food is nitrogenous, and easily digested, the nitrogen in the urine will greatly preponderate; if, on the other hand, the food is one imperfectly digested, the nitrogen in the solid excrement may form the larger quantity. When poor hay is given to horses, the nitrogen in the solid excrement will exceed that contained in the urine. On the other hand, corn, cake, and roots yield a large excess of nitrogen in the urine.

The ash constituents are very differently distributed in the solid excrement and urine; in the former is found nearly all the phosphoric acid, and the greater part of the lime and magnesia, while the latter contains the greater part of the potash. With sheep and horses, and probably more or less with other animals, a part of the potash is excreted in the perspiration.

Some idea of the general composition of the solid excrement, and of the urine, is given by the following table. The sheep were fed on meadow hay; the oxen on clover hay and oat straw, with about 8 lbs. of beans per day; the cows received in one case 154 lbs. of mangels, and in the other case 26 lbs. of lucerne hay and 66 lbs. of water per day.

PERCENTAGE COMPOSITION OF SOLID AND LIQUID EXCREMENT.

1. *SHEEP FED ON HAY*

	Solid excrement.		Urine.	
	Fresh.	Dry.	Fresh.	Dry.
Water	66·2	...	85·7	...
Organic matter	30·3	89 6	8·7	61·0
Ash	3 5	10·4	5·6	39·0
Nitrogen	0·7	2 0	1·4	9·6

2. *OXEN WITH NITROGENOUS DIET.*

	Solid excrement.		Urine.	
	Fresh.	Dry.	Fresh.	Dry.
Water	86·3	...	94·1	...
Organic matter	12·3	89·7	3·7	3·0
Ash	1·4	10·3	2·2	37·0
Nitrogen	0·3	1·9	1·2	20·6

3. *COWS FED ON MANGELS, AND ON LUCERNE HAY.*

	Mangels.		Lucerne Hay.	
	Solid excrement.	Urine.	Solid excrement.	Urine.
Fresh manure per day	lbs. 42	lbs. 88	lbs. 48	lbs. 14
	Per cent.	Per cent.	Per cent.	Per cent.
Water	83·00	95·940	79·70	88·2[illegible]0
Nitrogen	·33	·124	·34	1·540
Phosphoric acid	·24	·011	·16	·006
Potash	·14	·597	·23	1·690

The immense influence of the character of the diet, both on the quantity and quality of the manure, is well shown by the two experiments with cows; the difference appears chiefly in the urine.

The richness of the urine, both in ash constituents and nitrogen, is in all cases very evident. In the case of the more highly-fed oxen, the dry matter of the urine is seen to contain over 20 per cent. of nitrogen.

Manure Value of Foods.—The relative value of the manure produced by different foods is determined by the relative richness of the foods in nitrogen and ash constituents, but chiefly by the amount of nitrogen, this being the most costly ingredient of purchased manure. The average amount of nitrogen, and of the two most important ash constituents contained in ordinary cattle foods, is shown in the following table:—

MANURIAL CONSTITUENTS IN 1000 PARTS OF ORDINARY FOODS.

	Dry matter.	Nitrogen.	Potash.	Phosphoric Acid.
Cotton cake (decorticated) .	918	70·4	15·8	30·5
Rape cake	887	50·5	13·0	20·0
Linseed cake	883	43·2	12·5	16·2
Cotton cake (undecorticated) .	878	33·3	20·0	22·7
Linseed	882	3[illegible]·8	10·0	13·5
Palm-kernel meal (English) .	930	25·0	5·5	12·2
Beans	855	40·8	12·9	12·1
Peas	857	35·8	10·1	8·4
Malt dust	905	37·9	20·8	18·2
Bran	860	23·2	15·3	26·9
Oats	870	20·6	4·8	6·8
Rice meal	900	19·1	6·1	23·8
Wheat	877	18·7	5·2	7·9

MANURIAL CONSTITUENTS IN 1000 PARTS OF ORDINARY FOODS.—*continued.*

	Dry matter.	Nitrogen.	Potash.	Phosphoric Acid.
Rye	857	17·6	5·8	8·5
Barley	860	17·0	4·7	7·8
Maize	890	16·6	3·7	5·7
Brewers' grains . . .	234	7·8	0·4	3·9
Clover hay	840	19·7	18·6	5·6
Meadow hay	857	15·5	16·0	4·3
Bean straw	840	13·0	19·4	2·9
Oat straw	857	6·4	16·3	2·8
Barley straw	857	5·6	10·7	1·9
Wheat straw	857	4·8	6·3	2·2
Potatos	250	3·4	5·8	1·6
Swedes	107	2·2	2·0	0·6
Carrots	140	2·1	3·0	1.1
Mangels	120	1·8	4·6	0·7
Turnips	80	1·6	2·9	0·8

The manure value of different food thus varies extremely. One ton of decorticated cotton cake contains about four times as much nitrogen as a ton of wheat, barley or maize, and thirty-nine times as much as a ton of mangel wurzel.

The oil-cakes yield the richest manure, as they contain the largest amount of nitrogen and phosphoric acid, with a considerable amount of potash. Next to these come the leguminous seeds, malt-dust, and bran. Clover hay yields a rather richer manure than the cereal grains, while meadow hay stands below them. The cereal grains and the roots contain about the same proportion of nitrogen in their dry substance; the roots, however, supply much more potash. Potatos stand below roots in manurial value, when compared on the basis of their dry substance. Wheat-straw takes the lowest place when foods are compared on the basis of their dry substance. Bean and pea straw are far more valuable than the straw of the cereals.

To obtain the amount of nitrogen, potash, and phosphoric acid voided as manure, we have simply to subtract from the amounts of these constituents contained in the food the quantity retained by the animal. The manure resulting from nitrogenous foods, as decorticated cotton-cake, is frequently the cheapest form of nitrogen which a farmer can obtain. This is especially the case when the food is skilfully used, and gives a good return in animal increase, as well as furnishing a supply of manure.

The ash constituents present in animal manure have probably the full money value of the same constituents in artificial manures, but the nitrogen has a lower value than the nitrogen of ammonium salts or nitrate of sodium. The nitrogenous matter of the urine (urea) is rapidly converted into carbonate of ammonium by the action of certain bacteria present both in the atmosphere and in the soil; the carbonate of ammonium may afterwards be converted into nitrates in the soil. If these changes occurred without loss, the nitrogen of the urine would have an equal money value with the nitrogen of ammonium salts, or nitrate of sodium; owing, however, to the volatility of carbonate of ammonium, considerable losses are apt to occur during the decomposition of urine.

The nitrogen of the solid excrements is not in a form suitable for plant food, and will be only slowly converted into nitrates in the soil. Taking into consideration both the losses during preparation, and the slowness of action of farmyard manure, Lawes and Gilbert estimate that the manure actually obtained from food has not more than half the money value of the manurial constituents voided by the animal, if these are reckoned at the prices given for nitrogen, phosphates and potash in artificial manures.

Animal manure is more immediately available for the use of plants when applied directly to the land than when previously fermented with a great bulk of litter. During fermentation with litter the ammonia unites with certain of the carbonaceous matters present, forming compounds which are little soluble, and which decompose but slowly in the soil.

The feeding of animals on the land is a mode of applying manure which has many advantages; but the distribution of the manure is in this case irregular, and if carried out in autumn or winter the manure is subject to loss by drainage. The most effective plan of application is doubtless as liquid manure to growing crops. In winter time, however, the use of litter, and the preparation of farmyard manure (best under cover), becomes a necessity, and is on the whole the best course to adopt.

The treatment of farmyard manure, and its general composition, have been already described on pp. 31-33.

CHAPTER X.

THE DAIRY.

Milk.—Its constituents—Conditions affecting its richness. *Curdling.*—The action of bacteria. *Cream.*—The fat globules—Modes of raising cream—Composition of cream—Ripening of cream. *Skim-milk.*—Its composition. *Butter.*—The operation of churning—Composition of butter. *Butter-milk.*—Its composition. *Cheese.*—Rennet — Operation of cheese-making — Composition of cheese. *Whey.*—Its composition. *Annatto.*—Its nature and use. *Necessity for cleanliness.*

Milk.—The general composition of colostrum, and of ordinary cow's milk, has been already given on p. 117.

Cow's milk has generally a *specific gravity* of 1·032, the extremes being about 1·028 and 1·035. As the removal of cream raises the specific gravity, which can be brought back to the normal point by the addition of water, no safe conclusion as to the quality of milk can be based on this indication.

The *albuminoids* of milk are chiefly composed of two constituents of similar composition, casein and albumin. Casein is coagulated by the addition of acids, or by rennet, but not by boiling. Albumin is not coagulated by rennet, or by most acids, but is coagulated by heat. In colostrum albumin largely preponderates, so that the milk coagulates on boiling; in ordinary cow's milk the albumin forms about one-eighth of the total albuminoids.

The *fat* of milk chiefly consists of the glycerides of palmitic and oleic acid. The glycerides of stearic, myristic, lauric, capric, capryllic, caproic, and butyric acid are also present in small quantity. The last four of these acids are, when in the free state, more or less soluble in water. The glycerides of oleic acid, and of the soluble fatty acids, are fluid fats at ordinary temperatures; the remaining fats are solid. The proportion of fluid and solid fats varies somewhat with the diet and condition of the animal; in summer-time the proportion of fluid fats is greater than in winter.

The *sugar* contained in milk is known by chemists as lactose or lacton.

The composition of cow's milk is affected by various circumstances; under extreme conditions it may contain from 10 to over 16 per cent. of dry matter. The milk is poorer when the quantity produced is large, or the diet insufficient, and richer when these conditions are reversed. A cow is generally in full milk from the second to the seventh week after calving; after this period the milk gradually diminishes in quantity, but increases in richness. A separation of cream takes place in the udder; the milk first drawn is poor in fat, and the richness increases as milking proceeds, the last-drawn milk containing two or three times as much fat as the first-drawn. The evening's milk is usually somewhat richer than that of the morning, the assimilation of food taking place to a larger extent between the morning and evening than between the evening and morning milkings. The milk of old cows is said to be poorer than the milk of young cows. The richness of milk depends also much on the "race" of the cow, the fat being the constituent most affected.

The Jersey breed gives the richest milk, the fat frequently amounting to 5—6 per cent.

The influence of diet on the production of milk and butter has been already considered (p. 130).

Curdling.—The ordinary souring of milk is produced by various species of *bacteria*, which, during their growth convert the sugar of milk into lactic acid; this acidification of the milk induces the coagulation of the casein. The higher is the temperature, the smaller is the proportion of acid which will curdle milk. Milk is also curdled by other species of bacteria, which produce no, or very little, acidity, but apparently act by the formation of a rennet-like ferment. Other ferments, altering the condition of the albuminoids in milk, are produced by other species of bacteria. The presence of these ferment-forming bacteria sometimes occasions much difficulty in dairy work, and is the cause of many of the so-called "diseases" of milk. The development of these mischievous bacteria may be checked by cooling the milk while the cream is rising. The speedy work done by the centrifugal machine is also most valuable for this purpose. All bacteria are destroyed at a boiling heat. Milk that is free from micro-organisms is unchanged by keeping.

Cream.—The fat of milk occurs in the form of globules; the largest are about ·0005 to ·0006 inch in diameter, the smallest may be one-tenth this diameter, or even less. The average size of the globules is different with different breeds of cattle; thus they are larger in the milk of the Jersey than in the milk of the Ayrshire or Holstein breed.

The large globules diminish in number as the time from calving increases. As the fat globules have a lower specific gravity than the serum in which they float, they tend to rise to the surface, where they form a layer of cream. The largest globules are the first to rise; the smallest never rise at all. Milk containing an abundance of large globules is best for butter-making, as the cream then quickly and perfectly rises; but milk with small globules is probably best for cheese-making, as a more even distribution of fat throughout the curd is then obtained.

Milk, when it leaves the cow, will have a temperature of about 90° Fahr.; when set for cream it should be cooled as quickly as possible, as changes in composition would rapidly occur at a high temperature. Milk is usually set for cream in shallow vessels, the depth of milk being perhaps three inches; in these vessels the milk stands for thirty-six to forty-eight hours till the cream has separated. Under these conditions a large surface is exposed, the milk receives a large number of bacteria and moulds from the air, and a maximum amount of change takes place; the result is a decomposition of a part of the albuminoids and fats, the production of lactic acid, and the partial curdling of the milk. The cream obtained in this way is contaminated with curd, and contains various strongly-flavoured products of decomposition, which deteriorate the quality of the butter.

On Swartz's plan the milk is placed in metal pails, 16 inches deep, and surrounded by ice. The cream rises quickly, and can all be obtained in twelve to twenty-four hours from the time of setting. Cream thus prepared is perfectly sweet, and free from curd, the low temperature at which the milk has been kept having reduced chemical change to a minimum. It occasionally happens that milk will not yield its cream at low temperatures; this is sometimes the case with the milk of cows several months after calving, and especially when receiving a winter diet.

A third plan of separating cream is by subjecting the milk to extremely rapid horizontal revolution in a centrifugal machine; under these circumstances the fat globules rise into the centre of the revolving mass. In Laval's machine the new milk, at a temperature of 84°, enters in a continuous stream, and is immediately separated into cream and skim-milk, the former leaving the apparatus by a pipe at the top, the latter by another pipe from the side. Both the cream and skim milk thus obtained are, of course, perfectly sweet. The separation of cream in the centrifugal machine is far more complete than in either of the other processes. About 80 per cent. of the milk fat is removed by the ordinary process of shallow setting, and about 95 per cent. by a good machine. A much larger quantity of butter can thus be obtained with a machine than by any other mode of working.

Cream varies considerably in composition according to the manner in which it has been produced. The volume of the cream obtained is always greater at a lower temperature; this fact should be borne in mind when comparing results given by the creamometer. Cream raised in ice will contain about 20 per cent. of fat. Cream obtained by ordinary shallow setting may contain 25—40 per cent. of fat. Cream separated by the centrifugal machine will vary extremely according to the mode of working; it may be quite poor, or it may contain 50 per cent., or more, of fat. Casein, and the other constituents of milk, are always present in small quantity. In sweet cream the casein may be about one-tenth of the fat; in the cream from milk which has soured during setting the casein forms a much larger proportion.

The perfectly sweet cream obtained by using ice, or the centrifugal separator, is frequently slightly soured or "*ripened*" before churning. For this purpose a little buttermilk is stirred in, and the cream warmed to about 70°. As soon as the cream thickens it must be churned, or else immediately cooled, to prevent the change proceeding further. It is claimed that rather more butter can be obtained from ripened cream than from sweet cream; the flavour of the butter also is altered.

Skim Milk.—Milk thoroughly skimmed in the ordinary way will still contain about 0.8 per cent. of fat, and more than this quantity is frequently present. When ice has been used, the percentage of fat left in the milk will be 0·5 to 0·7; and when the centrifugal machine has been employed, 0·2 to 0·5. Skim milk obtained in the ordinary way will contain about as follows: water, 90·0; albuminoids, 3·6; fat, 0·8; sugar, 4·9; ash, 0·7. Its specific gravity is generally 1·034 to 1·037. Skim milk is a very nitrogenous food, the albuminoid ratio being as high as 1 : 1·8.

Butter.—The object of butter-making is to bring about the union of the fat globules which in milk and cream have existed separate from each other. The skilled butter-maker is not, however, satisfied with producing a solid mass of butter-fat; for butter to be of good quality it must possess a certain texture and grain, and be neither hard nor greasy; this desired result can only be attained by careful churning at a favourable temperature. If the temperature of the cream is too low the butter will be long in coming, and will be hard in texture. If the temperature is too high the butter will come very speedily, but the product will be greasy, destitute of grain, and deficient in quantity. No temperature can be fixed as the best at which churning should always take place The proportion of solid and fluid fats in the milk varies somewhat with the diet of the cows, and this necessitates a change in the temperature. A rather higher temperature will be required in winter than in summer. The temperature must also be higher for sour cream than for sweet cream. Generally speaking, perfectly sweet cream should be placed in the churn at 52° to 55° Fahr., and sour cream at 59° to 63°. When sour milk is churned for butter the temperature must be about 65°. The exact temperature most suitable for churning may be ascertained by recording every day the temperature employed, with the length of time occupied in churning, and the amount and character of the product; when this is done the temperature for each day can be regulated from the experience of the last working. The temperature will rise several degrees during churning.

Churning must always be stopped as soon as the butter appears in fine grains; any over-churning spoils the texture of the butter. The butter is then separated from the buttermilk, washed with cold water, and after standing to solidify is carefully worked and pressed to expel all watery matter; over-working in this stage will also spoil the grain, and make the butter greasy. Butter made from perfectly sweet cream keeps far better than butter made from sour cream, as the latter always contains curd, a substance very prone to change. Salt is generally added to improve the keeping quality of butter. Good churning should result in 96 per cent. of the cream fat being obtained as butter fat.

First-class butter will contain a minimum of about 10 per cent. of water, and 0·5 per cent. of casein. In ordinary fresh butter the water is usually 11—15 per cent., the fat 83—87, the casein 0·6—1·0, the milk sugar 0·2—0·7, and the ash 0·1—3·0 per cent. The amount of ash depends chiefly on the quantity of salt added. Of the fatty acids in butter about 6 per cent. are soluble in water when separated from the glycerol with which they are combined; this fact serves to distinguish butter from other animal fats in which soluble fatty acids are absent. When butter becomes rancid the glycerides of the fatty acids are partly decomposed, and the fatty acids liberated; the odour and flavour of rancid butter are largely due to free butyric acid.

Buttermilk.—The liquid remaining in the churn after the separation of the butter from the cream varies a good deal in composition; the average will be about as follows:—Water, 90·1; albuminoids, 4·0; fat, 1·1; sugar, 4·1; ash, 0·7 per cent. The albuminoid ratio would thus be 1 : 1·6.

Cheese.—This substance is prepared by the action of rennet on milk. Rennet is made by extracting the fourth stomach of the calf with water containing 5 per cent., or more, of common salt. Its power of coagulating milk is due to the presence of a ferment, which doubtless plays a similar part in the ordinary process of digestion in the calf's stomach. Rennet solidifies the milk by separating the casein from solution; the fat globules are separated at the same time, being entangled in the curd formed. The action of rennet is very slow in the case of cold milk; it acts most speedily at a temperature of 98° Fahr.; above this point the action rapidly declines, and ceases at about 130° Fahr. Milk becomes slightly sour when curdled by rennet, but the production of acid (lactic acid) is not essential to the curdling.

The composition of cheese depends greatly on that of the milk from which it is made; rich cheese is made from new milk, cream being sometimes added to the milk for the production of the richest sorts; poorer kinds of cheese are made from milk wholly or partially skimmed.

The temperature at which the milk is curdled is of great importance. If the temperature is low the curd is very tender, and the whey difficult to separate; if, on the other hand, the heat is too great, the curd shrinks too much, and becomes hard and dry. Temperatures from 75°—90° are employed for different kinds of cheese, but 80°—86° is the temperature most commonly chosen.

When the curd is sufficiently firm it is carefully cut in all directions, and the whey allowed to drain off. The curd is often scalded with hot whey after cutting, with the view of making it shrink and harden: the temperature used at this point must not exceed 100° Fahr. The drained and broken curd is next put into a press, to remove more effectually the last portions of whey. It is then pulverised in a mill, salted, again passed through the mill, and is then ready for filling into the frames.

Curd when put into the frames should contain, according to Voelcker, about 54 per cent. of water when thin cheese is to be made, and not more than 45 per cent. if thick cheese is manufactured. The curd from skim milk will contain much more water than a curd rich in butter. The frames filled with curd are subjected to a gradually increasing pressure for several days. The cheese is finally removed from the frame and placed in the cheese-room to ripen.

In making soft cheese the curd is not cut or pressed, but is simply allowed to drain in a cloth or frame.

Cheese ripens quickest at a moderate temperature; 65°—70° is frequently employed at first, and afterwards a lower temperature. During the operation a loss of water takes place, the loss being greatest in the case of poor cheese. If decay, or growth of mould, occurs, a further considerable loss of weight takes place, the casein and fat of the cheese being decomposed by the organic life thus introduced, while carbonic acid, ammonia, and a variety of other products are formed. It was once believed that fat was produced during the ripening of cheese; this, however, is not the case.

The different qualities of cheese are chiefly determined by the richness of the milk; its sweetness or acidity; the proportion of rennet used; the temperature of curdling; the scalding and manipulation of the curd; the pressure to which it is subject; the temperature of the cheese-room, and the age of the cheese. Curdling at a low or medium temperature, the omission of scalding, and a light pressure in the cheese frame, are employed in the case of cheeses intended to ripen early and develop mould.

A very rich cheese, as old Stilton, may contain about 20 per cent. of water, 44 per cent. of fat, and about 29 per cent. of casein. In a good Cheddar or Cheshire cheese we should find about 33 per cent. of water, 33 per cent. of fat, 28 per cent. of casein, and about 3 to 4 per cent. of ash constituents, nearly half of which would be common salt. In skim milk cheeses the percentage of water is greater, and that of fat less. Thus a poor single Gloucester may contain 38 per cent. of water, 22 per cent. of fat, and 31 per cent. of casein. In skim milk cheese made in Denmark, from milk from which the cream has been very completely removed by the ice system, only 4 or 5 per cent. of fat are present.

Whey.—The whey which drains from the curd in cheese-making is a perfectly transparent liquid, containing the sugar and albumin originally present in the milk; it should not contain more than a trace of butter. If, however, the curd has been roughly treated, the milk has been rich, and the temperature high, larger quantities of butter will be present, and the cheese suffer in consequence. When whey is rich in butter it is generally allowed to stand till the butter has risen; the butter may then be added to the next churning. The average composition of whey is about as follows:—Water, 93·4; albuminoids, 0·9; fat, 0·3; sugar and lactic acid, 4·8; ash, 0·6. The albuminoid ratio is 1 : 5·6.

Annatto.—This is prepared from the pulpy coating of the seeds of *Bixa Orellana.* The orange colouring matter is soluble in alkalis, and in oil. Solid annatto contains much alkali carbonate, it is therefore soluble in water. When used for colouring butter, a small quantity of annatto solution is added to the cream before churning. When cheese is to be coloured, the annatto solution is added to the milk before the rennet.

Cleanliness.—In all the operations of the dairy the greatest cleanliness must be observed; all vessels should be washed with hot water as soon as done with, to destroy any adhering ferment. Without such precautions no good butter or cheese can be made.

Information as to the loss to the farm by the sale of milk and dairy products has been already given on p. 78.

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THE END.

With the Publishers Complts