Morton's Hand Books of the Farm.

No I.

# CHEMISTRY OF THE FARM

BY

R. WARINGTON, F.R.S.

(FOURTH REVISION.)

TWENTIETH EDITION.



VINTON & CO., LTD., 9, BREAMS BUILDINGS,
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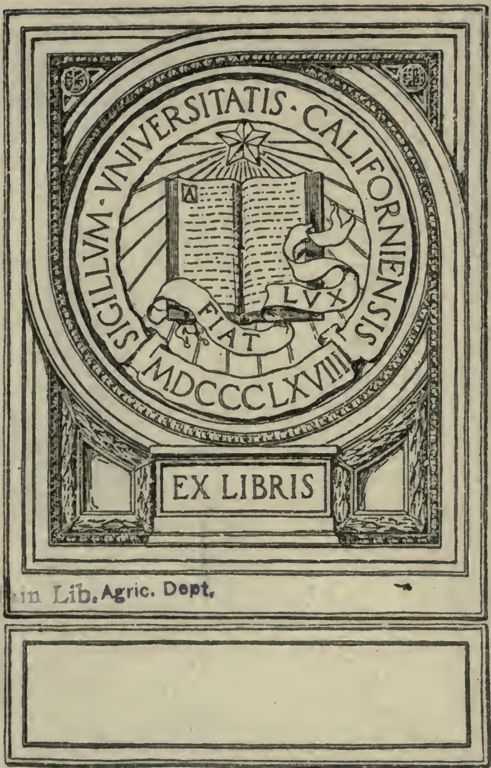
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No. 1.

# THE CHEMISTRY OF THE FARM

BY

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

*Formerly Sibthorpian Professor of Rural Economy in the University of Oxford.*

TWENTIETH EDITION

*(Fourth Revision)*



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1909.

# PREFACE

## TO THE FOURTH REVISION.

As "The Chemistry of the Farm" is now pretty widely known, and has been translated into several languages, a few words as to its origin will perhaps be of interest.

It is probably not generally known that the present work was originally undertaken by Sir J. B. LAWES. It was in the summer of 1878 that the late Mr. J. CHALMERS MORTON began to make arrangements for the preparation of a little Handbook of Agriculture for the use of Schools. The book he desired was to be similar to the "notes which a sharp lad would take home from a course of lectures." It was intended to be the work of several writers, and Sir J. B. LAWES was asked, and undertook, to contribute the part relating to the scientific application of manures. In November, 1878, Sir J. B. LAWES asked me to take his place in writing the chemical part of the proposed book; and he, at the same time, handed me the notes which he had already prepared. My contributions were first printed in "The Agricultural Gazette," and appeared at intervals during 1879-80. The work had then grown far beyond the limits originally assigned, and was finally published in 1881 as a separate volume.

"The Chemistry of the Farm" has doubled in size during the twenty-one years that have elapsed since its original publication. The alterations that have been made for the present revision are very considerable, the largest changes being made in the sections relating to the nutrition of animals. These alterations have been rendered necessary by the publication of the epoch-making investigations of ZUNTZ and HAGEMANN on the nutrition of the horse,[1] and of the equally important researches of KELLNER, KÖHLER, and their associates, on the nutrition of the ox.[2] By these laborious researches many important problems have been solved, and a foundation laid on which a really accurate science of feeding may be constructed.

In the new work of these German investigators, both the value of the food, and of the work which it undergoes, or accomplishes, is reckoned in units of heat. The fundamental facts established by their investigations have been brought together in a separate chapter (VII.). The discussions in this chapter, while introductory to much that follows, unavoidably assume a knowledge of some facts afterwards mentioned; students using the book will therefore do well to refer to this chapter several times in the course of their subsequent reading.

The chapter on Dairy Chemistry has been considerably enlarged; and here the writer has been indebted to the work of Mr. H. DROOP, RICHMOND, for much of the new matter which has been introduced.

As this book is intended for the use of students,

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[1] Untersuchungen über den Stoffwechsel des Pferdes bei Ruhe und Arbeit, von N. Zuntz und O. Hagemann, Berlin, 1898.

[2] Untersuchungen über den Stoff-und-Energie-Umsatz, des erwach, senen Rindes bei Erhaltungs-und-Produktions-futter, von O. Kellner, Berlin, 1900.

no apology seems needed for the cross references which frequently appear ; their object is to enable the student to bring at once together all the scattered facts and statements bearing upon the subject under discussion.

The metric system has been employed to some extent, as well as the ordinary English weights and measures. The former has been used chiefly for the expression of scientific ideas, the latter for practical purposes.

It is undoubtedly true that as science advances it becomes more complicated, and less capable of appreciation by the general reader. The modern student needs a more thorough training than one of bygone years, if he is to be able to grasp and put to practical use the new facts and ideas which scientific investigations are continually bringing forward. Agricultural education must proceed side by side with scientific research, if the latter is to be turned to any practical use by the farmer.

R. WARINGTON.

HARPENDEN,
*September*, 1902

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THE

# CHEMISTRY OF THE FARM.

## CHAPTER I.

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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 six chemical elements — carbon, oxygen, hydrogen, nitrogen, and sulphur, with a little phosphorus; 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 and phosphorus are 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. Nuclein and lecithin also contain phosphorus.

The *incombustible*, or 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 six chemical elements—potassium, magnesium, calcium, iron, phosphorus and sulphur. Iron is present in only very small quantity. These six 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 sometimes form a considerable portion of the ash; they are not, however, 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, and to a small extent in organic combination. 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 tons 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. 14 and 72.

COMPOSITION OF A CROP OF MEADOW GRASS.

| | | | |
|---|---|---|---|
| Water .. | | | 8,378 lbs. |
| Carbon .. | 1,315 | Combustible matter .. | 2,613 lbs. |
| Hydrogen | 144 | | |
| Nitrogen | 49 | | |
| Oxygen and Sulphur.. | 1,105 | | |
| 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 phosphorus, and, in most cases, 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. The exceptions to these general rules will be noticed presently.

**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 into the plant chiefly through the stomata of the leaves, and are dissolved by the cell sap; the carbonic acid is retained in greatest proportion, as it 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 the green 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 5,755 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, apparently, appropriated by the leaves of green plants. When rain occurs after severe drought, water may be taken up to some extent through the leaves.

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 cell 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 might be derived by a simple process of condensation—

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

The formation of *carbohydrates* 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 carbohydrates, however much it be exposed to light. The formation of carbohydrates 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.

Cane sugar ($C_{12}H_{22}O_{11}$) and starch ($C_6H_{10}O_5$) are among the earliest products; by enzymes these are converted respectively into glucose ($C_6H_{12}O_6$) and maltose ($C_{12}H_{22}O_{11}$), for the nourishment of distant parts of the plant, to which they are 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. In seeds, roots, and tubers, where matter is to be stored up for future use, the glucose is generally again converted into starch or cane sugar. The transformation of these substances presents no chemical difficulties, as all of them are carbohydrates—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; possibly 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 carbohydrates; 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 carbohydrates.

3. *Respiration.*—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. In the case of a green plant, 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.

Plants destitute of chlorophyll behave, as a rule, like animals; they consume much oxygen and give out carbonic acid.

4. *Transpiration.*—While some evaporation of water will occur through the cuticle of young plants, the transpiration of water vapour chiefly takes place through small openings, known as stomata, which are generally most abundant on the underside of the leaves. These stomata open widely when the plant is well supplied with water, and close more or less completely during drought; the rate of evaporation is thus

naturally regulated. Transpiration takes place chiefly in light; it will occur abundantly 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 (p. 27).

The results of transpiration 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 substances are introduced.

1. *Assimilation of Ash Constituents.*—The roots take up the soluble salts, and, indeed, 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 will thus frequently receive more of some substances than is 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 in 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 present in very small quantity in the water contained 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 amide bodies 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. In the case of soils very rich in organic matter, as peat bogs and some forest soils, nitrates may be entirely absent; in these cases ammonia, or

soluble nitrogenous organic compounds, must furnish the supply of nitrogen to the roots.

The parasitic plants, already referred to, feed on the nitrogenous compounds contained in the sap of the host plant. Fungi attack organic matter, living or dead, and obtain from it both their nitrogen and carbon.

**Co-operative Nutrition.**—In some cases the feeding power of roots is modified to a very considerable extent by their union with another vegetable organism. Thus certain trees (as oak, beech, hazel, chestnut, willow and pine), heaths and orchids, growing on a soil rich in humus, may possess no root hairs, but have their roots covered by a fungus, the hyphæ of which penetrate the root. This root fungus (*mycorhiza*) feeds on the decaying vegetable matter of the soil and nourishes the tree with the material which it has prepared.

Another remarkable instance is afforded by leguminous plants. All species of *papilionaceæ* 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, having the characters of a bacterium, present in the soil. 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 sand 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 facts supply a much-needed explanation of the remarkable power of assimilating nitrogen possessed by leguminous plants.

When two organisms grow together for their mutual advantage, the case is said to be one of *symbiosis*, or joint life.

**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, and are stored up in the seed. 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 otherwise 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.

It is in succulent crops, as meadow grass, clover, and mangels, that we find the greatest variation in the amount and composition of the ash, depending on variations in the character of the soil, the manure, and season. Similar variations will be observed in the ash constituents of the straw of grain crops. In such plants, or parts of plants, we find very variable quantities of soluble sodium and potassium salts, depending on the abundance of these in the soil. The amount of lime present is also largely dependent on the composition of the soil. In clover hay, and bean straw, lime or potash will preponderate in the ash according to the character of the soil on which the crop grows.

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 growing layer (cambium) between the wood and bark of a tree; they are also abundantly stored up in the seed, as a provision for a new generation.

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.

The composition of a few typical ashes will be found in the following table. By "pure ash" is understood the ash minus charcoal, sand, and carbonic acid. The ash of leguminous plants is especially rich in carbonates.

## ASH CONSTITUENTS OF PLANTS (WOLFF).

### 1. Ash Constituents in 1,000 Dry Substance.

| | Total Pure Ash | $K_2O$ | $Na_2O$ | $CaO$ | $MgO$ | $Fe_2O_3$ | $P_2O_5$ | $SO_3$ | $SiO_2$ | Cl |
|---|---|---|---|---|---|---|---|---|---|---|
| Wheat grain | 19·6 | 6·11 | 0·41 | 0·64 | 2·36 | 0·25 | 9·26 | 0·08 | 0·38 | 0·06 |
| ,, straw | 53·7 | 7·33 | 0·74 | 3·09 | 1·33 | 0·33 | 2·58 | 1·32 | 36·25 | 0·90 |
| Bean grain .. | 36·3 | 15·06 | 0·39 | 1·81 | 2·60 | 0·17 | 14·11 | 1·23 | 0·24 | 0·65 |
| ,, straw .. | 53·5 | 23·14 | 0·91 | 14·25 | 3·06 | 0·68 | 3·41 | 2·09 | 3·75 | 2·35 |
| Red clover in bloom .. | 68·6 | 22·15 | 1·35 | 23·95 | 7·48 | 0·74 | 6·61 | 2·22 | 1·85 | 2·59 |
| Mangel root | 75·8 | 39·58 | 12·33 | 2·83 | 3·26 | 0·57 | 6·47 | 2·29 | 1·55 | 7·55 |
| ,, leaf | 153·4 | 47·09 | 29·82 | 16·34 | 14·62 | 2·16 | 9·97 | 8·61 | 5·57 | 21·51 |
| Potato .. | 37·9 | 22·76 | 1·12 | 1·00 | 1·87 | 0·42 | 6·39 | 2·47 | 0·77 | 1·31 |
| Beech timber* | 4·3 | 1·23 | 0·08 | 1·62 | 0·48 | 0·05 | 0·29 | 0·06 | 0·26 | — |
| Beech leaves (August)* | 49·1 | 9·90 | 0·80 | 14·30 | 3·66 | 0·43 | 4·08 | 1·18 | 14·07 | 0·05 |

* Manganese was an ingredient of this ash, though not mentioned in the table.

2. PERCENTAGE COMPOSITION OF ASH.

| | Total Pure Ash | $K_2O$ | $Na_2O$ | Ca O | Mg O | $Fe_2O_3$ | $P_2O_5$ | $SO_3$ | Si $O_2$ | Cl |
|---|---|---|---|---|---|---|---|---|---|---|
| Wheat grain | 100 | 31·16 | 2·07 | 3·25 | 12·06 | 1·28 | 47·22 | 0·39 | 1·96 | 0·32 |
| ,, straw | ,, | 13·65 | 1·38 | 5·76 | 2·48 | 0·61 | 4·81 | 2·45 | 67·50 | 1·68 |
| Bean grain .. | ,, | 41·48 | 1·06 | 4·99 | 7·15 | 0·46 | 38·86 | 3·39 | 0·65 | 1·78 |
| ,, straw .. | ,, | 43·26 | 1·70 | 26·63 | 5·71 | 1·27 | 6·37 | 3·91 | 7·01 | 4·39 |
| Red clover in bloom .. | ,, | 32·29 | 1·97 | 34·91 | 10·90 | 1·08 | 9·64 | 3·23 | 2·69 | 3·78 |
| Mangel root | ,, | 52·22 | 16·26 | 3·73 | 4·30 | 0·75 | 8·53 | 3·02 | 2·04 | 9·96 |
| ,, leaf | ,, | 30·71 | 19·44 | 10·65 | 9·53 | 1·41 | 6·50 | 5·62 | 3·63 | 15·98 |
| Potato .. | ,, | 60·06 | 2·96 | 2·64 | 4·93 | 1·10 | 16·86 | 6·52 | 2·04 | 3·46 |
| Beech timber* | ,, | 28·62 | 1·91 | 37·65 | 11·23 | 1·25 | 6·76 | 1·37 | 5·98 | 0·01 |
| Beech leaves (August)* | ,, | 20·17 | 1·63 | 29·12 | 7·45 | 0·88 | 8·38 | 2·41 | 28·65 | 0·10 |

* Manganese was an ingredient of this ash, though not mentioned in the table.

**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. Some seeds will slowly germinate below 40° Fahr.; the quickest germination usually occurs between 60° and 80°. Under favourable 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 nearly 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 of the seed 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 the summer there is a storing up of concentrated

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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 flowering 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, albuminoïds, 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 redissolved, 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 physical constituents—Tenacity—Relations to water—Relations to heat—Formation of soils—Organic constituents—The plant food contained in soil, its quantity and condition—Oxidation in the soil, nitrification—Deoxidation in the soil—Movements of salts in soil, losses by drainage—Absorption of atmospheric nitrogen—Absorption of bases and acids—Influence of tillage and draining—Clay burning.

**The Atmosphere.**—One hundred volumes of air contain nearly 78 of *nitrogen* and 21 of *oxygen*, with 1 of *argon* and other gases.

The free nitrogen of the atmosphere is apparently made available to leguminous crops through their root tubercles (p. 11); it may also be assimilated by certain low organisms in the soil under special conditions.

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 1,057 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 eighteen years, is 2·6 lbs. per acre; the nitrogen as nitrates and nitrites about 1·1 lbs.; the organic nitrogen a nearly similar quantity. The *total nitrogen* is about 4·7 lbs. per acre.[1] In tropical rain the proportion of nitrogen as nitrates is generally increased, while the ammonia is diminished. The total nitrogen found in the rain in New Zealand, Barbadoes,

[1] The rain includes the snow, hail, and dew deposited on the rain-gauge.

British Guiana, and Madras does not exceed that found at Rothamsted. The amount of nitrogen is considerably larger in rain collected near towns.

*Chlorides* are always present in rain, especially in the neighbourhood of the sea. At Georgetown, British Guiana, the chlorides in the rain are equal, on an average, to about 186 lbs. of common salt per acre per annum; at Cirencester they amount to about 36 lbs.; at Rothamsted the quantity is about 24 lbs.

The *sulphates* found in the 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. *Physical Constituents.*—If a soil consisted of spherical particles, all of the same size, the empty spaces between these particles would amount to about 47 per cent. of the volume with the loosest packing, and to nearly 26 per cent. with the closest packing. The total empty space would be the same whatever the size of the particles. If the interspaces with the closest packing were occupied by another set of smaller spheres they would be reduced to 6·7 per cent. of the volume. If this process was again repeated they would become 1·7 per cent. With loose packing the proportion of interspace would, in all cases, be much larger.

In a natural soil the particles are of very various sizes, and of irregular shape; the first condition tends to diminish the proportion of interspace, the latter to increase it. Some of the particles of a soil are themselves porous, as particles of humus and limestone, and aggregates of smaller masses; this condition may considerably increase the volume of interstices.

The total surface presented by a mass of spherical particles doubles when their diameter is halved. The internal surface of a soil is thus much greater when it is made up of fine constituents; it is also increased when the particles are themselves porous. Upon the proportion of the interstices, and upon the amount of surface presented by the particles, the physical properties of a soil and its fertility largely depend.

By *mechanical analysis* the constituents of soil may be separated into groups of definite sizes; the coarser particles are separated by means of sieves, the finer by means of currents of water of different velocity. The finest particles in soil are those of pure clay, which remain permanently suspended in distilled water. Next to these come silt and sand of very varying degrees of fineness, and often very different chemical composition. The still coarser particles are grit, gravel and stones. The physical character of a soil depends in great measure on the prevailing size of its particles.

2. *Tenacity of Soil.*—The coarser elements of soil, including the fine sand, exhibit little cohesion; the tenacity of a heavy soil is due to the fine silt and clay. Clay owes its cementing power to the presence of a small quantity of a hydrated colloid (jelly-like) body, rarely, according to Schlœsing, exceeding 1·5 per cent.

of the clay. The remainder of the clay is made up of extremely fine, solid particles. Clay has, in fact, a constitution similar to that of common putty. In the purest natural clays the whole of the constituents have the same general chemical composition (hydrated silicate of aluminium), but in soils the non-colloid constituents of the clay may be of very various nature. In brick earth this matter is quartz sand; in marl it is carbonate of calcium.

The condition of clay soils depends much on whether the clay is coagulated or not. When the clay is uncoagulated the soil is sticky, impervious to water, and cannot be reduced to a fine tilth. When the clay is coagulated the soil has a granular structure, is pervious to water, and can be reduced to powder. Clay is effectually coagulated by frost, which by removing the water from the colloid cement causes it to shrink. It is also coagulated by lime, and by many salts, and especially by salts of calcium. Colloid clay will remain permanently suspended in distilled water; it is precipitated on the addition of a small quantity of a calcium salt. An application of chalk or lime to clay soils is well known to be extremely effective in diminishing their tenacity, rendering them pervious to water, and more easy of tillage.

In cultivated sandy soils humates are often of great value as cementing materials; these, like true clay, are colloid bodies. Schlœsing found that 1 per cent. of humic acid, in the form of calcium humate, was as effective as a cement for sand as the presence of 11 per cent. of a fat clay. Humates, however, lose their cementing properties on drying, while clay does not. The improvement of the texture of sandy soils by the continued use of farmyard manure, or by the ploughing in of green crops, is a fact familiar to the farmer. While humus increases the coherence of sand, it has a contrary effect on clay, and the ploughing in of long dung is one of the most effectual means of lightening a heavy soil.

In some sandy soils hydrated ferric oxide acts as a cementing material. Calcium carbonate will also tend to increase the coherence of sand. Well-cultivated mixed soils (loams) consist largely of compound particles, made up of various constituents held together by cementing materials; these coarse porous particles are highly favourable to a good physical condition of the soil.

3. *Relations to Water.*—In a natural soil consisting of solid particles of fairly uniform size, the interspaces are about 40 per cent. of the volume, whether the particles are large or small; but if the particles are a mixture of large and small (as gravel and sand) the volume of the interspaces is much reduced. On the other hand, if the particles are themselves porous, as in the case of chalk, loam, and especially of humus, the volume of the interspaces is much increased. It is this volume of the interspaces which determines the amount of water which a soil will contain when perfectly saturated, or the amount of air which it will contain when dry.

The influence of humus on the capacity of a soil for water is remarkable. The surface soil of the wheat-field at Rothamsted was sampled in January, 1869, when saturated with water: the unmanured land contained in the first six inches 29·9 of water per 100 of dry soil; the land manured with farmyard manure for twenty-six years contained at the same time 60·2 of water per 100 of dry soil.

Farm crops will not grow in a soil permanently saturated with water, and from which air is consequently excluded; the most luxuriant growth is obtained in soils one-half or two-thirds saturated.

A surface soil is seldom saturated, save immediately after heavy rain; it is the quantity of water which a soil will retain when fully drained which determines its capacity for supplying a crop with water. The amount of water permanently retained by a soil is not determined by the volume of the interspaces, but by the extent of internal surface, the water being held by adhesion on the surfaces of the particles; the smaller, therefore, are the particles of the soil, or the more porous, the greater is the amount of water retained. Two specimens of powdered quartz, one coarse, the other very fine, held when fully saturated more than 40 per cent. their volume of water; but when drained, the coarse quartz retained only 7·0 per cent., and the very fine quartz 44·6 per cent. of water; the latter lost, in fact, no water by drainage.

The soils retaining least water when drained are gravel and coarse sand. The amount retained increases as the particles become smaller. The presence of colloid bodies, as clay, humic acid and humates, increases the power of retaining water, as such bodies swell up when wetted and hold the water in a jelly-like substance. The addition of humus to soils is thus one of the best means of increasing their power of retaining water.

The surface soil may be supplied with water from below if a saturated subsoil exists at a moderate distance; such water is said to be raised by *capillary action*, which is simply a manifestation of the attraction for water exerted by the surfaces of soil particles. The finer are the particles of the soil, and the closer they are packed, the greater will be the height to which water will be carried by capillary action. The quantity of water reaching the surface diminishes, however, rapidly as the distance it has to travel increases. The quantity of water raised also diminishes when the fineness of the particles exceeds a certain point. It is not always the soil with the finest particles which brings most water to the surface. For every distance between the water-level and the surface there is a certain degree of fineness of the soil particles which will act most effectively. Capillary action is seldom able to maintain a sufficient supply of water at the surface. At Wisconsin crops suffer from drought, though a permanent water supply exists five feet below the surface. Capillary action is most effective in the case of silty soils; such soils, having been deposited from running water, consist of very fine uniform particles, but without any true clay.

The average annual *evaporation* from a water surface in the neighbourhood of London amounts to 20·6 inches, according to Greaves; the maximum monthly evaporation of 3·4 inches occurs in July, the minimum of 0·5 inches in December. The evaporation from a saturated soil is greater than from a water surface; as the soil dries the rate of evaporation rapidly diminishes. The average annual evaporation from a bare loam at Rothamsted is about 17 inches. Soils of various character evaporate equal amounts while saturated, but exhibit great differences as drying proceeds. It is the soil with coarsest particles and loosest texture which dries quickest and to the greatest depth.[1] Deep tillage must therefore be avoided in early summer, if the land is intended to carry a crop.

The greatest evaporation takes place from soil when it grows a crop. The water in a barley soil, and in an adjoining bare fallow, was determined at Rothamsted at the end of June, during the drought of 1870. It was found that down to fifty-four inches below the surface the barley soil contained nine inches less water than the soil under bare fallow. The injurious effect of weeds in summer-time is largely due to their robbing the soil of water.

Evaporation from the soil is diminished by protection from sun and wind. Stones lying on the surface act favourably in this direction. A crop shading the ground may keep the surface moist, while it is greatly increasing the loss of water from the subsoil. Economy of water is best effected by mulching with straw. Keeping the surface stirred to the depth of an inch or two, thus providing a mulching of loose, dry soil, is an excellent plan, and forms a fundamental part of successful cultivation in hot climates.

A perfectly dry soil has the power of taking up a small amount of water from moist air; this power is known as *hygroscopicity*. It is possessed scarcely at all by sand, to a greater extent by clay, especially ferruginous clays, and in the largest degree by humus.

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[1] In a long drought a greater amount of water may finally be evaporated from a consolidated soil of fine particles, owing to the greater store of water present, and the movement of this toward the surface; but for a long time such a soil will remain moister at the surface than a soil of open texture.

Water thus absorbed is too firmly held to be of use to crops, but in hot climates the evaporation of this hygroscopic water during the day lowers the temperature of the soil, and saves the crop from scorching (Hilgard). Soils may condense considerable amounts of water from the air when the temperature of the surface falls below the dew point.

A characteristically dry soil is one of coarse, non-porous particles, and loose texture—a gravel or coarse sand for example. Such a soil holds little water, and evaporates it freely. If the subsoil is one of free drainage the evil is at its worst. With dry soils the farmer should aim at increasing the amount of humus; crops should be sown early, and the land kept clean and solid; very shallow summer cultivation should be resorted to. Such land has a few distinct advantages. It furnishes the earliest crops to market gardeners, the soil being easily warmed. A little rain will also wet it to a considerable depth, and the whole of the water it contains is available for plants.

A soil is seldom too wet because it has too great a power of holding water when drained, the mischief is generally owing to want of drainage; the cure is therefore to be found in deep tillage and draining. Clay burning, applications of lime and chalk, or an increase in the proportion of humus, may, in special cases, be effective means for rendering the surface soil more pervious to water.

The wettest soil does not always supply the largest amount of water to a crop. A peaty soil holds most water, but much is not available to plants, being combined with colloid matter. A stiff clay fails in drought, the water being firmly held and moving with difficulty.

Soils composed of silt, or extremely fine sand, are those which yield water most effectually to a growing crop.

4. *Relations to Heat.*—The sources of heat to a soil are solar radiation and chemical action. The oxidation of organic matter in a soil will undoubtedly raise its temperature, but the effect is generally too small to be appreciable. At Tokio 40 tons of farmyard manure per acre were incorporated with the soil to a depth of one foot. During the next twenty days the average temperature of this soil was 2°·3 higher than that of unmanured soil; during the next five days the excess of temperature was only 0°·8. Chemical action is most vigorous during the summer months.

Both the amount of heat received from the sun and the amount of heat which the soil loses by radiation are largely influenced by the degree of transparency of the atmosphere. The greatest extremes both of heat and cold occur with a clear sky and dry air; in a cloudy, moist climate, the variations in temperature are comparatively small.

The heating effect of the sun is largely determined by the angle at which its rays strike the earth; it is greatest when these rays are perpendicular to the surface. The different power of the sun's rays at sunrise and at mid-day is familiar to all. At sunrise the solar radiation is weakened by diffusion over a wide area, and its intensity is further diminished by excessive atmospheric absorption. At mid-day the illumination has reached its maximum, and the sun's rays also pass through a minimum thickness of the atmosphere. The difference in the *angle of incidence* of the sun's rays is the prime cause of the immense difference between an Equatorial climate and that of Northern Europe. The effect is observed to some extent in our own fields, and explains why certain slopes or aspects are favourable to fertility. It is on a slope facing the south that the soil will reach its highest temperature during sunshine.

The *mean temperature* of both soil and subsoil is nearly the same as the mean temperature of the air at the surface. Every circumstance affecting the temperature of the air (as warm ocean currents) affects the mean temperature of the soil. When, however, a soil is freely exposed to the sky, the temperature at the surface reaches a far higher maximum, and falls to a lower minimum than is reached by the air above it. Schübler determined for two years the temperature of freely-exposed soil in his garden at Tübingen, at $\frac{1}{12}$ inch below the surface, shortly after noon, on every day when the weather was perfectly fine. The mean of these determinations was above 120° Fahr. for every month from April to September inclusive, and in July reached 146°; this latter temperature was 65° above that of the air taken at the same time.

A *dark-coloured* soil becomes hotter in the sun's rays than a light-coloured one, a larger proportion of the sun's energy being converted into heat; the extreme difference observed in the case of natural soils in European climates is about 8°. No difference will be observed on cloudy days. At night all soils will cool to the same point.

The quantity of heat required to produce the same rise in temperature (*specific heat*) is very different for the different constituents of soil, as will be seen from the following table:—

SPECIFIC GRAVITY AND SPECIFIC HEAT OF SOIL CONSTITUENTS.

| | Specific Gravity | Specific Heat of | |
|---|---|---|---|
| | | Equal Weights | Equal Volumes |
| Water .. .. .. | 1·00 | 1·000 | 1·000 |
| Humus .. .. .. | 1·23 | 0·477 | 0·587 |
| Lava and basalt.. .. | 2·7—3·0 | 0·20—0·28 | 0·54—0·84 ? |
| Clay .. .. .. | 2·44 | 0·233 | 0·568 |
| Calcium carbonate .. | 2·72 | 0·206 | 0·561 |
| Quartz, felspar, granite | 2·65 | 0 189 | 0·499 |

Thus the same quantity of heat will raise 1 lb. of water and 5 lbs. of chalk or quartz sand to the same temperature; and during cooling, 1 lb. of water will give out five times as much heat as 1 lb. of chalk or quartz. Or, looking only at the solid constituents of soil, the same amount of heat will raise 3 lbs. of humus and 8 lbs. of quartz to the same temperature.

The specific heat of different soils is, from a practical point of view, best shown by the quantity of heat required to raise equal volumes or depths to the same temperature. With dry soils, including only hygroscopic water, about three cubic feet would be heated by the sun to the same degree as one cubic foot of water. In this condition there is little difference between different soils; a dry peat will consume the least heat, and a dry clay the most. When, however, soils become wet great differences appear. In a freshly-drained condition, a coarse gravel or sand will warm to the greatest depth, while soils retaining more water will warm to a smaller depth. The specific heat of wet peat does not differ greatly from that of its own bulk of water.

The depth to which a soil will be heated depends, however, partly on the *conductive power* of its constituents. Quartz has the greatest power of conducting heat of any soil constituent. Air is the worst conductor of heat present in the soil. A dry soil, in fine powder, is thus a very poor conductor of heat, each particle of soil being surrounded by air. Consolidation improves the conductivity, and the presence of stones has a still greater effect. Wetting the soil doubles the conductivity of quartz sand, chalk, or clay, by displacing the air. We see, therefore, that a dry, pulverulent, loose soil will get very hot at the surface when exposed to the sun, but the heat will penetrate to a small depth. A solid, stony soil, especially when wet, is the one in which heat will pass most easily to the subsoil. The suitability of gravelly soils for early spring crops has been already noticed.

The presence or absence of much water is the condition which chiefly determines the cold or warm character of a soil. We have already noticed the high specific heat of water, in consequence of which the same amount of sunshine will warm a wet soil far less than a dry one. A still more potent reason for the coldness of wet soils is, however, the *loss of heat during evaporation*. If one pint of water is evaporated from 97 pints, the 96 pints remaining will have fallen 10° Fahr. in temperature, or this amount of heat must have been supplied from some external source. Undrained meadows, and heavy clays, are thus cold soils, because much of the heat of the sun is in these cases consumed in evaporating water. Parkes found that an undrained peat bog, 30 feet deep, had a uniform temperature of 46° below a distance of one foot from the surface. In the middle of June he found the temperature 47° at seven inches below the surface, while the drained portion had a temperature of 66° at this depth, and a temperature of 50° at two feet below the surface. Draining is the only cure for a cold, wet soil.

The *temperature of the subsoil* is practically constant throughout the year at a certain distance from the surface; this distance will be a few feet in the tropics, but becomes very considerable in northern latitudes, where there is a wide difference in the summer and winter temperature. Between the point of constant temperature and the surface the changes of season are felt, but the maximum and minimum temperatures in the subsoil always occur after they have been reached at the surface. At a certain depth the seasons are reversed, and the maximum temperature occurs in the subsoil while it is winter at the surface. At Greenwich Observatory, in a well-drained gravel, the variations of day and night are slightly felt at three feet from the surface. At 25·6 feet the maximum temperature usually occurs in the latter part of November, and the minimum in the first week in June; the difference between the two is about 3°. It follows from what has been stated that the soil and subsoil are generally warmer than the air in autumn, and cooler than the air in spring.

5. *Formation of Soils.*—All soils have been produced by the disintegration of rocks, through the prolonged

action of water, air and frost; and, in the later stages of their history, by the action of vegetable and animal life, and their products. The original matter from which all subsequent formations have been derived consists of the *igneous rocks*, composed chiefly of silica and alumina united with variable proportions of oxide of iron, potash, soda, lime, magnesia, and small quantities of many other substances. Such rocks always contain some phosphoric acid, frequently as apatite.

Some soils are derived directly from the decomposition of igneous rocks, as in the case of soils derived from lava, basalt, and granite. In most cases, however, the igneous rocks have undergone disintegration during geologic ages, and have been redeposited on the sea bottom, the deposit being generally associated with the remains of vegetable and animal life. The *sedimentary rocks* thus produced consist either of sand, clay, or limestone, or mixtures of these, in various states of aggregation. The *sand* consists of little altered fragments of the hardest and most resistant constituents of the original rock; it is chiefly composed of quartz, but generally contains besides small quantities of felspar, mica, and other minerals. *Clay* is a hydrated silicate of aluminium; it is a result of the chemical decomposition of potash or soda felspars. These felspars are decomposed by the prolonged action of water containing carbonic acid; the alkalies and a part of the silica are removed in solution, and clay remains. During the decomposition of igneous rocks the lime and magnesia have been removed in solution, and have accumulated in the ocean; the precipitation of the lime and magnesia as carbonate has been brought about through the agency of vegetable and animal life. From the calcareous muds thus deposited our *limestone* rocks have originated. From the sandstones, clays, and limestones thus produced, our present soils have been mostly formed.

The action of the *weather* on soils is similar in kind to that which has already taken place on a larger scale on rocks. The expansion of water when freezing tends to reduce a soil to fine powder. The oxygen of the air takes a share in the disintegration if silicates containing ferrous oxide are present. The most potent chemical agent is, however, the carbonic acid present in rain, and to a still larger extent in the water permeating soils containing vegetable matter. This solution of carbonic acid dissolves, and removes as drainage water, the carbonates of calcium and magnesium; it also, especially when reinforced by the presence of the carbonates just mentioned, attacks any undecomposed silicates, and removes in solution the alkalies and some of the silica which they contain. When a soil has become the seat of vegetation the chemical agents of decomposition gain in power; the carbonic acid in the soil is much increased, and is assisted by the humic acids, and by the nitric acid, which appear on the scene; the solvent action of plant roots must also be taken into account.

Weathering action is thus destructive, and especially tends to remove from the soil in drainage water the lime, magnesia, and alkalies which it contains; a surface soil is thus generally poorer in lime, and frequently in potash, than the subsoil beneath it. The impoverishment of the soil is hindered by its absorptive power (pp. 43, 45), but chiefly by the conservative action of vegetation. The plant is continually collecting from the soil and subsoil dissolved or easily soluble matter, storing these in its tissues, and at its death leaving them upon the surface soil. When natural vegetation has continued this action for ages, as in an undisturbed prairie or forest, a surface soil is produced rich in vegetable matter, and containing an accumulation of plant food in a very available form.

6. *Organic Constituents.*—In all sedimentary rocks there is some organic matter, containing both carbon and nitrogen, a residue of ancient vegetable or animal life; the nitrogenous organic matter in our deeper subsoils is mostly of this ancient character. The much larger quantity of organic matter present in a surface soil is, on the other hand, a residue of recent life, or of applications of organic manure, and has a different composition (p. 40).

The brown or black organic matter of surface soils, to which we give the name of *humus*, is a product of processes of fermentation (as in a peat bog), or of partial oxidation (as in an arable soil); and when exposed to air in a surface soil is continually undergoing further change. Humus is a mixture of many ill-defined bodies; it may be roughly divided into humic acids and humin. If a soil is treated with cold dilute hydrochloric acid, and washed, the bases with which the humic acids were combined are removed; if now ammonia be added, the humic acids come into solution as ammonium salts, while the insoluble humin is left. The basic alkali humates are readily soluble, but the acid humates of potassium and sodium are very sparingly soluble. The combinations of humic acid with calcium and iron are insoluble. Humic acid combines with ammonia to form an amide. The humus of soil always contains nitrogen; the amount is very variable, depending on its past history. It has apparently in part an amide nature, and yields ammonia and soluble nitrogenous bodies when boiled with dilute acids or alkalies.

The humic matter of soils is of great agricultural importance; not only does it profoundly modify the physical properties of soil, it is also the principal source of the nitrogenons food of plants. A soil rich in humus is rich in nitrogen; a soil poor in humus is poor in nitrogen. The old pasture at Rothamsted, with roots removed, contains when dry, in the first nine inches, 0·245 per cent. of nitrogen, and 3·36 per cent. of carbon, corresponding to about 5·6 per cent. of humus. In very rich English pastures the percentage of nitrogen will reach 0·5 or 0·6. The soil of old kitchen gardens, and the black soil of Manitoba, may contain a similar amount. The arable soil at Rothamsted, a heavy loam, contains 0·10—0·15 per cent. of nitrogen; and its clay subsoil, down to nine feet, 0·04—0·05 per cent. A sandy subsoil will contain less nitrogen.

7. *Plant Food in Soil.*—The proportion of plant food present in soils is very small, even when the soil is extremely fertile, the bulk of the soil serving chiefly as a support, and as a sponge to hold water. A good arable loam may contain 0·15 per cent. of nitrogen, 0·15 per cent. of phosphoric acid, 0·2 per cent. of potash (soluble in hydrochloric acid), and 0·5 per cent. of lime: much larger quantities may, of course, occasionally be present. Plant food is not equally distributed throughout a soil. If a soil is separated

by sifting, or by currents of water, into finer and coarser particles, the finer particles will be found much the richest in plant food.

The weight of soil on an acre of land is so enormous that small proportions of plant food may amount to very considerable quantities. Nine inches' depth of arable loam will weigh, when perfectly dry, about 3,000,000 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 3,000 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 *available condition* of the plant food depends much on the character of the soil. A much smaller proportion of plant food will render a sand fertile than would be required in the case of a clay. This is partly from the far greater development of the roots in a sandy soil, and partly from the different condition in which the mineral food is held. Hilgard has also pointed out that the presence of lime in a soil, especially when associated with humus, much increases the availability both of potash and phosphoric acid, so that smaller quantities of these suffice when lime is present.

Food can be taken up by the roots of plants only when it is in solution, or in a condition capable of being dissolved by contact with the acid sap of the root hairs. Matter which is in neither of these conditions is useless to the plant, though it may afterwards become available by the chemical actions within the soil. Most of the ingredients of soil are in an insoluble condition : this fact is really of the utmost advantage, as else soils would lose their fertility by heavy rain.

The *chemical analysis* of soils usually aims at determining the total amount of the various matters present in a soil, or else the quantities soluble in strong hydrochloric acid; it does not therefore succeed in furnishing a measure of the soil's fertility. Dyer has lately employed with success a 1 per cent. solution of citric acid for soil analysis; this solution has an acidity somewhat similar to that possessed by root sap. By extracting the soils of the experimental wheat and barley fields at Rothamsted with this solution, he found that when the soil contained ·03 per cent., of phosphoric acid, soluble in 1 per cent. citric acid, manuring with phosphates was not needed; but that when only ·01 per cent. was present, phosphatic manure was urgently required. When the potash soluble in 1 per cent. citric acid amounted to ·004 per cent. potash manures were apparently not required for barley; in the case of wheat, ·005 or ·006 per cent. apparently sufficed. Wood, working with calcareous Norfolk soils, found that ·008 per cent. of potash soluble in 1 per cent. citric acid was quite insufficient for barley, but ·013 was sufficient.

8. *Oxidation in Soil.*—The materials from which the nitrogenous matter of soils is derived contain always a large proportion of carbon. In the roots and stubble of cereal crops the relation of nitrogen to carbon is about 1 : 43; in those of leguminous crops 1 : 23; in moderately rotted farmyard manure 1 : 18. In an aerated soil these materials are oxidised 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 1 : 10; and a clay subsoil 1 : 6. These figures represent the proportion of nitrogen to carbon in the commonest forms of humic matter. Humus represents merely a stage in the decomposition of organic matter; in the end, the whole of the carbon, hydrogen and nitrogen appear as carbonic acid, water, and ammonia or nitrates.

The nitrogen contained in humus is not in a condition to serve as a food for ordinary crops, the gradual decomposition of soil humus is thus generally essential to fertility. Many kinds of fungi and bacteria are capable of converting the nitrogen of organic matter into ammonia; the final *nitrification* of ammonia is performed by two species of bacteria, one of which produces nitrites, which the other changes into nitrates. Fresh vegetable residues are more easily nitrified than old humic matter. Nitrification does not begin till the earlier stages of decomposition are past.

The nitrifying bacteria occur most abundantly in the surface soil; the depth to which their action extends depends on the porosity of the subsoil. In the clay subsoil at Rothamsted the organisms did not always occur in small quantities of soil taken at more than three feet below the surface. 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. The nitrifying organisms may be killed by severe drought.

The oxidation of humus not only makes the nitrogen which it contains available as plant food, it also liberates the ash constituents combined with the humus, and enables them to take part again in the nourishment of plants.

Oxidation is most active in soils under tillage. Thus 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 often 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: under such conditions an unlimited accumulation of organic matter may take place if plants capable of growing in these circumstances are present.

9. *Deoxidation in Soil.*—When a soil is not in an aerated condition, but has the spaces between its

particles filled with water, the nitrates present in it are destroyed by certain kinds of bacteria, the oxygen of the nitrate combining with carbon to form carbonic acid, while the nitrogen escapes as gas. The process of denitrification requires the presence of fermentable organic matter; when this is present in sufficient proportion denitrification may occur even in the presence of air.

In a peat bog, or in any water-logged soil, the decomposition of the organic matter is brought about by anaerobic organisms (see p. 52), and is of a putrefactive character. Under these circumstances also nitrogen may be lost as gas.

10. *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, a part of the subsoil water is slowly brought to the surface by capillary action, 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 action has little influence in the case of coarse 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 much, depending on the richness of the soil in nitrogen, the previous conditions as to tillage, 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 bare fallow.

11. *Absorption of Atmospheric Nitrogen.*—The behaviour of soils to atmospheric nitrogen still remains ill defined. A soil may, in some circumstances, give up ammonia to the air, in other circumstances it may absorb ammonia from the air. The free nitrogen of the air does not combine with the inorganic or with

the humic constituents of soil, but it may be brought into combination by living organisms in the soil. The bacillus isolated from soil by Winogradsky assimilates nitrogen only when supplied with fermentable organic matter, and in the absence of oxygen and ammonia; the absence of oxygen is apparently sufficiently assured by the presence of some organism making a large use of that gas. The bacterium-like organism which forms the tubercles on leguminous plants inhabits the soil, it assimilates nitrogen freely when in union with the roots of the host plant, but it has not been proved that it assimilates nitrogen in the soil when not in union with the plant. A soil bacterium (probably one of those already mentioned) is also capable of living in union with certain green algæ, and under these circumstances is capable of assimilating nitrogen. In all these cases it appears that the supply of carbohydrates furnished by a green plant is needed if nitrogen is to be assimilated. Whether nitrogen can be assimilated when humus is the only organic matter available is at present doubtful. The practical conclusions are thus at present limited. The enrichment of the soil with nitrogen when leguminous plants hold possession of the land is, however, a fact well assured and of the highest importance. With the exception of this fact, it is well to remember that with land under tillage the losses of nitrogenous matter by oxidation and drainage generally greatly exceed any gains, and a necessity thus exists for restorative cropping and manuring.

Attempts have been made to increase the fertility of soils by adding to them the living organisms which assimilate nitrogen from the air; such applications have generally failed, probably because soils are already sufficiently provided with these organisms.

12. *Absorption of Bases and Acids.*—If a solution containing phosphoric acid, potash, or ammonia is poured upon a sufficiently large quantity of fertile soil, the water which filters through will be found nearly destitute of these substances. This retentive power of soil for phosphoric acid, potash, &c., is of the utmost agricultural importance, as it enables soils to maintain their fertility when washed by rain, and permits of the economic use of many soluble manures. The ingredients of the soil which exercise a 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. When a solution of phosphate of calcium in carbonic acid is placed in contact with an excess of hydrated ferric oxide, the phosphoric acid is gradually absorbed and the calcium left in solution as carbonate. Hydrated alumina acts in the same manner. Ferric oxide and alumina have also a retentive power for ammonia, potash, and other bases, but the compounds formed are more or less decomposed by water. To the hydrous double silicates the permanent retention of potash and other bases is chiefly due. Humus has a great absorbent power for ammonia; it also retains other bases with which it can form insoluble compounds.

Magnesia, lime, and soda are retained by soil, but in a less powerful manner than are potash and ammonia. When a solution of a salt of potassium or ammonium is placed in contact with a fertile soil, lime will come into solution and take the place of the potash or ammonia, which is, by preference, absorbed. The relative mass of the acting bodies has, however, a great influence, and it is possible to liberate potash from a soil by the application of a large quantity of a sodium salt, although the sodium is the weaker base.

Soils destitute of lime 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.

Phosphoric acid is the most firmly retained of all the substances absorbed by soil. The bases absorbed by soil are slowly removed by the action of water. The action of the water is least in a soil which has absorbed little, or has been already washed, and greatest when the soil has been heavily manured. A soil always contains some plant food in solution.

The permanent 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 much more 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, or humus. Different crops have very different powers of attacking these various forms of plant food.

13. *Tillage and Draining.*—The operations of tillage and draining serve in many important ways to make the conditions of plant life more favourable, and to increase the amount of plant food which is at the disposal of a crop; many of these have been already noticed.

By tillage, aided by frost, and by alternate drought and rain, the surface soil is pulverised, and brought into a loose, open condition. The fine tilth thus obtained allows of a rapid extension of the delicate root fibres, and favours a happy condition of soil moisture.

By the action of the *plough* the residues of crops, weeds and manure are buried, and incorporated with the soil. The deep tillage of heavy land allows rain to penetrate it, and establishes the drainage of the surface soil, and increases its temperature. A shallow surface tillage preserves the moisture of the soil in time of drought. By *rolling* a pulverised soil we increase the moisture at the surface, and the depth to which the soil is warmed by the sun.

Another important result of tillage is that the soil is thoughly exposed to the influence of the air. Soils containing humus or clay will, under this condition, absorb some ammonia from the atmosphere. The oxidation of the nitrogenous organic matter present in the soil will also be greatly facilitated, carbonic and nitric acids being produced. The disintegration and solution of particles of rock will take place from the mechanical and chemical actions brought into play. Of the chemical results brought about by tillage the increased production of nitrates must be ranked as 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 the roots penetrate, and consequently the extent of their feeding ground, is increased; 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 by lack of drainage.

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 the roots of crops, and by worms. The porosity of stiff soils is largely increased by the two agencies last named.

14. *Clay 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 mixed with vegetable rubbish and burnt in heaps, which are then spread over the land and ploughed in. If the soil contains lime this will attack the silicates of the soil, 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.

# 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 Guano — Bones — Oilcakes — Phosphatic Slag and Ground Phosphates — Superphosphate — Gypsum — Lime, Chalk, and Marl—Potassium Salts—Common Salt. Relative Value of Manures.*—Results of comparative experiments—Price per unit. *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 at the surface, 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, and the amount of drainage and the losses by drainage are much increased. 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 its fertility is to be maintained. Hence the necessity for manuring.

A nearly complete return to the land would be accomplished by manuring it with the excrements of he 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 often obliged to purchase manures for the land in exchange for the crops and stock sold off it.

On naturally poor soils it may be necessary to make a 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 manures 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 X.

The treatment of the manure is most important. The largest part of the nitrogen is voided in the form of urine, and generally the richer the diet the higher will this proportion be. If 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 great superiority of *box manure* to that made in an open yard. Holdefliess found that a quantity of food and litter which, in a deep stall, yielded 10 tons of manure, containing 108 lbs. of nitrogen, yielded, when carried daily to a heap, only 7½ tons, containing 64 lbs. of nitrogen.

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 while the manure is in the stable. Müntz and Girard found the loss in the case of horses and cows to amount to about 30 per cent. of the nitrogen voided by the animal. A still greater loss occurred with sheep, in consequence of the concentrated nature of their urine. This loss may be diminished by a liberal use of litter, and especially by using peat or peat moss instead of straw (p. 212). The addition of loam to straw considerably increases its power of retaining ammonia. Sprinkling powdered gypsum, superphosphate, or kainite on the fresh manure also greatly diminishes the loss of ammonia.

Farmyard manure readily undergoes decomposition: this decomposition proceeds quite differently according as air is admitted or excluded. If the manure is thrown loosely in a heap it becomes very hot, and rapidly wastes; the organic matter is in this case virtually burnt, and yields carbonic acid, water and ammonia; the work is performed by *aerobic* organisms.[1] If, on the other hand, the manure is consolidated and kept thoroughly moist, so that air is excluded, the mass ferments with but little rise in temperature, carbonic acid and methane ($CH_4$), with some hydrogen and nitrogen, are given off, the loss of weight is far less than in the previous case, and the litter is chiefly converted into humic matter. This fermentation is the work of *anaerobic* organisms.[1]

The ammonia present in fresh manure gradually disappears, it apparently combines with the humic matter arising from the decomposition of the litter, an amide being produced.

It is sometimes best to cart the fresh manure on to the land and at once plough it in; the losses in the heap are thus prevented, and a greater bulk of manure added to the soil; heavy land is especially benefited by such treatment. When the manure must be kept, it should be made without delay into a solid heap, which must not be allowed to get dry. A manure pit under cover may be provided with a pump by which drainage

[1] Aerobic organisms (fungi and some bacteria) require oxygen for the performance of their work. Anaerobic organisms (yeasts and some bacteria) decompose organic matter without consuming oxygen.

can be thrown on to the manure in dry weather. When the heap is made in the open it should be covered by a layer of earth. The fermentation of farmyard manure may be greatly hindered by mixing with it a small quantity of kainite; loss of nitrogen is thus prevented, but the decomposition of the litter becomes imperfect.

Well-made rotten manure is a more concentrated plant food than fresh manure, and is much preferred for light soils, which long manure would leave too open and liable to drought.

Farmyard manure will contain from 65—80 per cent. of water. The nitrogen will usually be about 0·45 per cent., but may rise 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—3 per cent., exclusive of the sand and earth always present. Of these ash constituents 0·4—0·8 will be potash, and 0·2—0·4 phosphoric acid. One ton of farmyard manure will thus supply 10—15 lbs. of nitrogen, 9—18 lbs. 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 many soils by increasing the proportion of humus present. Heavy land is greatly lightened, and made more pervious to air and water, by ploughing in fresh manure. Sandy soils are consolidated, and their power of retaining water much increased by the admixture of rotten manure.

**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 consists chiefly of the dried excrements of sea fowl. When guano has been deposited in the absence of rain it contains a large amount of nitrogenous matter, phosphates, and alkali salts. If exposed to rain the original nitrogenous matter is decomposed and disappears, the alkali salts are washed out, and the guano remaining is then almost purely phosphatic. The largest deposits of guano are on the Peruvian coast and the adjacent islands. Guano is also imported from the south-west coast of Africa. The present imports contain 2—10 per cent. of nitrogen, 10—30 per cent. of phosphoric acid, and 0·2—3·4 per cent. of potash. From its great variation in composition, guano should always be purchased on analysis.

To obtain a constant composition different kinds are sometimes mixed, and any deficiency in nitrogen made up by the addition of sulphate of ammonium; such mixtures are known as *equalised guano.*

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 part exists as phosphate of ammonium, a salt readily soluble in water.

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, potatoes, 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 an excellent manure for corn crops and potatoes. Admixture with superphosphate and potassium salts is more necessary for obtaining a profitable result with ammonium salts than it is when nitrate of sodium is employed.

If sulphate of ammonium is applied as a top-dressing to arable land containing much carbonate of calcium, some loss of ammonia is apt to occur from the volatilisation of carbonate of ammonium; this loss would be greatly diminished by mixing the ammonium salt with superphosphate, and by applying the dressing in showery weather. Sulphate of ammonium generally gives its best results when ploughed or harrowed in.

The ammonia is converted into a nitrate in a few days or weeks after the application of the salt to a moist, fertile soil; but nitrification may be much retarded by dry weather. 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 calcium salts are more or less removed by drainage. Ammonium salts produce little effect in soils destitute of lime, as in such cases nitrification is much delayed; the evil may be cured by an application of lime in autumn.

**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. Inferior qualities of the nitrate occasionally contain sufficient perchlorate of potassium to produce an injurious effect on cereal crops; such nitrate may generally be used successfully for mangels.

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 applied with the seed, and the nitrate added afterwards as a top dressing.

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

Nitrate of sodium is especially suited for soils containing much clay. 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 nitrogenous manure, and is therefore the best manure to employ when a late top 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 waste, 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—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. of nitrogen, and 14—17 per cent. of 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 as manure is rather considerable, as they contain a good deal of nitrogen, with phosphates and potash (see p. 219). On light soils rape cake is often used as a manure for barley.

**Phosphatic Slag and Ground Phosphates.**—Some phosphates when finely ground may be successfully employed as manure without previous conversion into superphosphate. The phosphate at present most used for this purpose is Thomas' slag. *Phosphatic slag* is of various qualities, containing 10—22 per cent. of phosphoric acid, with a considerable excess of lime. The soils most suitable for manures of this class 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. All undissolved phosphates must be employed in extremely fine powder. Good basic slag is generally sold with a guarantee that 80 per cent. of the powder shall pass through a sieve having 10,000 meshes in a square inch.

Thomas' slag is an effective manure for swedes; it is especially excellent as a dressing for old pastures, on which it generally develops a considerable growth of white clover. For pasture the inferior qualities of slag may be employed. Much of the special action of basic slag depends on the large amount of lime which it contains.

**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 a small proportion of undissolved phosphate; this amount will be more considerable if the manure has been 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 which has been rendered soluble.

Besides the soluble phosphate, and the undissolved phosphate, a superphosphate will sometimes contain what is known as "*reduced phosphate*"—that is, phosphate which was once soluble but has now lost its 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 by making use of the fact that, though insoluble in water, reduced phosphate is soluble in a solution of citrate of ammonium. Reduced phosphate has an agricultural value between soluble and undissolved phosphate.

Superphosphate is at present principally made from mineral phosphates imported from Algeria, Tunis, Florida, South Carolina, and Belgium. Ordinary superphosphate will contain about 26 per cent. of soluble phosphate, with 2—3 per cent. of undissolved phosphate, or about 13 per cent. of total phosphoric acid. Higher qualities are made for special purposes.

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 nitrogenous matter. 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 gradually 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 an 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 and oats. Its use tends to early maturity in the crop. Superphosphate also greatly favours the growth of clover, beans and other leguminous crops.

**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. On virgin soils gypsum has frequently a wonderful effect on clover. 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.

**Lime, Chalk, and Marl** are frequently manures of the greatest importance. On soils naturally destitute of lime, as is the case with many clays, sandstones, and moor soils, these manures will supply an indispensable element of plant food. Some marls will also supply a small quantity of phosphoric acid, and of potash (if glauconite is present). In most cases, however, the beneficial influence of these manures is due to the chemical actions which lime performs in the soil, and to the improvement in physical texture which it produces (see pp. 23, 46, 56).

*Burnt lime* is much more powerful in its action 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. Lime prepared from magnesium limestone (dolomite) is apparently of less value as a manure than that made from normal limestone.

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 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 is usually considered to consist of sulphate of potassium, sulphate and chloride of magnesium, and chloride of sodium. Kainite will contain about 12·5 per cent. of potash. Commercial *sulphate of potassium* will contain 50—52 per cent., the commercial *chloride* (or *muriate*), 52—58 per cent. of potash.

Kainite, common salt, and other salts of potassium and sodium are antiseptics, and consequently hinder the decay of organic matter. They may be used to prevent the decomposition of animal manure in the stable or manure heap, but should not be sprinkled on farmyard manure in the furrow before growing potatoes or roots, as any hindrance to decomposition is then injurious. It is better, for several reasons, to apply any considerable dressing of alkali salts in the autumn; their prejudicial effects will thus be obviated.

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

Potash manures produce their greatest effect on meadow and pasture; leguminous crops, potatoes, and root crops may also be considerably benefited by their use. Some garden crops, as artichokes and celery, are greatly assisted by potash manures. Kainite is best for grass, but sulphate of potassium should be used for potatoes. Many soils, especially clay soils, are naturally well furnished with potash; on such 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; it has also been used successfully for cabbage. The little value which it possesses is probably due to its action in the soil, where it will help to set free more important constituents, and particularly potash.

**Relative Value of Manures.**—This may be arrived at either by regarding their relative effect on crops, or by reference to the market price of their constituents; the two methods do not necessarily give the same result, though they naturally tend to agreement. Wagner, as the result of numerous experiments with nitrogenous manures applied to crops, and continued for several years, gives the relative value of nitrogen various forms as follows :—

| | |
|---|---|
| Nitrate of sodium .. .. .. .. .. .. | 100 |
| Sulphate of ammonium .. .. .. .. .. | 90 |
| Blood, powdered horn, green crops.. .. .. .. | 70 |
| Steamed bone dust, fish manure, meat guano .. .. | 60 |
| Farmyard manure .. .. .. .. .. .. | 45 |
| Wool dust .. .. .. .. .. .. .. | 30 |
| Powdered leather .. .. .. .. .. .. | 20 |

Working in the same way, Wagner found that taking the effect of phosphoric acid in superphosphate as 100, its effect in Thomas' slag was 58, and in Peruvian guano 30, during the first year of their application. Such average figures give a correct general idea of the relative values of manures ; but the values will in fact vary considerably with different soils and seasons.

Taking the market prices of manures, it is possible in many cases to calculate the cost per lb. of their constituents. A common phrase in the manure trade is "*price per unit.*" When the units in a percentage analysis are multiplied by this price we obtain the value per ton. Thus, if nitrate of sodium containing 15·6 per cent. of nitrogen is worth £9 a ton, the value of nitrogen per unit is 11s. 6d. Again, if a mineral superphosphate is worth £2 15s. a ton, and contains 67 per cent. of gypsum worth £1 5s. per ton, and 12 per cent. of soluble phosphoric acid, the unit value of the phosphoric acid is 3s. 2d. If we regard the gypsum as of no value, the price per unit of the phosphoric acid becomes 4s. 7d.

**Application of Manures.**—A manure can be efficacious only when its constituents are brought into contact

5

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, basic slag and other 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 manure, or meat guano, with or without superphosphate; but dressings of Peruvian 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, and leaf rather than root. As a rule, early applications of manure are more profitable than late ones.

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, oilcakes, or green crops ploughed in—are in such cases very suitable. If top dressings of soluble manures are used for soils of this class they should be applied later than for soils holding a greater volume of water.

Some complications may arise when farmyard manure is applied with artificial manures. Neither nitrates or ammonium salts give their best results when placed in contact with fermentable organic matter in the soil. The possibility of loss is greatly diminished by using well-rotted manure, and may be still further prevented by applying the nitrate subsequently as a top dressing. Salts of potassium and sodium, superphosphate, and sulphate of ammonium, should not be sprinkled on the dung in the furrow, but either mixed with the soil before the dung is carted on, or (if the crop is grown on the flat) sown broadcast after the dung is ploughed in, and before harrowing (see p. 63).

**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. Other nitrogenous manures generally yield a smaller return than nitrate of sodium (see p. 65).

The return from a dressing of manure is very much diminished when the quantity applied is excessive. To obtain the largest return from the manure the farmer should use sufficient manure to obtain a fairly good crop, but no more. A more liberal manuring may be profitable when the crop is fetching a high price. Liberal manuring will not produce crops larger than the character of the soil and season admit of.

Most soluble and active manures produce their principal effect at once, and are of little benefit to subsequent crops. Ammonium salts or nitrates usually 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, bones, and Thomas' slag, 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. It is evident that a small quantity of an active manure will accomplish the same work as a large quantity of one less active.

At Rothamsted, where 14 tons of farmyard manure were applied annually for twenty years to barley grown continuously, and the manuring then ceased, about thirteen years elapsed before the produce of barley fell to that originally given by the unmanured land. On grass land, after eight years similar manuring, the hay crop took nine years to fall to its original level.

When 14 tons of farmyard manure are annually applied to wheat or barley at Rothamsted, about thirteen years elapse before the maximum produce is reached, as the residues up to this point are increasing in amount.

The residues of phosphatic and potassic manures are available for subsequent crops, but are distinctly less effective than fresh applications of the same manures. Dyer found that where $3\frac{1}{2}$ cwts. of superphosphate had been annually applied for forty to fifty years on the heavy loam at Rothamsted, nearly the whole of the unused phosphoric acid remained in the surface nine inches, and that from one-third to one-half of this was still soluble in weak citric acid. Where 200 lbs. of sulphate of potassium had been annually applied for forty to fifty years, only 40—65 per cent. of the unused potash apparently remained in the surface nine inches; a considerable part of the remainder was found in the subsoil, and a small part had escaped in the drainage water. In twenty-seven inches of soil about one-quarter of the unused potash was found soluble in a 1 per cent. solution of citric acid.

Where farmyard manure is continuously employed, a somewhat larger proportion of the phosphoric acid and potash which it contains passes into the subsoil, than where superphosphate and potassium salts have been applied. The distribution of the constituents in question is apparently aided by the organic matter of the manure.

# 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—Grass land 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 potatoes. *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 shows the average composition of ordinary farm crops, and of the annual produce of three descriptions of forest. 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 fodder and root crops is thus especially liable to variation. Some information on this subject will be found on page 137.

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

| | Weight of Crop | | Total Pure Ash | Nitrogen | Sulphur | Potash | Soda | Lime | Magnesia | Phos-phoric Acid | Chlorine | Silica |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | At Harvest | Dry | | | | | | | | | | |
| | lbs. | lbs. | lbs. | lbs. | lbs. | lbs. | lbs. | lbs. | lbs. | lbs. | lbs. | lbs. |
| WHEAT, grain, 30 bushels | 1,800 | 1,530 | 30 | 34 | 2·7 | 9·3 | 0·6 | 1·0 | 3·6 | 14·2 | 0·1 | 0·6 |
| ,, straw .. .. | 3,158 | 2,653 | 142 | 16 | 5·1 | 19·5 | 2·0 | 8·2 | 3·5 | 6·9 | 2·4 | 96·3 |
| Total crop .. | 4,958 | 4,183 | 172 | 50 | 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 | 14 | 3·2 | 25·9 | 3·9 | 8·0 | 2·9 | 4·7 | 3·6 | 56·8 |
| Total crop .. | 4,527 | 3,827 | 157 | 49 | 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 | 34 | 3·2 | 9·1 | 0·8 | 1·8 | 3·6 | 13·0 | 0·5 | 19·9 |
| ,, straw .. .. | 2,835 | 2,353 | 140 | 18 | 4·8 | 37·0 | 4·6 | 9·8 | 5·1 | 6·4 | 6·1 | 65·4 |
| Total crop .. | 4,725 | 3,978 | 191 | 52 | 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, &c. .. | 2,208 | 1,877 | 99 | 15 | .. | 29·8 | .. | .. | .. | 8·0 | .. | .. |
| Total crop .. | 3,888 | 3,377 | 121 | 43 | .. | 36·3 | .. | .. | .. | 18·0 | .. | .. |

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

| | Weight of Crop | | Total Pure Ash | Nitrogen | Sulphur | Potash | Soda | Lime | Magnesia | Phosphoric Acid | Chlorine | Silica |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | At Harvest | Dry | | | | | | | | | | |
| | lbs. | lbs. | lbs. | lbs. | lbs. | lbs. | lbs. | lbs. | lbs. | lbs. | lbs. | lbs. |
| MEADOW HAY, 1½ tons .. | 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 | 98 | 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 | 78 | 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 | 107 | 9·3 | 67·1 | 2·3 | 29·2 | 9·9 | 29·1 | 5·4 | 7·3 |
| TURNIPS, root, 17 tons .. | 38,080 | 3,126 | 218 | 61 | 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 | 110 | 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 |

* Calculated from a single analysis only.

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

| | Weight of Crop | | Total Pure Ash | Nitrogen | Sulphur | Potash | Soda | Lime | Magnesia | Phosphoric Acid | Chlorine | Silica |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | At Harvest | Dry | | | | | | | | | | |
| | lbs. | lbs. | lbs. | lbs. | lbs. | lbs. | lbs. | lbs. | lbs. | lbs. | lbs. | lbs. |
| MANGELS, root, 22 tons .. | 49,280 | 5,914 | 426 | 98 | 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 | 149 | 14·0 | 300·7 | 118·7 | 42·9 | 42·5 | 52·9 | 83·1 | 17·9 |
| POTATOES, tubers, 6 tons | 13,440 | 3,360 | 127 | 46 | 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 produce | .. | 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 | 5·3 | 4·3 | .. | 6·3 |

**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 *gramineous* 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 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.

The spring tillage for barley and oats aids nitrification in the soil, and consequently less nitrogenous manure is required for these crops than for wheat. Maize is not only spring-sown, but has also a much later period of growth than the cereals already mentioned, and will thus have command of the nitrates produced during the whole summer. Owing probably to this fact it is a crop much less dependent on nitrogenous manure than wheat.

As cereal crops derive their nitrogen almost exclusively from nitrates, and are dependent (save in the case of maize) on the quantity of these salts occurring in the soil before the middle of summer, they rank, notwithstanding the small quantity of nitrogen which they contain, among the crops 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. For wheat, superphosphate or slag may be ploughed in before drilling the seed, and nitrate of sodium applied as a top dressing in spring. For barley and oats, sulphate of ammonium and superphosphate may be harrowed in immediately before sowing the seed. 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 be required. Owing to the accumulation of humic matter in the surface soil of grass land it becomes after many years impoverished in lime, which is dissolved, and removed in the drainage water; dressings of lime, chalk, or basic slag, will in such cases greatly improve its fertility. 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 such treatment produces a coarser herbage.

The natural clovers of a meadow are destroyed by the continued application of highly nitrogenous manures, and especially of ammonium salts, a hay consisting almost exclusively of grass being produced. The clovers are developed by the application of manures supplying potash or lime without nitrogen; basic slag is of great use for this purpose. The effect of pasturing with sheep or cattle 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. Land is often laid down temporarily to grass with the view of restoring its fertility.

**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 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. The special agent residing in these tubercles is a micro-organism derived from the soil (see p. 11). When attempting to grow a leguminous crop for the first time on a hitherto unfertile peat or sand, it has been found advantageous to scatter on the land a little soil which has already grown the leguminous crop in question, and thus supply the necessary organism. On soils long cultivated such treatment is seldom successful. Apart from the tubercles, leguminous plants are nourished in the ordinary way through their root-hairs, and 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 several years.

Potash manures and superphosphate have generally a very beneficial effect upon leguminous crops; they fail, however, to cure clover sickness. Farmyard manure, 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. The land receives an abundant tillage before sowing the seed, and the crops are hoed afterwards; they remain also in possession of the soil till the end of autumn. Under these circumstances they display a great power of taking up nitrogen from the soil. 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 the use of a phosphatic manure, which is generally drilled with the seed. Superphosphate or basic slag may be used for this purpose.

*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 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. When large crops are to be grown potash manure must not be omitted. 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 roots should receive a smaller proportion of nitrogen 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. The application of sulphate of potassium and superphosphate is generally necessary if roots containing a large percentage of sugar are desired.

*Potatoes* are surface feeders, and require a liberal general manuring to ensure an abundant crop; farm-yard manure is thus generally employed. Very good results are given by a mixture of sulphate of ammonium, superphosphate and sulphate of potassium ploughed in before sowing.

**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 annually assimilated is returned to the soil 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 3,000 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**.—Manures can be used with true economy 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 many 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 its most remunerative return.

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 meadows mown for hay, artificial grasses, turnips, and potatoes.

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 use superphosphate as well as nitrate of sodium for his wheat? What dressing of the nitrate is most economical? Is superphosphate alone sufficient for his turnip crop, or should ammonia 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 by some 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. The supply is often insufficient, as is shown by the much larger crops grown by irrigation. On the other hand, an excess of water in the soil prevents root development, and much percolation 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 necessarily 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 (see further, pp. 16, 137).

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 autumn and winter has a considerable influence on the crops of the following summer. In a wet autumn or 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. A top dressing of nitrate in the spring is in such cases of the greatest value. On the same land, after a dry autumn and winter, no application of nitrate may be required. 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 potatoes, practically no root residue remains in the soil; the residue, in the case of root crops is, in fact 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 a pine forest, 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. At Rothamsted the normal percentage of nitrogen and carbon is maintained in the soil where large crops of wheat are continuously grown with purely inorganic manures; but the soil has become greatly impoverished where no manure, or where an insufficient manure, has been applied (see p. 102).

**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 into the soil 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, or even water, 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 (see p. 101).

# 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 grass, 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 —Gain of nitrogen from the atmosphere—Economy of nitrogen—Use of catch crops—Sale of produce other than corn and meat. *Equilibrium in Soils.*

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 manures are 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 land for wheat. The soil is repeatedly 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 storing of water in it. (3) 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. (4) The absorption of some ammonia from the atmosphere by the soil. (5) The oxidation of ammonia, and of the vegetable and animal remains in the soil, carbonic acid and nitrates being produced.

The production of nitric acid is one of the most important results 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 (equal to 218—352 lbs. of nitrate of sodium) in the first twenty 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 fifteen 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.[1] Supposing the season of fallow, and the following autumn and 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

[1] A nearly similar quantity of nitrates will often be available to crops such as turnips, for which the land receives a summer tillage.

produced will be more or less washed out, and the benefit of the fallow greatly diminished. A mass of soil at Rothamsted, five feet deep, left for thirty years uncultivated, unmanured, and kept free from weeds, has lost by drainage in the last twenty-three years from 15—60 lbs. of nitrogen in the form of nitrates per acre per annum, the loss being least in dry seasons and most in wet ones. Bare fallow can be used with advantage only on clay soils, and in a tolerably dry climate; with a large rainfall 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. The consumption of the crop off the land, and the bringing back of farmyard manure, is the most imperfect of these modes of restoration, owing to the losses which occur during the making of farmyard manure.

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 nitrates 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 and stems, and humus. When such land is ploughed up, the vegetable matter and humus are oxidised, and gradually yield their nitrogen as nitric acid; the ash constituents which they contained are at the same time liberated, and become once more available as plant food.

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 grass, we may refer to the arable land laid down to grass at Rothamsted, which gained nitrogen during thirty-three years at the rate of about 52 lbs. per acre per annum. This land was regularly manured with farmyard and artificial manure. 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, in fact, to a large 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. Leguminous crops are clearly to be preferred before all others for the purpose of green manuring, as in their case nitrogen is obtained from the atmosphere.

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 crops 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 continual application of nitrogenous manures if fertility is to be maintained. Maize, with its much later period of growth, is better able to supply itself with nitrogen from the soil, and yields in consequence a much larger crop per acre.

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.[1]

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, potatoes, turnips and barley. In accordance with this we find that superphosphate is a very effective manure for the last-named 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

[1] The writer was indebted to Sir J. B. Lawes for the important ideas contained in the two preceding paragraphs.

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. Gramineous 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. 72-74; these also furnish reasons for the alternation of crops. It will be seen, for example, 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 two bushels both of wheat and barley are returned to the land as seed. If the whole of this produce were removed from the land, the average annual loss would amount to 73 lbs. of nitrogen, 22 lbs. of phosphoric acid, and 61 lbs. of potash per acre. If, on the other hand, only corn and meat are sold; if we assume 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; that half a ton of straw is fed per acre in the course of the rotation, and the rest used as litter; and that the whole of the manure annually produced is *returned without loss* to the land; then the quantities of nitrogen, phosphoric acid and potash lost to the farm per acre during the four years' rotation, as the excess of exports over imports, will be as follows :—

ESTIMATED LOSSES PER ACRE DURING A FOUR-COURSE ROTATION BY SALE OF CORN AND MEAT.[1]

| | 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 of hay .. | 10·9 | 6·51 | 0·82 |
| 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 seen to be 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, of course, be greater than we have stated if urine has run to waste in the stables, or if the farmyard manure has suffered by rain and drainage.

The loss of phosphoric acid would be replaced, even if no cake were employed, by the use of 2 cwts. of superphosphate for the swedes.

[1] It is assumed that the crops are consumed by sheep and cattle of *all ages*, and not simply by fattening stock.

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 nitrogen voided by the animals (a case which is by no means improbable), 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 generally much exceed this figure.

Against the losses of nitrogen we have enumerated we have to place the amount annually supplied to the land by the rainfall—say, 4 lbs. per acre; and also the unknown and more considerable quantity absorbed as ammonia from the atmosphere by soil and plant. Of far 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, consisting of swedes, barley, clover or beans, and wheat, 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.

The loss or gain of nitrogen in the soil is, to a considerable extent, under the farmer's control. Much may be done to improve the land without the purchase of nitrogenous manures. Attention should be given to three points: (1) the diminution of the losses occurring during the making of farmyard manure, and (2) during autumn and winter drainage, and (3) the turning to full account the power of leguminous crops to obtain nitrogen from the atmosphere. The best treatment of farmyard manure has been already considered (p. 51). We will now say a few words on the remaining points.

The losses to the soil by autumn and winter drainage may generally be prevented by skilful cropping. In the case of a bare fallow it has been found advantageous to sow mustard early in August, and plough the crop in in October before wheat sowing; the nitrogen of the nitrates is thus converted into vegetable matter, and preserved from loss by drainage.

An ordinary rotation supplies in part the conditions needed for the preservation of nitrates. When clover is sown among barley, and is left in possession of the land after harvest, the protection against loss of nitrates is complete. When, however, wheat is followed by barley or turnips, the land is left unprotected after the wheat harvest, and will lose large quantities of nitrates during a wet autumn or winter. This loss may be prevented by the judicious use of *catch crops*. The wheat stubble may be sown with mustard, turnips, rape, rye grass, crimson clover, vetches, peas, &c. According to circumstances, the crop obtained may be ploughed in in November, or in the following spring. The plan may prove thoroughly effective even when the catch crop appears small, as the younger the plant the richer it is in nitrogen. The advantage is, of course, greater when a leguminous plant serves as the catch crop. Some German agriculturists have now adopted rotations to which no nitrogenous manure is applied. When the corn is hand-high a leguminous crop is sown among it; this remains after harvest, and is ploughed in deeply in the autumn or spring. The plants most recommended by these investigators are white lupins; a mixture of Bokhara and alsike clover; and a mixture of red clover, alsike, and hop clover. The particular cropping best suited for each variety of soil and climate can only be ascertained by experiments in the particular locality.

When it is desired to make the utmost use of the natural sources of fertility, the land may be allowed to remain more than one year in grass and clover; or one green crop may be followed by another, as *trifolium incarnatum* by turnips; or a perennial leguminous crop may be 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 profitable 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 farmyard 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.

**Equilibrium in Soils.**—The gains of nitrogen in a soil laid down to pasture proceed to a certain point and then cease. The annual application of a heavy dressing of farmyard manure to arable land will increase for many years the nitrogen in the soil, but the increase annually becomes less, and at last ceases. On the other hand, if arable land in high condition is left unmanured, and continuously cropped with corn, the crops will at first rapidly diminish; but after some years a falling off will no longer be perceived, and the small crop then obtained will become a fairly constant quantity. In every case an equilibrium is established between the annual supply of organic matter, and the quantity annually oxidised. With an increased supply of organic matter, as crop residue or manure, the quantity of organic matter in the soil increases; but the agents of putrefaction and oxidation—the insects, fungi, and bacteria—increase with the increased supply of food, until the decrement by decomposition is equal to the increment by supply. When, on the other hand, a soil is falling out of condition, the living organisms in the soil are necessarily starved, and gradually diminish in numbers, till their requirements are again exactly satisfied by the supply of root and stubble annually afforded them. We have also to bear in mind that when the accumulation of organic matter has reached a certain point, the conditions for anaerobic fermentation may easily occur during wet weather, resulting in denitrification, and a loss of nitrogen in the form of gas (see p. 41).

The increased waste as the soil becomes richer is a point which those who farm highly should always bear in mind. To farm highly with profit demands more scientific knowledge and more practical skill than when a lower standard of production is aimed at. The last bushel of corn in a big crop, the last ton of roots, and we may add the last stone in weight gained by a very fat animal, costs far more to produce than any other. When prices run high, it may pay to push production to its utmost limit ; when profits are small it certainly does not pay to do so.

# 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 of the processes which occur in it.

**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 at.

These contain carbon, hydrogen and oxygen; the nitrogenous substances contain nitrogen, and generally a little sulphur, in addition.

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. The whole of these nitrogenous bodies contain very similar amounts of nitrogen—namely, 15—18 per cent. Besides the nitrogenous matters constituting tissue, the animal juices contain a variety of nitrogenous substances, as sarcine, creatine, &c., 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—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, and in the sweat of horses. Blood, on the other hand, always contains a preponderance 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 |

PERCENTAGE COMPOSITION OF BUTCHER'S CARCASE.

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Water .. | 62·3 | 54·0 | 45·6 | 48·6 | 57·3 | 39·7 | 33·0 | 55·3 | 38·6 |
| Nitrogenous matter .. | 16·6 | 17·8 | 15·0 | 10·9 | 14·5 | 11·5 | 9·1 | 14·0 | 10·5 |
| Fat .. | 16·6 | 22·6 | 34·8 | 36·9 | 23·8 | 45·4 | 55·1 | 28·1 | 49·5 |
| Ash .. | 4·5 | 5·6 | 4·6 | 3·6 | 4·4 | 3·5 | 2·8 | 2·6 | 1·4 |

Water is in nearly every case the largest ingredient of the animal body. The proportion of water is greatest in young and lean animals, and diminishes towards maturity, and especially during fattening. The proportion of nitrogenous matter and ash tends to increase from youth to maturity, but diminishes during fattening. Fat forms in most cases the principal solid ingredient of well-fed animals; its proportion increases very largely 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 1,000 lbs. The table also gives the nitrogen and ash constituents in wool, milk, and eggs; it thus supplies information as to the loss which a farm will sustain by the sale of animal produce. The composition of wool is quoted from German analyses.

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 the 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. The German analyses quoted in the table probably refer to merino sheep. The fleeces of the four Hampshire

Down sheep analysed at Rothamsted contained about 6·5 per cent. of nitrogen, and yielded 2—3 per cent. of ash.

ASH CONSTITUENTS AND NITROGEN IN 1,000 POUNDS OF VARIOUS ANIMALS AND THEIR PRODUCTS.[1]

| | 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 .. .. .. | 5·76 | 2·00 | 1·70 | 1·70 | 0·20 |
| Hen's eggs .. .. | 20·00 | 4·22 | 1·75 | 60·82 | 1·09 |

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

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

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 *butcher's 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 composition of the *increase* of an animal varies much under different circumstances. The increase of a young growing animal will contain much water, nitrogenous matter, and ash; while the increase of an adult fattening animal will consist chiefly of fat. It follows that a smaller amount of food is needed to produce a pound of increase under the former than under the latter conditions.

The percentage composition of the increase of oxen, sheep, and pigs, when passing from the "store" to the "fat" condition has been calculated by Lawes and Gilbert with the following results:—

PERCENTAGE COMPOSITION OF THE INCREASE WHILST FATTENING.

| | Water | Nitrogenous Matter | Fat | Ash |
|---|---|---|---|---|
| Sheep .. .. .. | 22·0 | 7·2 | 68·8 | 2·0 |
| Oxen .. .. .. | 24·6 | 7·7 | 66·2 | 1·5 |
| Pigs .. .. .. | 28·6 | 7·8 | 63·1 | 0·5 |
| Mean .. .. | 25·1 | 7·6 | 66·0 | 1·3 |

The increase during the fattening stage of growth is seen to contain eight to nine parts of fat 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 energy (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 energy. 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 energy 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; to accomplish this result it is burnt in the body.

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

*The albuminoids* occurring in grain, roots, and other forms of vegetable food, are similar in general 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, under some circumstances, 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 even during rest. The amount of digestible albuminoid required for this purpose is but small (see p. 181).

When the nitrogenous tissues of the animal, or the albuminoids consumed as food, are oxidised in the body, the nitrogen they contain is not burnt, but excreted in the form of a nitrogenous substance, urea. The urea produced is about one-third the weight of the albumin oxidised.[1] When the albuminoids, either of the food or of the wasting tissues, are only partially oxidised, fat as well as urea may be produced.

*The amides* (*e.g.*, asparagine) consumed as food are burnt in the body, and their nitrogen excreted as urea. Amides cannot supply the place of albuminoids as muscle-formers, but they help to protect the albuminoids of the food from waste, and 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. An animal is apparently capable of selecting certain fats in the food for storing up, and even of transforming one kind of fat into another. The fat of the food is either burnt in the

[1] 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.

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 carbohydrates* of the food are chiefly starch, pentosans, sugars, and celluloses; 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, carbohydrates. Carbohydrates 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.

The carbohydrates 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 much larger increase of muscle when accompanied by a liberal supply of carbohydrates or fat. In this case the non-nitrogenous ingredients of the food supply the demands for heat and work, and the albuminoids can be devoted to the renovation or increase of tissue.

If an adult animal receives the small quantity of albuminoids and salts necessary to supply the daily waste of tissue, we should assume, from what has gone before, that the whole of its remaining wants might be met by supplies of carbohydrates and of fat. This is to a great extent true; but a diet very poor in albuminoids is not found to be consistent with real bodily vigour.

*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 digested ash constituents 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. The work of digestion is partly mechanical and partly chemical. The food is reduced to a soft pulp by mechanical force and driven through the alimentary canal. The solution of the food is accomplished by means of certain enzymes (hydrolysing agents) supplied by the secretions of the canal.

Of the *carbohydrates* of the food some, as fruit sugar, are already soluble and diffusible, and need no digestion; others, as starch and cellulose, are naturally insoluble. The digestion of carbohydrates 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 paunch and its return to the mouth in chewing the cud. The digestion of the cellulose by a fermentative process commences in the paunch.[1] The further solution of

[1] None of the secretions of the alimentary canal are capable of digesting cellulose; but, according to Horace Brown, oats and other seeds contain an enzyme capable of dissolving cellulose; this enzyme is especially developed during germination. To what extent such an enzyme is generally present in vegetable food is as yet unknown,

starch and cellulose is effected in the intestines. The pancreatic juice has a powerful hydrolysing action on starch, maltose being produced. In the intestines the maltose is converted into dextrose. Cane sugar is converted into dextrose and lœvulose, and milk sugar into dextrose and galactose, or into lactic acid, before absorption takes place. Cellulose is dissolved in the colon by a fermentative process, due to the action of bacteria, in which acetic and butyric acids, carbonic acid and a little marsh gas (methane) 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 commonly known as ptyalin, pepsin, and trypsin, but the number of enzymes present is doubtless more considerable.

*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

---

but the possibility of the digestion of cellulose by this means must not be overlooked. Cellulose digested in this manner would have a higher feeding value than cellulose broken up by bacterial fermentation. German writers teach that digestible cellulose is of more value to ruminant animals than to a horse; the solution of cellulose in the paunch is thus apparently of practical importance to the animal.

food takes place more or less in all parts of the alimentary canal, but chiefly in the small intestines. The absorbed matters pass finally 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 decomposition.

(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 from the lungs 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 plasma of the blood 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 taken up.

(4) *Excretion.*—The products which result from the oxidation of animal tissues, 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 and by perspiration; 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 and excreted as sulphates.

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. When an animal is supplied with known quantities of food per day, the composition of which has been ascertained by chemical analysis, it is possible by collecting the fæces, and submitting them to the same chemical analysis, to determine how much of each constituent of the food has been digested by the animal (see p. 141).

# CHAPTER VII.

## NUTRITION IN TERMS OF ENERGY.

Measurements of mechanical and chemical operations by units of heat. *Fuel value of food constituents and animal products. Heat value of foods to the animal.*—Relation of units of heat to units of work. *Energy consumed in operations of digestion.*—Distinction between fibrous and non-fibrous foods. *Relation of heat value of food to heat value of animal increase obtained.*

**Fuel Value of Foods and Animal Products.**—The quantitative results both of mechanical and chemical operations are often best expressed in terms of energy. The most convenient form of energy to make use of in such discussions is heat. The unit of heat employed is the "calorie," which represents the quantity of heat required to raise one gram of water from 0° to 1° on the scale of the Centigrade thermometer. A Calorie one thousand times larger than this is employed for the expression of large quantities of heat, and this will be employed in the present work.[1]

The relative quantities of energy supplied by the different organic constituents of food, or stored up in the various constituents and products of the animal body, are shown by the quantities of heat produced when these substances are completely burnt. These quantities of heat express the "fuel value" of the substance. When one gram of the following dry sub-

[1] The large Calorie should always be spelt with a capital.

stances is burnt in oxygen the quantities of heat produced are as under:—

| | Calories. | | Calories. |
|---|---|---|---|
| Animal fat ... | ... 9·4 | Cellulose ... ... | 4·1 |
| Earthnut oil ... | ... 8·8 | Cane Sugar ... ... | 4·0 |
| Wheat gluten ... | ... 5·8[1] | Glucose ... ... | 3·7 |
| Animal muscle ... | ... 5·7 | Asparagine ... ... | 3·4 |
| Starch ... ... | ... 4·1 | Urea ... ... | 2·5 |

**Heat Value of Foods to Animal.** — The amount of heat produced by a food in the animal body may be found by first ascertaining the quantity of heat produced when the food is burnt outside the body, and then subtracting from this the heat produced by burning the solid matter of the animal excrements obtained during the consumption of the food by the animal. The difference represents the net energy which the body has received as the result of the feeding. Besides the unburnt matter contained in the fæces and urine, we must also in some cases take into account the unburnt gases which escape from the intestines, and also from the paunch of ruminant animals, these gases consist of methane ($CH_4$) with a little hydrogen. The gases in question are not produced from the albuminoids, or from the fatty constituents of the food; they are formed by the fermentation of the carbohydrates. Those carbohydrates which are quickly digested and absorbed, as sugar and starch, yield a smaller proportion of methane than cellulose, which remains longer in the intestines. To estimate the unburnt gases given off by an animal receiving a fixed ration, the animal must be placed

1 This, and all other values for gluten, includes Kellner's subsequent corrections in 1901. The gluten is reckoned at 16 per cent. of nitrogen.

from time to time in a respiration chamber, the whole of the air entering and leaving the chamber being measured and analysed.

Kellner ascertained, by numerous experiments with oxen, the net heat value to the animal of 1 gram of the digestible matter in various foods: his results were as follows:—

| Food | Fuel Value of 1 gram Digested Organic Substance | Losses of Combustible Matter | | | Actual Heat Value to to the Ox |
|---|---|---|---|---|---|
| | | In the Urine | As Methane | Total | |
| | Cals. | Per cent. | Per cent. | Per cent. | Cals. |
| Earthnut oil .. | 8·8 | .. | .. | .. | 8·8 |
| Wheat gluten.. | 5.8 | 18·7 | .. | 18·7 | 4·7 |
| Starch .. .. | 4·1 | .. | 10·1 | 10·1 | 3·7 |
| Meadow hay .. | 4·5 | 8·5 | 10·3 | 18·8 | 3·6 |
| Oat straw .. | 4·5 | 4·7 | 12·2 | 16·9 | 3·7 |
| Wheat straw .. | 4·5 | 5·6 | 20·0 | 25·6 | 3·3 |

The loss in the urine chiefly depends on the proportion of nitrogenous matter in the food, and reaches its maximum in the case of a pure albuminoid, as wheat gluten. The loss of combustible matter, as gas, reaches its maximum in wheat straw, the food most difficult of digestion employed in the experiments.

For the maintenance of animal life a certain quantity of heat must be developed (p. 178). The heat values ascertained for foods in the manner just described may be used to calculate the amount of food which will suffice for a maintenance ration. When used for such a purpose, 100 of the digestible matter of starch, 100 of the digestible matter of oat straw of good quality, 103 of meadow hay, 113 of wheat straw, 80 of wheat gluten, and 43 of earthnut oil (all in the state of digested substance) are equivalent quantities, and produce a similar amount of heat when given to oxen. The fat has thus 2·3 times, and the albuminoid (wheat gluten) about 1·25 times, the value of starch, while the digestible part of foods rich in cellulose, as hay and oat straw, has a value similar to that of starch, a somewhat lower value being, however, observed in the case of wheat straw.

The work, internal and external, done by an animal can also be expressed in terms of heat. One Calorie is equivalent to 425 meterkilograms; that is to say, the energy required to heat 1 kilogram of water one degree would also raise 1 kilogram to the height of 425 meters. We shall discuss later on (pp. 176, 183) the relations of food to mechanical work, we need here only notice the work performed during the processes of digestion, and during the production of new animal substance.

**Energy used in Digestion.**—Zuntz has determined the amount of energy employed by the horse during the mastication and digestion of various foods. He has done this by determining how much more oxygen is consumed during mastication and digestion than before or after these operations are accomplished. The energy involved in these operations is partly consumed in mechanical and partly in chemical work. Zuntz has expressed his results both in Calories and in terms of the digested food reckoned as starch; we shall give the latter figures. One thousand parts of the foods used contained the following quantities of fibre, and yielded the following results in the horse :—

| | Total Fibre in 1,000 of Food | Digested Matter (including fibre) per 1,000 of food | | |
|---|---|---|---|---|
| | | Total Reckoned as starch | Used for Digestion Work | Remaining for use by the Horse |
| Maize .. .. | 17 | 785 | 82 | + 703 |
| Beans .. .. | 69 | 720 | 111 | + 609 |
| Linseed cake .. | 94 | 690 | 125 | + 565 |
| Oats .. .. | 103 | 615 | 124 | + 491 |
| Lucerne hay .. | 266 | 453 | 219 | + 234 |
| Potatoes .. | 10 | 226 | 27 | + 199 |
| Meadow hay .. | 260 | 391 | 209 | + 182 |
| Clover hay .. | 302 | 407 | 239 | + 168 |
| Carrots .. | 16 | 113 | 21 | + 92 |
| Wheat straw .. | 420 | 181 | 297 | − 116 |

It appears from these results that the work of mastication and digestion (chiefly the latter) involves the combustion of a quantity of nutritive matter, which when deducted from the nutritive matter gained by the digestive process greatly diminishes its amount. We see further that this diminution in the finally available food is nearly connected with the quantity of cellulose which the food contains. In the case of maize nearly 90 per cent. of the digestible matter is finally left for use by the horse; with potatoes 88 per cent.; with oats 80 per cent.; with meadow hay 46·5 per cent.; while in the case of wheat straw the consumption of energy while the food is passing through the animal is actually greater than the energy finally obtained from the digested straw.[1] Zuntz reckons that 9 per cent. of the digested food is generally to be deducted for digestion work, but that each gram of fibre in the food, whether digested or not, consumes energy equal to 2·6 Calories for its mastication and passage through the alimentary canal. We must bear in mind that the excessive wastefulness of fibrous foods shown in these investigations on the horse is not true to an equal extent in the case of ruminant animals. With them the fibre is softened in the paunch before mastication takes place, and the digestion of the fibre has made some progress before the intestines are reached; moreover, the fæces are far more watery in character, and should pass through the system with less effort. The proportion of fibre digested by the ox and sheep is also considerably higher than the proportion digested by the horse (see p. 146). The general indications of these valuable experiments are, however, very plain, and must apply more or less to every animal.

Foods have a very different value for different purposes. We have already seen that the value of a food for the production of heat is simply the fuel value of the digested matter minus the fuel value of the urine

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[1] More information is required as to the utilisation of straw by the horse. Müntz fed a horse with wheat straw alone from November 19 to January 20, when the horse died thoroughly exhausted. The horse digested during December 375 lbs. of organic matter for 1,000 lbs. of straw supplied. This is double the amount assumed as digested in Zuntz's table, and would leave a small balance for the use of the animal.

and the intestinal gases. Any internal work, mechanical or chemical, following the consumption of the food, does not disturb its heat value to the animal, *provided the energy thus developed does not exceed in its heat value the immediate requirements of the animal.* All internal work appears finally as heat; such work is thus only a mode of providing heat, and if the work were not performed the same quantity of digested food would have to be burnt in the body to provide the heat necessary for the animal. The consumption of energy during the digestion of fibrous foods is thus not to be regarded as waste when the animal is merely kept on a maintenance diet. The waste begins as soon as the labour of digestion results in more heat than the animal requires. The excess of heat then produced is waste, for the energy has not been developed in the muscles of the limbs and cannot therefore appear as useful work, nor does it in any way aid in the production of animal increase.

**Production Value of Foods.**—Kellner has not only determined the true heat values to the ox of the foods already mentioned, he has also ascertained their production values. For this purpose he chose rather lean oxen, and gave them a fixed moderate ration, which resulted in a small continuous increase in weight. He then added to this ration the food to be experimented with, and determined the amount of increase produced. The increase in the nitrogenous tissues was calculated from the amount of nitrogen stored up in the animal body (excess of nitrogen in food over nitrogen in excrements). The increase in fat was calculated from the amount of carbon stored up in the body (excess of carbon in food over carbon in excrements and breath), the carbon in the increase of the nitrogenous tissues being first deducted. This mode of work involves the use of a respiration chamber, and is far more exact than any calculation from the alterations in live weight. Kellner's results are shown in the following table :—

HEAT VALUES OF DIGESTED FOODS AND OF THE INCREASE OBTAINED IN A FATTENING OX.

| | Heat Value to the Ox of 1 gram of Digested Substance | Loss of Energy in Production Processes | Heat Value of Increase Obtained |
|---|---|---|---|
| | Cals. | Per cent. | Cals. |
| Earthnut oil .. | 8·8 | 43·7 | 4·9 |
| Wheat gluten .. | 4·7 | 55·3 | 2·1 |
| Starch .. .. | 3·7 | 41·1 | 2·2 |
| Molasses .. .. | 3·6 | 36·4 | 2·3 |
| Straw pulp .. .. | 3·6 | 36·9 | 2·3 |
| Meadow hay .. | 3·6 | 58·5 | 1·5 |
| Oat straw .. .. | 3·7 | 62·4 | 1·4 |
| Wheat straw .. | 3·3 | 82·2 | 0·6 |

The table starts with the heat values of the digested foods, which have been arrived at by the calculations shown in the table on p. 120. Before these digested foods can be utilised for the production of fatty or nitrogenous tissue, a part is consumed to provide the energy required for the digestion of similar food daily received by the animal; a part is also consumed during the chemical and mechanical processes involved in the production of tissue. The whole of the food thus consumed appears finally as heat: the remainder of the food substance appears as animal increase. Of the digested fat, 56·3 per cent. was stored up, and 43·7 per cent. burnt in passing through the animal system. Of the digested albuminoid, 44·7 per cent. was stored up as nitrogenous tissue and fat, and 55·3 per cent. burnt in the process. Of starch, 58·9 per cent. of its heat value was stored up, while 41·1 per cent. disappeared as heat. In the case of fibrous foods the losses rapidly increase with the proportion of fibre present, the loss in the case of meadow hay being 58·5 per cent., with oat straw 62·4 per cent., and with wheat straw 82·2 per cent. By a happy experiment Kellner showed that the very low results yielded by straw were not due to its chemical nature, but to its mechanical condition. He used in some of his experiments the straw pulp prepared by paper manufacturers by boiling rye straw under high pressure with an alkaline solution; of this softened, disintegrated cellulose, 88 per cent. was digested by the oxen, and the digested matter yielded as large a return in increase as was obtained from starch or sugar.

The very inferior results obtained from straw confirm the conclusions of Zuntz when using straw as food for horses. The digested matter of the straw, or its equivalent in other digested food, is so largely consumed in providing the energy demanded by the laborious process of straw digestion, that in the case of the horse there was no balance remaining for other animal requirements, while in the case of the ox only 17·8 per cent. of the heat value of the digested straw was finally available for the production of animal increase.

The relative value of the different foods for the production of increase is shown by the Calories in the right-hand column. Digestible albuminoids, starch, sugar, and soft cellulose, appear all to have a very similar value, while the oil has 2¼ times the value of starch. The straw pulp contained more than one-third its weight of furfuroids (oxycelluloses, &c.), these evidently, therefore, took part in the formation of fat.

Kellner concludes from his experiments that 100 parts of digested starch may yield a maximum of 23·3 of fat in the body, the rest of the starch being consumed in the transformation process. Of the pure albuminoid used (wheat gluten), 7 per cent. of the available heat value was in his experiments stored up in the animal as nitrogenous tissue, while 38 per cent. was stored up as fat. Turning these heat values into weights it appears that 100 parts of digested gluten produced about 7 parts of dry nitrogenous increase, and 19·8 parts of fat. The proportion of nitrogenous increase to fatty increase may be expected to vary under different circumstances.

The increase in *live weight* obtained by feeding with albuminoids, starch, sugar, or fat, will not necessarily take place in the proportions shown by the calorific values of these foods, nor in the proportions of their capacity for producing fat; this will be due to the varying proportions of lean flesh and fat which will be formed under various circumstances, and to the fact that when albuminoids are stored up as lean flesh they are always associated with much water, while a purely fatty tissue contains very little water.[1] The

[1] Lean flesh will contain about three parts of water to one of dry nitrogenous matter. Purely fatty tissue, as kidney fat, will contain only about 5 or 6 per cent. of water.

storing up of albuminoids thus occasions a much greater increase in live weight than the storing up of fat, although the heat value of the two products may possibly be the same. It must not be forgotten that carbohydrates and fat when added to a meagre diet, not too poor in albuminoids, occasion a vigorous storing up of albuminoids as well as a production of fat. In ten experiments made by Kellner, in which a considerable amount of a pure carbohydrate was added to a meagre diet supplied to oxen slowly gaining in weight, the carbohydrate produced an average increase of 1 part of dry lean flesh and 4·6 parts of fat. This subject will be treated in more detail further on, p. 190. The calorific values given in the preceding table represent the whole product, lean and fat, obtained by the use of the respective foods.

# CHAPTER VIII.

## 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 hay-making 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 ensilage—Influence of one food on the digestibility of another—Common salt. *Comparative Nutritive Value of Foods.*—Quantities of digestible matter in 1,000 parts of food.—Comparative power of producing heat, work, and increase—Proportion of albuminoids to non-albuminoids—Influence of proportion of water—General conclusions.

In Chapter VI. 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 the feeding values of the foods actually employed on the farm.

The nourishing value of a food is largely determined by two factors: (1) Its composition; (2) its digestibility. The first of these determines the richness of the food in albuminoids, fat, carbohydrates, and ash constituents. The second determines the extent to which these various constituents become available in the animal body. We will consider, first, the composition of ordinary foods.

9

PERCENTAGE COMPOSITION OF ORDINARY FOODS.

| Food | Water | Nitrogenous Substance | | Fat | Soluble carbo-hydrates | Fibre | Ash |
|---|---|---|---|---|---|---|---|
| | | Albu-minoids | Amides, &c. | | | | |
| Cotton cake (decorticated) | 8·2 | 43·2 | 1·8 | 13·5 | 20·8 | 5·5 | 7·0 |
| ,, ,, (undecort.) .. | 12·5 | 20·7 | 1·3 | 5·5 | 34·8 | 20·0 | 5·2 |
| Linseed cake .. .. | 11·7 | 26·9 | 1·1 | 11·4 | 33·2 | 9·0 | 6·7 |
| Rape cake .. .. .. | 10·4 | 28·1 | 4·6 | 9·8 | 29·1 | 10·3 | 7·7 |
| Earthnut cake .. .. | 11·5 | 45·1 | 1·9 | 8·3 | 23·1 | 5·2 | 4·9 |
| Beans .. .. .. | 14·3 | 22·6 | 2·8 | 1·5 | 48·5 | 7·1 | 3·2 |
| Peas .. .. .. .. | 14·0 | 20·0 | 2·5 | 1·6 | 53·7 | 5·4 | 2·8 |
| Wheat .. .. .. | 13·4 | 10·7 | 1·3 | 1·9 | 69·0 | 1·9 | 1·8 |
| Rye .. .. .. .. | 13·4 | 10·5 | 1·0 | 1·7 | 69·5 | 1·9 | 2·0 |
| Oats .. .. .. .. | 13·0 | 10·6 | 0·7 | 5·4 | 57·3 | 10·0 | 3·0 |
| Barley .. .. .. | 14·3 | 10·2 | 0·4 | 2·1 | 66·0 | 4·5 | 2·5 |
| Maize .. .. .. | 11·0 | 9·8 | 0·6 | 5·1 | 70·0 | 2·0 | 1·5 |
| Malt sprouts .. .. | 10·0 | 16·6 | 7·1 | 2·2 | 44·1 | 12·5 | 7·5 |
| Wheat bran .. .. | 13·2 | 12·1 | 2·0 | 3·7 | 56·0 | 7·2 | 5·8 |
| Brewer's grains .. .. | 76·2 | 4·9 | 0·2 | 1·7 | 10·7 | 5·1 | 1·2 |
| ,, ,, (dried) .. | 9·5 | 19·8 | 0·8 | 7·0 | 42·3 | 15·9 | 4·7 |
| Rice meal .. .. .. | 10·3 | 11·3 | 1·0 | 12·0 | 47·8 | 8·6 | 9·0 |
| Oat straw .. .. .. | 14·5 | 3·5 | 0·5 | 2·0 | 37·0 | 36·8 | 5·7 |
| Barley straw .. .. | 14·2 | 3·2 | 0·3 | 1·5 | 39·1 | 36·0 | 5·7 |
| Wheat straw .. .. | 13·6 | 3·3 | | 1·3 | 39·4 | 37·1 | 5·3 |
| Pea straw .. .. .. | 13·6 | 9·0 | | 1·6 | 33·7 | 35·5 | 6·6 |
| Bean straw.. .. .. | 18·4 | 8·1 | | 1·1 | 31·0 | 36·0 | 5·4 |
| Pasture grass .. .. | 76·7 | 2·9 | 1·1 | 0·9 | 10·9 | 5·2 | 2·3 |
| Clover (bloom beginning) .. | 81·0 | 2·6 | 0·8 | 0·7 | 8·0 | 5·2 | 1·6 |
| Clover hay (medium) .. | 16·0 | 10·5 | 2·5 | 2·5 | 37·2 | 25·0 | 6·3 |
| Meadow hay (best) .. | 15·0 | 10·2 | 1·8 | 2·3 | 39·5 | 24·0 | 7·2 |
| ,, ,, (medium) .. | 15·0 | 8·0 | 1·2 | 2·2 | 42·0 | 25·4 | 6·2 |
| ,, ,, (poor) .. | 14·0 | 6·3 | 0·5 | 2·0 | 41·1 | 31·0 | 5·1 |
| Grass silage (stack) .. | 67·0 | 3·3 | 1·5 | 1·5 | 13·2 | 9·7 | 3·8 |
| Clover silage (stack) .. | 67·0 | 3·3 | 2·7 | 2·2 | 10·5 | 11·9 | 2·4 |
| Maize silage .. .. | 79·1 | 1·0 | 0·7 | 0·8 | 11·0 | 6·0 | 1·4 |
| Potatoes .. .. .. | 75·0 | 1·2 | 0·9 | 0·2 | 21·0 | 0·7 | 1·0 |
| Cabbage .. .. .. | 85·7 | 1·7 | 0·8 | 0·7 | 7·1 | 2·4 | 1·6 |
| Carrots .. .. .. | 87·0 | 0·7 | 0·5 | 0·2 | 9·3 | 1·3 | 1·0 |
| Mangels (large) .. .. | 89·0 | 0·4 | 0·8 | 0·1 | 7·7 | 1·0 | 1·0 |
| ,, (small) .. .. | 87·0 | 0·4 | 0·6 | 0·1 | 10·2 | 0·8 | 0·9 |
| Swedes .. .. .. | 89·3 | 0·7 | 0·7 | 0·2 | 7·2 | 1·1 | 0·8 |
| Turnips .. .. .. | 91·5 | 0.5 | 0·5 | 0·2 | 5·7 | 0·9 | 0.7 |

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

The total "*nitrogenous substance*" in a food is obtained by multiplying the percentage of nitrogen by 6·25,[1] it thus represents approximately the amount of albuminoids present, *if the whole of the nitrogen exists in this form.* It is now, however, well known 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.

It appears from these numbers that the greater part of the nitrogen in ripe seeds exists as albuminoids; in rape cake, in leguminous seeds, and in rye and wheat, the proportion of albuminoid nitrogen is rather lower than in the other cases. 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.

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[1] The use of this factor assumes that the nitrogenous matter contains on an average 16 per cent. of nitrogen. The amount of nitrogen in various albuminoids varies from about 15—18 per cent. Some of the amides present in foods contain more nitrogen and some less nitrogen than albuminoids. Our knowledge of the composition of foods is only in a few cases sufficiently exact to enable us to state the exact weight of albuminoids and amides present.

ALBUMINOID NITROGEN PER 100 OF TOTAL NITROGEN.

| | | | |
|---|---|---|---|
| Cotton cake (decorticated) | 96 | Barley straw .. .. | 90* |
| ,, ,, (undecort.) .. | 94 | Oat straw .. .. | 88* |
| Earthnut cake .. .. | 96 | | |
| Linseed cake .. .. | 96 | Grass (young) .. .. | 73 |
| Rape cake .. .. .. | 86 | Clover (young) .. .. | 70 |
| | | Clover (bloom beginning) | 76 |
| Beans .. .. .. | 89 | | |
| Peas .. .. .. .. | 89 | Meadow hay .. .. | 87 |
| | | Clover hay .. .. | 81 |
| Barley .. .. .. | 96 | | |
| Oats .. .. .. .. | 94 | Grass silage (stack) .. | 68 |
| Maize .. .. .. | 94 | Maize silage .. .. | 59 |
| Rye .. .. .. .. | 91 | Clover silage (stack) .. | 55 |
| Wheat .. .. .. | 89* | | |
| | | Cabbage heads .. .. | 68* |
| Brewer's grains .. .. | 96 | Potatoes .. .. .. | 58 |
| Rice meal .. .. .. | 92 | Carrots .. .. .. | 62 |
| Wheat bran .. .. | 86 | Turnips .. .. .. | 49 |
| Malt .. .. .. .. | 79 | Mangels .. .. .. | 39 |
| Malt sprouts .. .. | 70 | | |

In immature produce the proportion of non-albuminoid nitrogen is much more considerable. It is present in considerable amount in young fodder crops, but forms a much smaller proportion in mature hay. During the operation of ensilage the proportion of non-albuminoids is much increased. The largest proportion of non-albuminoid nitrogen is reached in the case of 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.

The substances reckoned as *fat* in a food analysis include all the matters soluble in ether or petroleum. In the case of grains, and their products, the ether extract consists almost wholly of fats and fatty acids;

but in the case of hay, straw, and roots other matters are also present (p. 136).

The "*soluble carbohydrates*" mentioned in the table include not only the soluble sugars, mucilage, &c., but also starch, pectin, pentosans,[1] and a considerable part of the cellulose; these latter are not soluble in water, but are dissolved in the process of boiling with weak acid and alkali employed by the analyst to separate the coarse fibre. The soluble carbohydrates of a food analysis are thus a mixture of very various constituents, which have probably not the same feeding value. Unfortunately the exact composition of these mixed carbohydrates has been but little studied.

The "*fibre*" left by the process of extraction employed in food analysis varies much in constitution; among its ingredients are the typical cotton cellulose, oxycellulose, and lignin. Oxycellulose forms the chief constituent of the fibre of gramineous hay and straw. As already mentioned, the proportion of fibre by no means represents the whole of the cellulose, a part being reckoned as soluble carbohydrate according to the present method of food analysis.

We will now consider the average composition of the various foods mentioned in the table on p. 130.

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[1] Pentosans are generally insoluble in water, but dissolve in alkali. When heated with dilute acids they are converted into pentoses—that is, sugars containing a multiple of five atoms of carbon in their molecule. These sugars are not fermentable, and are very imperfectly burnt in the animal system; they have thus little nutritive value. The amount of pentosans present is usually calculated from the quantity of furfural produced when the food is boiled with hydrochloric acid. The quantity thus calculated may, however, be considerably in excess of the truth, as oxycellulose also yields furfural. The group of furfural yielding bodies is thus of very mixed character, and is best described as furfuroids.

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, potatoes contain the largest, and white turnips the least proportion of dry matter. The influence of the proportion of water on the nutritive value of a food is discussed on p. 165.

We have already seen (Chapter VII.) that fat and albuminoids are the most concentrated forms of food which an animal can consume; those foods which are rich in fat and albuminoids 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. Linseed cake, even when pure, varies a great deal in composition, according to the kind of linseed and the amount of pressure used. Cakes made from East Indian seed will usually contain 25—30 per cent. of nitrogenous substance; cakes from Russian seed 27—33 per cent.; cakes from American Western seed 34—38 per cent. The oil in American cakes is about 7—10 per cent.; in ordinary English and Russian pressed cakes 9—13 per cent.; in a few English and Russian cakes 15—16 per cent. Decorticated cotton cake and earthnut cake are, when of good quality, equal or superior to linseed cake, but they are at present but little used by the English farmer. The oil in decorticated cotton cake varies from 9—17 per cent., according to the degree of pressure used. Pure oilcakes contain no starch.

The leguminous seeds, beans, peas and lentils are rich in albuminoids, but not in fat. The fat of beans and peas contains a good deal of lecithin, a fatty body containing both nitrogen and phosphorus. The principal carbohydrate of leguminous seeds is starch.

The cereal grains are much poorer in albuminoids, containing only about one-half the proportion found in leguminous seeds. 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 carbohydrate—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 sprouts (known also as malt combs) consist 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.

The straw of cereal crops contains a smaller proportion of nitrogenous matter than any other food employed by the farmer. Various celluloses form 80—90 per cent. of the dry matter. Starch is absent. Oat straw is generally more nutritious than that of barley or wheat. Straw has a higher feeding value when cut before perfect ripeness is reached; the presence of clover or weeds will also increase its food value. Pea straw is a food of much higher quality.

In the case of green fodder, hay and silage, an increased proportion of the nitrogen is in the form of amides. The fat credited to these foods also 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. About 30 per cent. of the ether extract of hay consist of unsaponifiable matter. Among the soluble carbohydrates, starch is frequently absent. Meadow hay, according to Grandeau, contains only 4—8 per cent. of starch. 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.

In tubers and roots the supply of albuminoids is but small, a large proportion of the nitrogen existing as amides. The carbohydrates are, however, of much higher nutritive value than in the case of fodder crops or straw. In potatoes, starch forms the principal constituent. In turnips and mangels from one-third to two-thirds of the dry matter consists of sugar.

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, cabbage, and turnips, and generally in all leafy produce; it occurs in least quantity in the cereal grains and in potatoes. 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 220.

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. In the United States it has been found advantageous to give wood ashes or ground bones when maize is used alone as a pig food. Growing pigs required 517 lbs. of maize meal to produce 100 lbs. of increase, but 466 lbs. sufficed when wood ashes were added; the breaking strength of the thigh bones was also more than doubled by this addition to the food. Animals will frequently receive no inconsiderable amounts of lime in their drinking water. Soda is easily supplied, when needed, in the form of common salt (see p. 154).

**Circumstances producing Variation in Composition.**—The composition of all vegetable foods is liable to variation, depending on the variety of plant grown, its state of maturity, and the character of the soil, manure, and season. The influence of the variety grown is well illustrated in the case of oats, the different varieties of which will differ much in composition. The perfectly matured produce of any plant, the ripe seed for instance, will not generally vary much in composition under the ordinary conditions of climate and manuring, and an average composition, such as is given in the table, will be found in most cases pretty correct. Great variations in climate may, however, determine considerable changes in composition. South Russian wheat is, for instance, far more nitrogenous than English wheat. When, however, we turn to immature produce, such as meadow grass, turnips, or mangels, we find that the composition depends largely 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 carbohydrates and fibre 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 MEADOW HAY HARVESTED AT DIFFERENT DATES.

| Date of Cutting | Nitrogenous Substance | | Fat | Soluble Carbo-hydrates | Fibre | Ash |
|---|---|---|---|---|---|---|
| | Albuminoids | Amides, &c. | | | | |
| May 14 .. | 11·5 | 6·2 | 3·2 | 40·8 | 23·0 | 15·3 |
| June 9 .. | 9·4 | 1·8 | 2·7 | 43·2 | 34·9 | 8·0 |
| ,, 26 .. | 7·8 | 0·7 | 2·7 | 43·3 | 38·2 | 7·3 |

The albuminoid nitrogen amounted in the first cutting to 65·2 per cent., in the second cutting to 84·0 per cent., and in the third cutting to 92·5 per cent. of the total nitrogen.

Young grass is much richer in albuminoids, 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 carbohydrates into fibre, crops such as potatoes and mangel improve, the carbohydrates 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 green crops and roots is generally considerable. A luxuriant crop will always contain more water than one in less active growth. Very large mangels may contain only 6—8 per cent. of dry matter, while in quite small roots the proportion may be as high as 14 per cent. Luxuriance also retards maturity. A heavily manured mangel will contain, at the same date, a smaller proportion of sugar than a similar mangel grown on poorer soil. Liberal nitrogenous manuring, while greatly increasing the bulk of the crop, will thus at the same time diminish the proportion of carbohydrates, and increase the proportion of nitrogen, ash constituents, and water present. 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 only, the albuminoid nitrogen amounted to 38 per cent. of the total nitrogen; while in a crop of 28 tons, manured with nitrate of soda and superphosphate in addition to the dung, the albuminoid nitrogen was only 29 per cent. of the total. It is evident, therefore, that the large mangels or turnips, produced by very liberal manuring, are less nutritious than smaller roots. At the same time, it must not be forgotten that the total amount of food produced per acre is much greater under liberal manuring. Potatoes, unlike mangels, deteriorate but little in quality as they increase in size. Turnips grown with superphosphate alone on exhausted land are deficient in nitrogenous constituents.

In the case of hay the composition is further affected by the *conditions of hay-making*, and by the subsequent changes in the rick. Hay that has suffered from rain during hay-making 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 fermentation, 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 bacteria 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 a smaller destruction of albuminoids, but they become much less digestible. The loss of solid matter in the silo is greater in proportion to the air admitted. It is least when the material is sufficiently moist and is firmly consolidated. The loss is less in large silos than in small.

In stack silage the outside portion and the inner mass are of very different character, air being freely present on the outside, but nearly excluded in the solid interior. The character of the inner mass depends on the degree of moisture, the loose or close packing of the material, and the speed with which the stack is built and subjected to pressure.

**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 experiemental 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 some small errors, arising from 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.[1]

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

[1] The error introduced by reckoning intestinal secretions as undigested food is generally very small, but it becomes considerable in certain cases. Thus, when an animal is fed on food very poor in nitrogen, as straw, it sometimes appears as if no nitrogenous matter had been digested, the nitrogen furnished by the intestinal secretions being equal or greater than the nitrogen assimilated. We have, therefore, to bear in mind that the digestion coefficients found for nitrogenous matter are always somewhat below the truth, and that this is especially so in the case of foods poor in nitrogen. It is obvious, however, that even when the amount digested is incorrectly reckoned, the *net gain of nitrogenous matter to the animal is truly stated.* As far as the animal is concerned it comes to the same thing whether we say that 70 per cent. of the nitrogenous matter in the food is assimilated, while at the same time a quantity equal to 5 per cent. is excreted ; or whether we say that 65 per cent. is assimilated, and take no note of the excretion. The remarks just made apply equally to the digestion coefficients found for fat, when this is present in very small quantity (as in the case of hay or straw), biliary matters soluble in ether being reckoned as undigested fat.

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 table (p. 144) shows the average results obtained with ruminating animals fed on the foods respectively mentioned. The figures given express the "digestion coefficients" found for each constituent of the food consumed.

The digestibility of the foods in the upper division of the table has been for the most part determined by feeding animals on these foods alone. The digestibility of the foods in the lower division of the table has been found by supplying them 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—60 per cent. of that supplied; with hay of exceptional quality the proportion digested may rise to 70 per cent. With straw only about 45—55 per cent. of the organic matter is digested, the minimum occurring with wheat straw.

The digestibility of the nitrogenous matter in hay and straw increases 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. This general fact is shown by digestion experiments made in the laboratory with pepsin and trypsin solutions, as well as by experiments with an animal;

EXPERIMENTS WITH CATTLE, SHEEP AND GOATS.

| Food | Digested for 100 of each Constituent supplied | | | | |
|---|---|---|---|---|---|
| | Total Organic Matter | Nitrogenous Substance | Fat | Soluble Carbo-hydrates | Fibre |
| Pasture grass .. .. | 74 | 74 | 64 | 77 | 69 |
| Meadow hay (best) .. | 67 | 65 | 57 | 68 | 63 |
| Meadow hay (medium) | 61 | 57 | 53 | 64 | 60 |
| Meadow hay (poor) .. | 56 | 50 | 49 | 59 | 56 |
| Clover hay (best) .. | 61 | 62 | 60 | 70 | 47 |
| Clover hay (medium) | 57 | 55 | 51 | 65 | 45 |
| Lucerne hay (bloom beginning) | 62 | 77 | 39 | 70 | 43 |
| Lucerne hay (full bloom) | 56 | 70 | 39 | 63 | 42 |
| Maize silage .. .. | 62 | 48 | 85 | 68 | 56 |
| Oat straw .. .. | 48 | 30 | 33 | 44 | 54 |
| *Barley straw .. .. | 53 | 20 | 42 | 54 | 56 |
| *Wheat straw .. .. | 43 | 11 | 31 | 38 | 52 |
| *Bean straw .. .. | 55 | 49 | 57 | 68 | 43 |
| *Cotton cake (decorticated) | 81 | 87 | 95 | 76 | ? |
| *Cotton cake (undecorticated) | 54 | 74 | 90 | 51 | 16 |
| *Linseed cake .. .. | 80 | 86 | 90 | 80 | 50 |
| *Peas .. .. .. | 90 | 89 | 75 | 93 | 66 ? |
| Beans .. .. .. | 89 | 88 | 82 | 92 | 72 ? |
| Oats .. .. .. | 71 | 78 | 83 | 77 | 26 |
| *Barley .. .. | 86 | 70 | 89 | 92 | ? |
| *Maize .. .. .. | 91 | 76 | 86 | 93 | 58 |
| Rice meal .. .. | 75 | 63 | 85 | 86 | 26 |
| Wheat bran .. .. | 71 | 78 | 72 | 76 | 30 |
| Malt sprouts .. .. | 81 | 78 | 50 | 86 | 85 |
| Brewers' grains .. | 62 | 70 | 82 | 63 | 39 |
| Potatoes .. .. | 88 | 66 | ? | 93 | ? |
| *Mangels .. .. | 88 | 77 | ? | 96 | ? |
| *Turnips .. .. | 88 | 62 | ? | 99 | ? |

* These results are erived from a few experiments.

the differences are, however, exaggerated in animal experiments, from the circumstances mentioned in the previous note (p. 142). Amides, being soluble bodies, have been usually reckoned as digestible albumin.

Of the fibre in hay and straw, about 45—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 gramineous 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 left undigested is much richer in carbon than the portion digested. It appears, therefore, that while cellulose is digested to a considerable extent, the lignin which forms in the tissues as the plant increases in age, and which contains a larger proportion of carbon, is much less digestible. Chemical analysis also 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—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 fats 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 undigested albuminoids of food have a different composition from the digested; the undigested albuminoids contain phosphorus, and are partly composed of nuclein.

The ready-formed sugars, and the starch of foods, are usually completely 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:—

DIGESTION OF HORSE AND SHEEP COMPARED.
EXPERIMENTS WITH HORSES.

| Food | Proportion of each Constituent digested for 100 supplied | | | | |
|---|---|---|---|---|---|
| | Total Organic Matter | Nitrogenous Substance | Fat | Soluble Carbohydrates | 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 |

* These results are the mean of a few experiments.

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

EXPERIMENTS WITH SHEEP.

| Food | Proportion of each Constituent digested for 100 supplied. | | | | |
|---|---|---|---|---|---|
| | Total Organic Matter | Nitrogenous Substance | Fat | Soluble Carbohydrates | Fibre |
| *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 |

* These results are the mean of a few experiments.

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 carbohydrates, fibre, and fat. Of the carbohydrates 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.

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, in which horses were fed on one kind of food alone, it was found that they digested 94·5 per cent. of the organic constituents of maize, 93·3 per cent. of wheat bran, 84·5 per cent. both of barley and beans, 75·1 per cent. of oats, 43·3—61·0 per cent. of meadow hay, 49·4 per cent. of wheat straw, and 94·6 per cent. of carrots. The grain was supplied in a crushed state. A horse is capable of digesting uncrushed maize, but with uncrushed oats a part will escape digestion.

(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.

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.

EXPERIMENTS WITH PIGS.

| Food | Digested for 100 supplied | | | | |
|---|---|---|---|---|---|
| | Total Organic Matter | Nitrogenous Substance | Fat | Soluble Carbohydrates | Fibre |
| *Sour milk .. | 97 | 96 | 95 | 99 | .. |
| *Meat flour .. | 95 | 97 | 87 | .. | .. |
| Pea meal .. | 91 | 88 | 49 | 97 | 68 |
| Maize meal .. | 92 | 86 | 76 | 95 | 40 |
| Barley meal .. | 84 | 79 | 69 | 91 | 22 |
| *Rye bran .. | 67 | 66 | 58 | 75 | 9 |
| Potatoes .. | 93 | 73 | .. | 98 | 55 |

* The numbers in these cases are the mean of a few experiments.

(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 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. With, however, a very abundant and rich diet the proportion digested may be seriously diminished.

The influence of *labour* on digestion is inconsiderable. The mean of Grandeau and Leclerc's numerous experiments on Paris cab horses was as follows :—

| | Food Digested. |
|---|---|
| At rest .. .. .. .. .. .. | 1,000 |
| Walking exercise .. .. .. .. | 1,032 |
| At work walking .. .. .. .. | 1,007 |
| Trotting .. .. .. .. .. | 976 |
| At work trotting .. .. .. .. | 973 |
| At work in cab.. .. .. .. .. | 959 |

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 given dry than when previously cooked. When food has been treated with boiling water the digestibility of the albuminoids is distinctly diminished.

Differences in the *quality* of a food may 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 138 ; 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 just 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. Illustrations of the different digestibility of hay of various qualities have been already given on pp. 144 and 146.

Fodder crops do not sensibly diminish in digestibility by being made into hay, if hay-making 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.[1] Hay appears to lose some of its digestibility by keeping. In hay which has become brown by heating, the digestibility of the albuminoids, and of the soluble carbohydrates, is diminished, while the digestibility of the fibre is increased.

In *silage* the digestibility of the albuminoids is also seriously diminished. Wolff cut meadow grass early in October, dried a part, and constructed with the remainder a silage stack. The grass was tolerably dry, and no leakage from the stack occurred. In March and April the dried grass and the silage were consumed by sheep. The digestion coefficients found were as follows:—

| | Digested for 100 consumed | | | | | |
|---|---|---|---|---|---|---|
| | Total Organic Matter | Nitrogenous Substance | Albuminoids | Fat | Soluble Carbohydrates | Fibre |
| Grass .. | 59·8 | 56·0 | 49·3 | 45·7 | 60·8 | 61·8 |
| Silage .. | 54·2 | 27·2 | 2·4 | 60·9 | 52·1 | 71·2 |

The albuminoids in the silage thus appeared to be almost indigestible; the amides only were taken up by the sheep. Similar, though less striking, results have been obtained by other experimenters.

*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,

[1] Though the digestibility of the hay may be nearly the same as that of the original green fodder, the labour required to digest the hay will be greater, and its value for the production of work and increase will therefore be somewhat diminished.

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 potatoes, to which variable quantities of meat flour were afterwards added: the albuminoids of the meat were entirely digested, while the proportion of the potatoes 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 ($\frac{1}{2}$ lb. 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 carbohydrate 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 p. 163) 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 carbohydrates, as potatoes 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 potatoes or mangels some nitrogenous food. When this is done the proportion of roots or potatoes may be double that just mentioned without a serious loss of digestibility. Potatoes 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 proportion of the nitrogenous to the non-nitrogenous constituents of the diet is not less than 1 : 8.

*Common salt* is well known to be a useful addition to the food of animals, but experiments have failed to show that it increases the digestibility of food. When sodium salts are deficient in the food, salt supplies the blood with a necessary constituent. Sodium salts are tolerably abundant in roots and cabbage, and small in quantity in hay and straw; they are absent in grain of all kinds. According to Bunge, salt is needed only in the case of foods containing a large proportion of potash to soda. Of these the potato is the most prominent example. A small quantity of salt is recommended as a general ingredient of animal diets; but an excess of salt interferes with nutrition by increasing the quantity of water drunk, and with this the degradation of albumin and the production of urea.

**Comparative Nutritive Value of Foods.**—(1) *Proportion of Digestible Matter.* Having made ourselves acquainted both with the composition, and with 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 1,000 lbs. of ordinary foods when supplied to sheep or oxen. 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 nitrogenous substance.

DIGESTIBLE MATTER IN 1,000 LBS. OF VARIOUS FOODS.

| | Total Organic Matter | Nitrogenous Substance | | Fat | Soluble Carbo-hydrates | Fibre |
|---|---|---|---|---|---|---|
| | | Albu-minoids | Amides, &c. | | | |
| Cotton cake (decorticated) | 691 | 374 | 18 | 128 | 158 | 13 |
| ,, ,, (undecorticated) | 422 | 150 | 13 | 50 | 177 | 32 |
| Linseed cake .. .. | 655 | 230 | 11 | 103 | 266 | 45 |
| Peas .. .. .. | 747 | 175 | 25 | 12 | 499 | 36 |
| Beans .. .. .. | 733 | 196 | 28 | 12 | 446 | 51 |
| *Wheat .. .. .. | 786 | 92 | 13 | 15 | 656 | 10 |
| Oats .. .. .. | 600 | 81 | 7 | 45 | 441 | 26 |
| Barley .. .. .. | 715 | 70 | 4 | 19 | 607 | 15 |
| Maize .. .. .. | 786 | 73 | 6 | 44 | 651 | 12 |
| Rice meal .. .. | 612 | 67 | 10 | 102 | 411 | 22 |
| Wheat bran .. .. | 585 | 90 | 20 | 27 | 426 | 22 |
| Malt sprouts .. .. | 681 | 114 | 71 | 11 | 379 | 106 |

* In the absence of experiments, it is assumed that wheat is digested like other foods of the same class.

DIGESTIBLE MATTER IN 1,000 LBS. OF VARIOUS FOODS.

<table>
<tr><th rowspan="2"></th><th rowspan="2">Total Organic Matter</th><th colspan="2">Nitrogenous Substance</th><th rowspan="2">Fat</th><th rowspan="2">Soluble Carbo-hydrates</th><th rowspan="2">Fibre</th></tr>
<tr><th>Albu-minoids</th><th>Amides, &c.</th></tr>
<tr><td>Brewers' grains .. ..</td><td>137</td><td>34</td><td>2</td><td>14</td><td>67</td><td>20</td></tr>
<tr><td>" " (dried)..</td><td>529</td><td>136</td><td>8</td><td>57</td><td>266</td><td>62</td></tr>
<tr><td>Pasture grass .. ..</td><td>156</td><td>19</td><td>11</td><td>6</td><td>84</td><td>36</td></tr>
<tr><td>Clover (bloom beginning)</td><td>123</td><td>17</td><td>8</td><td>5</td><td>63</td><td>30</td></tr>
<tr><td>Clover hay (medium) ..</td><td>440</td><td>47</td><td>25</td><td>13</td><td>242</td><td>113</td></tr>
<tr><td>Meadow hay (best) ..</td><td>511</td><td>60</td><td>18</td><td>13</td><td>269</td><td>151</td></tr>
<tr><td>" " (medium)</td><td>485</td><td>40</td><td>12</td><td>12</td><td>269</td><td>152</td></tr>
<tr><td>" " (poor) ..</td><td>460</td><td>29</td><td>5</td><td>10</td><td>242</td><td>174</td></tr>
<tr><td>Maize silage .. ..</td><td>124</td><td>1</td><td>7</td><td>7</td><td>75</td><td>34</td></tr>
<tr><td>Bean straw .. ..</td><td>412</td><td colspan="2">40</td><td>6</td><td>211</td><td>155</td></tr>
<tr><td>Oat straw .. ..</td><td>381</td><td>7</td><td>5</td><td>7</td><td>163</td><td>199</td></tr>
<tr><td>Barley straw .. ..</td><td>426</td><td>4</td><td>3</td><td>6</td><td>211</td><td>202</td></tr>
<tr><td>Wheat straw .. ..</td><td>351</td><td colspan="2">4</td><td>4</td><td>150</td><td>193</td></tr>
<tr><td>Potatoes .. .. ..</td><td>213</td><td>5</td><td>9</td><td>1</td><td>195</td><td>3</td></tr>
<tr><td>Mangels (large) .. ..</td><td>89</td><td>1</td><td>8</td><td>½</td><td>74</td><td>6</td></tr>
<tr><td>" (small) .. ..</td><td>109</td><td>2</td><td>6</td><td>½</td><td>96</td><td>5</td></tr>
<tr><td>Swedes .. .. ..</td><td>87</td><td>2</td><td>7</td><td>1</td><td>71</td><td>6</td></tr>
<tr><td>Turnips .. .. ..</td><td>68</td><td>1</td><td>5</td><td>1</td><td>56</td><td>5</td></tr>
</table>

The figures in this table represent average results; with different qualities of food, and different animals, somewhat different quantities of matter will be digested.

(2) *Capacity for Producing Heat, Work, and Increase.*—The quantity of digestible constituents which a food contains does not sufficiently indicate its nutritive worth, owing to the unequal value of its various constituents, the unequal losses which take place during the processes of digestion and utilisation, and the unequal labour which the process of digestion requires in various cases. Thanks chiefly to the laborious researches of Kellner and Zuntz, already noticed, we are now able to estimate more or less exactly what is the final value to the animal of a digested food.

The most accurate method of ascertaining the value of any food is to experiment with it; but as the necessary investigations have as yet been made in only a few instances, we must proceed at present on the general plan of valuing food by summing together the values of its constituents. The only common function of food constituents which can be used for this purpose is their capacity for producing heat in the body. We have already seen (pp. 120-125) that the initial value of food; the losses which it suffers during digestion; the labour expended in this operation; and the final value of food to the animal, can all be expressed in terms of heat. We must, however, bear in mind that this method of determining the value of food to an animal fails in one point. The amount of heat which a food is capable of producing does not necessarily express its power of increasing or renewing the nitrogenous tissues of the body, this depends solely on the amount of the albuminoid constituents of the diet. We may, however, safely assert that the amount of heat generated by the combustion of the digestible constituents of any food, after making the deductions already referred to, will form a true guide to its nutritive value whenever 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.

We have already seen (p. 123) that the value of any food to an animal may be quite different according as it is employed for the purpose of maintaining the condition of the animal when at rest, or when employed for the production of increase or the performance of external work; and that this is especially true in the case of fibrous foods, as hay or straw. The heat which is the final outcome of the mechanical labour employed in the digestion of these fibrous foods is quite capable of warming the animal, but the energy thus developed is not generated in the muscles of the limbs and is thus useless for performing external work, and it is equally useless for the production of animal increase. As soon, however, as the animal is supplied with a liberal diet in order to perform work or yield increase, the quantity of waste heat available for warming the animal is so greatly increased, that the heat produced by the digestion labour ceases to be of any use to the animal. Foods are thus to be valued at the full heat value of their digestible constituents, including fibre, when used in limited quantities for maintenance only, deduction being simply made for the unburnt matter contained in the urine and intestinal gases (table, p. 120).

The valuation of food for the production of increase is less easy. Kellner's average results (table, p. 125) supply us with the relative values of fat, albuminoids, and carbohydrates for the production of increase in the ox, but the value of digestible fibre is not given. We have, however, the values for the production of increase actually obtained when meadow hay, oat straw of good quality, and wheat straw were added to a rather meagre diet for the purpose of fattening. If we take the digestible fat, albuminoids, and carbohydrates of the meadow hay, and give to each the average calorific value found for it in Kellner's production experiments, we find that the sum of these values is almost identical with the calorific value actually obtained when the hay was used as food. A similar calculation in the case of the oat straw shows also a near agreement with the value actually obtained by experiment. With wheat straw the case is different; the calculated value is here much above that found on actual trial. With the exception, therefore, of straw of this character, the simple omission of the digested fibre from the calculation appears to give results nearly agreeing with the truth. We must remember, however, that this is only the case so long as we are dealing with ruminant animals; in the case of the horse, as Zuntz has shown, giving no value to the fibre does not suffice to obtain an accurate expression of the value of a labour ration.

In the following table we give the calculated values of ordinary cattle foods both for maintenance and production purposes. To obtain the *maintenance value in terms of starch*, we refer to the amounts of digestible constituents contained in 1,000 lbs. of the food (pp. 155, 156), and make the following simple calculation:—

$$\text{Albuminoids} \times 1{\cdot}25 + \text{Amides} \times 0{\cdot}6 + \text{Fat} \times 2{\cdot}3 + \text{Carbohydrates} + \text{Fibre}.$$

## COMPARATIVE VALUES OF ORDINARY FOODS FOR OXEN AND SHEEP.

| | For Maintenance | | For Production | |
|---|---|---|---|---|
| | Value of 1,000 lbs. expressed as Starch | Quantities equivalent to 1 lb. of Starch | Value of 1,000 lbs. expressed as Starch | Quantities equivalent to 1 lb. of Starch |
| | lbs. | lbs. | lbs. | lbs. |
| Cotton cake (decorticated) | 944 | 1·06 | 82 | 1·21 |
| Maize .. .. .. | 859 | 1·16 | 825 | 1·21 |
| Wheat .. .. .. | 823 | 1·21 | 783 | 1·28 |
| Linseed cake .. .. | 842 | 1·18 | 733 | 1 36 |
| Barley .. .. .. | 755 | 1·32 | 721 | 1·39 |
| Rice meal .. .. | 758 | 1·32 | 713 | 1·40 |
| Peas .. .. .. | 796 | 1·25 | 702 | 1·42 |
| Beans .. .. .. | 786 | 1·27 | 670 | 1·49 |
| Oats .. .. .. | 676 | 1·48 | 626 | 1·60 |
| Wheat bran .. .. | 635 | 1·57 | 578 | 1·73 |
| Brewers' grains (dried).. | 634 | 1·58 | 533 | 1 88 |
| Malt sprouts .. .. | 695 | 1·44 | 518 | 1·93 |
| Cotton cake (undecorticated) | 519 | 1·93 | 442 | 2·26 |
| Meadow hay (best) .. | 536 | 1·87 | 359 | 2·79 |
| ,, ,, (medium).. | 506 | 1·98 | 337 | 2·97 |
| Clover hay (medium) .. | 459 | 2·18 | 319 | 3·13 |
| Meadow hay (poor) .. | 479 | 2·09 | 294 | 3·40 |
| Bean straw .. .. | 421 | 2·38 | 252 | 3·97 |
| Oat and barley straw .. | 412 | 2·43 | 207 | 4·83 |
| Potatoes .. .. .. | 212 | 4·72 | 202 | 4·95 |
| Mangels (small).. .. | 108 | 9·26 | 99 | 10·10 |
| Wheat straw .. .. | 357 | 2·80 | 96* | 10·41* |
| Maize silage .. .. | 131 | 7·63 | 92 | 10·87 |
| Clover (bloom beginning) | 131 | 7·63 | 92 | 10·87 |
| Mangels (large) .. .. | 87 | 11·49 | 76 | 13·16 |
| Swedes .. .. .. | 86 | 11·63 | 75 | 13·33 |
| Turnips .. .. .. | 68 | 14·71 | 59 | 16·95 |

* These figures are the production values actually obtained in Kellner's experiments.

To obtain the *production value in terms of starch*, the calculation is still simpler :—

$$\text{Fat} \times 2{\cdot}3 + \text{Albuminoids} + \text{Carbohydrates.}$$

The totals obtained by these calculations express the value of each food, both for maintenance and production purposes, in terms of dry, digestible starch.[1] The table also shows what weight of each food is equivalent in effect to 1 lb. of starch.

The different rank which a fibrous food takes according to the work which it has to perform is clearly shown in this table. It appears that 2 lbs. of oat straw, or wheat straw, may replace 1 lb. of corn if the ox or sheep is merely on a maintenance diet; but that 1 lb. of corn will have as great an effect as 4 lbs. of oat straw, or 8 lbs. of wheat straw, when the animal has to grow or fatten.

The equivalent quantities of different foods shown in the table agree fairly with those ascertained by actual feeding experiments. Thus the very numerous, but somewhat rough, Danish experiments with fattening pigs, showed that 4 lbs. of potatoes, or 7—8 lbs. of mangel, would adequately replace 1 lb. of corn meal (rye, barley, or maize). In American experiments with pigs, 4½ lbs. of potatoes were equivalent to 1 lb. of maize meal. In the old French estimates, 5 lbs. of turnips, or ½ lb. of peas or barley, were reckoned equal to 1 lb. of best meadow hay.

The table teaches us that an equal weight of corn

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[1] It should, of course, be remembered that starch has a different value for maintenance and production, the standard unit does not therefore represent the same number of Calories on both sides of the table on p. 160.

or oilcake will have a nearly similar feeding value if supplied to an animal receiving a sufficient amount of albuminoids in its diet, as, for instance, if given to sheep feeding on grass or clover. In the Woburn experiments, the rotation clover was consumed on the land by sheep receiving 728 lbs. of decorticated cotton-cake, or 728 lbs. of maize meal, per acre. The average gain in weight of ten sheep, in eight annual trials, was 362½ lbs. when receiving the cake, and 356¼ lbs. when fed with an equal quantity of maize.

The general practical lesson to be drawn from this section is that many foods can be substituted for each other without altering the value of the whole diet. A farmer should 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 (see p. 219).

(3) *Proportion of Albuminoids to Non-Albuminoids.*— A point of some 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.[1]

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[1] The equivalent of the non-nitrogenous matter in starch may be found with sufficient accuracy by multipying the digestible fat by 2·3, and adding to this the amount of digestible carbohydrates and the digestible fibre. The non-albuminoids are approximately found by adding to this total the digestible amides, previously multiplied by 0·6.

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 : 1·3 |
| ,, (undecorticated) | 1 : 2·0 | 1 : 2·2 |
| Linseed cake .. .. | 1 : 2·3 | 1 : 2·4 |
| Beans .. .. .. | 1 : 2·3 | 1 : 2·8 |
| Peas .. .. .. .. | 1 : 2·8 | 1 : 3·3 |
| Brewers' grains .. .. | 1 : 3·3 | 1 : 3·5 |
| Malt sprouts.. .. .. | 1 : 2·8 | 1 : 4·9 |
| Wheat bran .. .. .. | 1 : 4·6 | 1 : 5·8 |
| Red clover (bloom beginning) | 1 : 4·2 | 1 : 6·4 |
| Oats .. .. .. .. | 1 : 6·5 | 1 : 7·1 |
| Pasture grass .. .. | 1 : 4·5 | 1 : 7·4 |
| Meadow hay (best) .. .. | 1 : 5·8 | 1 : 7·7 |
| Wheat .. .. .. | 1 : 6·7 | 1 : 7·7 |
| Clover hay (medium) .. | 1 : 5·3 | 1 : 8·5 |
| Barley .. .. .. | 1 : 9·0 | 1 : 9·5 |
| Bean straw .. .. .. | 1 : 9·5 | — |
| Rice meal .. .. .. | 1 : 8·7 | 1 : 10·1 |
| Maize .. .. .. .. | 1 : 9·7 | 1 : 10·5 |
| Meadow hay (medium) .. | 1 : 8·6 | 1 : 11·4 |
| ,, (poor) .. .. | 1 : 13·2 | 1 : 15·2 |
| Potatoes .. .. .. | 1 : 14·3 | 1 : 41·1 |
| Swedes .. .. .. | 1 : 8·8 | 1 : 41·8 |
| Mangels (small) .. .. | 1 : 12·8 | 1 : 52·9 |
| Oat straw .. .. .. | 1 : 31·5 | 1 : 54·4 |
| Turnips .. .. .. | 1 : 10·6 | 1 : 66·3 |
| Mangels (large) .. .. | 1 : 9·0 | 1 : 86·0 |
| Barley straw.. .. .. | 1 : 61·0 | 1 : 107·2 |
| Maize silage .. .. .. | 1 : 15·6 | 1 : 129·3 |
| Wheat straw .. .. | 1 : 88·1 | — |

In the first column of the preceding table 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, and the amides have been reckoned among the non-albuminous constituents at their proper heat value. We shall employ these latter ratios in the present work.

These figures show in a striking manner the wide differences that exist amongst foods as to the proportion of albuminoids which they supply. The oilcakes and leguminous seeds are seen to be rich in albuminoids, and roots and straw very poor, while cereal grains and their products occupy a middle place. The differences are far greater than was formerly supposed, when it was customary to assume that the whole of the nitrogen of food was albuminoid. The poverty of a diet of roots and straw chaff in digestible albuminoids is one reason of the excellent effects produced by the addition of oilcake or leguminous corn. Oilcake, 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 carbohydrates 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 good hay, and is thus receiving a sufficiency of albuminoids, the use of oil-cake or beans may be without especial advantage to the animal, and they may be economically replaced by some cereal grain.

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 by Wolff 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 some of the non-nitrogenous constituents. Hay is thus a more nitrogenous food for horses than for sheep.

The advantage of employing a fixed albuminoid ratio in any diet is less than has been generally supposed, the same effect being often produced by diets varying within pretty wide limits. The proportion of albuminoids most suitable for various diets will come under consideration in the next chapter.

(4) *Influence of Proportion of Water.*—The nutritive value of a food to the animal is affected by the quantity of water with which it is associated. All the water in the food or drink has to be raised to the temperature of the animal body, while a part is exhaled as vapour in the breath and perspiration, and in this process of vaporisation a very considerable further amount of heat is consumed. Kellner found that for 100 of water consumed by oxen in a stable as food and drink, 46·3 appeared as an average in the fæces, 29·2 in the urine, while 24·5 was vaporised. The quantity of water required by an animal depends partly on the kind of food supplied; fibrous foods, as straw and hay, require considerably more water than corn. The oxen in the stable consumed about 4 of water to 1 of dry matter when fed on straw and hay, and only 3 to 1 when starchy and oily foods were given. Foods rich in albuminoids increase the demand for water, as more urea has to be removed from the system.

A warm atmosphere, and exercise, will greatly increase the amount of perspiration, and consequently the amount of water consumed (p. 185).

With sheep the normal proportion of water to dry food is about 2 : 1 ; with horses 2—3 : 1 ; with cattle 3—4 : 1. Sheep recently shorn require less water than sheep with a heavy fleece.

Roots contain an excessive amount of water. 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 18·4 lbs. of water, of which 15·2 lbs. is beyond that necessary for nutrition. This 15·2 lbs. of water has to be raised from near the freezing point to the temperature of the sheep's body, a rise of 70° Fahr. To warm the water to this extent will require the combustion of about 73 grams of dextrose (the sugar in turnips), equal to nearly 11 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 66 grams of dextrose. 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.

(5) *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. 157). From this point of view, fat has more than twice the value of any other food constituent; digestible albuminoids and carbohydrates have a similar value, while digestible fibre is nearly equal to starch when the food is used for mere maintenance, and is to be reckoned as valueless when the food has to produce external work or increase. If, however, the value of the food constituents is to include, as it must in practice, their manure value, the nitrogenous substances and the ash constituents will then become of greatest worth. The manure value is at present scarcely taken into account in determining the market price of foods.

The practical effect of any food must depend, in great measure, on the conditions under which it is employed. 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 oilcake, 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 a 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 to science.

# CHAPTER IX.

## RELATION OF FOOD TO ANIMAL REQUIREMENTS.

*The Requirements of the Young Animal.*—Composition of colostrum and milk—Suitable albuminoid ratio of the food—Food requirements in different stages of growth—Importance of ash constituents. *The Adult Animal.*—Production of heat—Production of work—Maintenance diets—Labour diet—Influence of pace. *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 milk—Albuminoid ratio for milking cows—Comparative yield of nitrogenous produce by cows and oxen—Influence of diet on the quality of milk and butter.

**The Young Growing Animal.**—The special feature of the nutrition of young animals is the rapid formation of nitrogenous tissue and bone, for which purpose an abundant supply of albuminoids and of suitable 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 :—

PERCENTAGE COMPOSITION OF COLOSTRUM.

| | Water | Albuminoids | Fat | Sugar, &c. | 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 .. | 74·7 | 17·6 | 3·6 | 2·6 | 1·5 | 1 : 0·6 |

PERCENTAGE COMPOSITION OF MILK.

| | | | | | | |
|---|---|---|---|---|---|---|
| Ewe .. | 80·8 | 6·5 | 6·9 | 4·9 | 0·9 | 1 : 3·1 |
| Sow .. | 84·6 | 6·4 | 4·8 | 3·2 | 1·0 | 1 : 2·2 |
| Goat .. | 85·7 | 4·3 | 4·8 | 4·4 | 0·8 | 1 : 3·5 |
| Cow .. | 87·0 | 3·6 | 3·9 | 4·8 | 0·7 | 1 : 3·7 |
| Human .. | 87·4 | 2·3 | 3·8 | 6·2 | 0·3 | 1 : 6·2 |
| Ass .. | 89·6 | 2·3 | 1·6 | 6·0 | 0·5 | 1 : 3·9 |
| Mare .. | 90·8 | 2·0 | 1·2 | 5·6 | 0·4 | 1 : 3·9 |

PERCENTAGE COMPOSITION OF DRY MATTER.

| | Albuminoids | Fat | Sugar | Ash |
|---|---|---|---|---|
| Cow's colostrum .. | 69·5 | 14·2 | 10·3 | 6·0 |
| Cow's milk .. .. | 27·7 | 30·0 | 36·9 | 5·4 |

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 almost perfect digestibility. If we take the heat-producing value of dry digestible starch as 100, then the heat-producing capacity of dry cow's milk will be about 133. 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 proportion of the nitrogenous to the non-nitrogenous constituents in milk is much higher than in most vegetable foods. The analyses in the table show a relation varying from 1 : 2·2 to 1 : 3·9 in the milk of farm animals, and in colostrum the proportion of albuminoids 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. When calves are fed on separated milk, the addition of cod-liver oil has been found very beneficial.

A young animal makes a very economical use of the milk which it receives. At Wisconsin, young lambs fed with cows' milk doubled in weight in twenty-five days, gaining 1 lb. for 5·8 lbs. of milk consumed. If the milk contained 13 per cent. of dry matter, $\frac{3}{4}$ lb. of dry matter produced 1 lb. of increase. A young calf can store up as flesh 69 per cent. of the albuminoids in its milk, and assimilate at the same time 98 per cent. of the lime, and 74 per cent. of the phosphoric acid. During the first few weeks of a calf's life, 10 lbs. of milk, containing 1·3 lbs. of dry matter, will yield 1 lb. of live weight. A calf will sometimes gain in weight as rapidly as a fattening ox ten times as heavy. These extraordinary rates of increase are due to the very large amount of food consumed in relation to the weight of the body; to the watery nature of the increase in a young animal, and the small formation of fat.

As the animal grows and takes more exercise, 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, carbohydrates 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. It is interesting to remark that human milk, which forms the sole support of the child for a far longer period than is the case with farm animals, contains the smallest proportion of nitrogenous matter.

An animal when very young consumes more food in relation to its body weight than in any later period of its life. As growth proceeds, the quantity of food eaten per day steadily increases, but the proportion of food to body weight considerably diminishes, at the same time the daily increase in live weight becomes gradually less. The return in increase for food consumed thus gets steadily less as the animal matures, till at last the point is reached at which no further gain in weight takes place unless fattening conditions are resorted to. The following table is adapted from that of Wolff-Lehmann, and shows the alterations in

| | Digestible Food (Fibre ½) Reckoned as Starch | | Nitrogenous to Non-Nitrogenous Substance in Food |
|---|---|---|---|
| | Per head, per day | Per 1,000 lbs. live weight, per day | |
| | lbs. | lbs. | |
| Oxen, weight 165 lbs. .. | 3·5 | 21·5 | 1 : 4·2 |
| ,, ,, 330 lbs. .. | 6·3 | 19·0 | 1 : 4·7 |
| ,, ,, 550 lbs. .. | 8·7 | 15·8 | 1 : 6·0 |
| ,, ,, 770 lbs. .. | 10·7 | 13·9 | 1 : 6·8 |
| ,, ,, 935 lbs. .. | 12·3 | 13·2 | 1 : 7·2 |
| Sheep, weight 66 lbs. .. | 1·38 | 20·9 | 1 : 4·0 |
| ,, ,, 84 lbs. .. | 1·50 | 17·8 | 1 : 4·8 |
| ,, ,, 101 lbs. .. | 1·65 | 16·3 | 1 : 5·2 |
| ,, ,, 121 lbs. .. | 1·67 | 13·8 | 1 : 6·3 |
| ,, ,, 154 lbs. .. | 1·97 | 12·8 | 1 : 6·5 |
| Pigs, weight 44 lbs. .. | 1·7 | 38·0 | 1 : 4·0 |
| ,, ,, 110 lbs. .. | 3·3 | 30·0 | 1 : 5·0 |
| ,, ,, 143 lbs. .. | 4·0 | 28·0 | 1 : 5·5 |
| ,, ,, 198 lbs. .. | 5·0 | 25·1 | 1 : 6·0 |
| ,, ,, 286 lbs. .. | 6·3 | 22·0 | 1 : 6·4 |

the rations of growing animals deduced from German experiments. In this table only one-half of the digestible fibre has been reckoned by the German authors as available food, but the whole of the digestible fibre is included in calculating the ratio of nitrogenous to non-nitrogenous matter.

It is very important that the food supplied to growing animals should contain a sufficient amount of ash constituents, and especially of lime; for remarks on this subject see p. 136.

**The Adult Animal.**—The food of an adult animal, not gaining or losing in weight, is employed for the renovation of the tissues, the formation of hair, wool, horn, &c., and for the production of heat and mechanical work by its combustion in the body.

*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 as excrementitious matters, which are the products or residues of the process of combustion. The temperature of the body of the animals on the farm varies from 100°—104° Fahr., the horse having the lowest temperature and the sheep and pig the highest. The heat produced in the animal is lost by radiation from the surface of the body, much is also consumed in vaporising the water which is exhaled through the lungs and skin.

The smaller is the animal the greater is the loss of heat per unit of weight, and consequently the more liberal must be the supply of food. Rubner determined the quantity of heat given off per day by a series of dogs of different weight; his results are shown in the next table.

HEAT EVOLVED BY DOGS OF DIFFERENT WEIGHT.

| Body Weight | Heat evolved per day | |
|---|---|---|
| | Actual | Per Kilo. of Body Weight |
| Kilograms | Calories | Calories |
| 3 | 273 | 90·9 |
| 6 | 409 | 68·1 |
| 18 | 830 | 46·1 |
| 24 | 982 | 40·9 |
| 31 | 1184 | 38·2 |

Thus while the heat evolved, measured in Calories, increased largely with the increased weight of the animal, the heat per unit of body weight (or volume) diminished greatly as the animals became larger. This is due to the fact that small bodies have, in proportion to their weight, a much greater surface than large bodies,[1] and it is *the extent of surface* which determines the rate of cooling. Thus, in the case of the two dogs weighing 3 and 24 kilos., their relative weight and volume were clearly 1 : 8; their relative surface was, however, 1 : 4, and their relative heat production 1 : 3·6.

If we look back at the daily rations for animals of various weights just given (p. 173), we shall also find that the quantity of food increases at nearly the

[1] This fact may be easily grasped by comparing a single cube with another built up of eight similar cubes. The bulk and weight of the large cube are clearly eight times that of the single cube, but its total surface is obviously only four times that of the single cube.

same rate as the increase of surface. Thus, while the oxen increase in weight from 1—5·7, their surface increases from 1—3·2, and their food from 1—3·5. The pig increases in weight from 1—6·5, its surface from 1—3·5, and its food from 1—3·7. In the case of sheep the question is complicated by the thick covering of wool; the weights in the table rise from 1—2·33, the surface (if calculated as in other cases) from 1—1·76, and the food from 1—1·43.

*Production of Work.*—The work performed by an animal is partly internal and partly external. The *internal* work consists in the muscular movements concerned in mastication, digestion, 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 a man 12 stone in weight has been calculated as equal to 242 foot-tons; that is to say, the power exerted by the heart would raise 1 ton to a height of 242 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 horse of 500 kilos. weight (1,102 lbs.), without a load, will represent an exertion equivalent to 720,976 kilogrammeters, or 2,328 foot-tons. During labour, about 31 per cent. of the total energy developed in the muscles appears as external work, the rest will appear as heat. The temperature of the body in fact rises during labour, and perspiration is increased.

It was formerly supposed that muscular force was produced by the oxidation of the nitrogenous constituents of the muscle, and that a diet very 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 which produces work is generated by the oxidation of organic matter in the muscular tissues; this organic matter may be derived from albuminoids, but it far more usually consists of carbohydrates or fat.[1] Wolff found that it was indifferent whether the digestible substance supplied to a horse consisted of starch (3 lbs. per day were employed in one experiment), or of linseed oil, or of the mixed constituents occurring in ordinary horse foods; the labour value of the food was determined in every case solely by *its heat-producing power*. The animal body has been compared to a steam engine, in which food is burnt in place of coal. The proportion of the generated energy which finally appears as mechanical work is, however,

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[1] For the sake of simplicity the function of glycogen in the animal body has not been discussed. Glycogen is a carbohydrate formed in the animal body which acts as a *reserve* of energy; during rest it is stored up in the muscle, it disappears during labour. Glycogen can be formed in the animal from the carbohydrates of the food and from albuminoids. We must not hastily conclude that glycogen, or the sugar derived from it, is the only substance oxidised to produce muscular energy; all we can assert is that it takes an important part in this work.

far greater in the case of an animal than in the case of a steam engine.

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 to maintain the condition of the animal is reduced to its smallest limits. The minimum quantity of food required by an animal is most accurately found by ascertaining the various gains and losses of energy taking place with a known but barely sufficient diet; the balance of energy dissipated as heat, after allowance has been made for all gains and losses in the animal, is an exact measure of the minimum requirements of the body. Kellner has made numerous experiments of this kind with lean, full-grown oxen, kept in a stable at a temperature of about 60° Fahr., and receiving diets varying in quality and quantity. The total food required varies with the size of the ox; but, as we have already seen (p. 174), in proportion to its *surface*, and not according to its weight. In the following table the calculated minimum food requirement for oxen of various weights is given[1] both in terms of heat and in pounds of digested organic matter and starch.[2] By referring to the table on p. 160, the amount of any ordinary food equivalent to this quantity of starch can be ascertained.

MINIMUM FOOD DAILY REQUIRED BY LEAN OXEN.

| Live Weight of Ox | Actual | | | Per 1,000 lbs. Live Weight | | |
|---|---|---|---|---|---|---|
| | Digestible Organic Matter | Reckoned as Starch | Heat Value of Food | Digestible Organic Matter | Reckoned as Starch | Heat Value of Food |
| lbs. | lbs. | lbs. | Cals. | lbs. | lbs. | Cals. |
| 990 | 6·75 | 6·39 | 10,740 | 6·82 | 6·45 | 10,848 |
| 1,100 | 7·24 | 6·85 | 11,520 | 6·58 | 6·23 | 10,473 |
| 1,210 | 7·72 | 7·30 | 12,280 | 6·38 | 6·03 | 10,149 |
| 1,320 | 8·18 | 7·74 | 13,010 | 6·19 | 5·86 | 9,856 |
| 1,430 | 8·62 | 8·16 | 13,720 | 6·03 | 5·70 | 9,594 |
| 1,540 | 9·06 | 8·57 | 14,420 | 5·89 | 5·57 | 9,364 |
| 1,650 | 9·48 | 8·98 | 15,100 | 5·75 | 5·44 | 9,151 |
| 1,760 | 9·90 | 9·36 | 15,760 | 5·63 | 5·32 | 8,955 |

The quantity of food reckoned as sufficient for maintenance in this table is really rather too small

[1] The maintenance diet for an ox of *any other weight* can be calculated from the figures in the table, recollecting that the relative surface, and therefore food requirement, of any two animals is as the cube root of the square of their respective volumes or weights.

[2] Kellner states that 1 gram of the digestible organic matter of the hay used had the value of 3·5 Calories. As he reckons 1 gram of starch as 3·7 Calories, the equivalent quantities of starch have been calculated on this basis.

for practical use, a margin admitting of a small production must be allowed in order to provide for the growth of hair, hoofs, &c., if the animal is to continue permanently in health. Lean oxen of 1,370 lbs. weight, fed on hay, will require in practice a daily ration of 10 lbs. digestible organic matter, or 7·3 lbs.[1] per 1,000 lbs. live weight. Of this 7·3 lbs. of digestible matter, 0·7 lb. will be nitrogenous substance, including (if ordinary hay was used) 0·54 lb. albuminoids. The ratio of nitrogenous to non-nitrogenous substance is here 1 : 9·4, and the true albuminoid ratio 1 : 12·4.

A fat ox requires more food to maintain an unchanged condition than a lean ox of the samé size. Kellner experimented with fat oxen up to 1,888 lbs. live weight. An ox of 800 kilos. (1,760 lbs.) required a daily ration supplying 19,920 Calories, or one-quarter more food than a lean ox of the same weight. A fat ox also requires a rather larger proportion of albuminoids in its diet.

It is essential that a maintenance ration should supply enough albuminoids to replace the daily waste of the nitrogenous tissues. While the albuminoids of the maintenance ration serve this special purpose, they at the same time form an effective part of the heat-producing food, as they take the place of matter that is being burnt in the body. An animal is receiving the minimum amount of albuminoids required for its sustenance when any diminution in the daily supply occasions a larger amount of nitrogen to leave the

[1] If the digestible matter of the hay is to be valued at 3·5 Calories per gram, and starch at 3·7 Calories, as before, then the 10 lbs. and 7·3 lbs. of digestible organic matter will be equal to 9·46 lbs., and 6·9 lbs. of starch.

animal in the form of urine than is contained in the digested food. When the intake and output of nitrogen are the same, an animal is said to be in a condition of nitrogen-equilibrium. This condition of equilibrium can be obtained with a mininum supply of albuminoids only when the food contains a sufficient amount of carbohydrates and fat for the heat requirements of the animal; if the heat-producing food is deficient the albuminoids are partly burnt in the body before they can serve for the renovation of tissue, and a larger quantity is consequently required. An animal cannot be long kept in health with the smallest quantity of albuminoids producing nitrogen-equilibrium, as the growth of hair, wool, hoofs, &c., is always in progress; a truly maintenance diet must thus supply rather more albuminoids than the minimum. Armsby found that a supply of 0·6 lb. of true albuminoids per day was sufficient for the permanent maintenance of an ox of 1,000 lbs. weight receiving a diet having an albuminoid ratio of 1 : 11; but that when a greater proportion of carbohydrates was given, this amount of albuminoids might be considerably reduced without disturbing the nitrogen-equilibrium, and without, at least for a time, any injurious results to the animal. For an economical maintenance diet an unnecessary excess of albuminoids must be avoided, as the presence of any excess in the system determines a greater demand for food. The amount of albuminoids needed becomes larger when the animal receives an increased supply of drinking water. The demand for albuminoids stands in relation to the weight, and not to the surface of the animal.

The maintenance requirements of the horse have been carefully determined by Zuntz. A horse of 1,100 lbs. live weight will require food supplying 12,100 Calories per day, equivalent to about 7 lbs. of digestible starch. Owing to the great consumption of energy during the digestion of fibrous foods by the horse, already referred to (pp. 121, 126), fibre can be used to only a limited extent in the rations. Zuntz found that for a successful maintenance diet, at least one-third of the energy of the food must remain over for use in the animal body after all the energy demanded by the work of digestion had been expended. A reference to the table on p. 122 will show that meadow hay meets this requirement, but that straw does not. The proportions in which straw may be mixed with other foods can be calculated from the figures given in this table. Thus a daily ration of 10 lbs. straw chaff and $6\frac{2}{3}$ lbs. maize would yield the required 7 lbs. of digestible organic matter, while only one-half of the energy produced would be consumed in the work of digestion, leaving a sufficient balance for the remaining internal work and other requirements of the body.

The experiments of Grandeau with Paris cab horses show a similar food requirement as those of Zuntz. A horse of 1,000 lbs. weight, taking only half an hour's walking exercise per day, required from 7—7·8 lbs. of digestible organic matter (hay), including 0·45 lb. of albuminoids, to maintain its condition.

The experiments on sheep are few, and have been made with comparatively rough methods. Shorn sheep, fed on meadow hay, will require, according to German experiments, about 11·8 lbs. of digestible organic matter, containing 1·0 lb. of albuminoids, per 1,000 lbs. live weight, to preserve their condition.

Sheep apparently require more liberal rations per unit of weight than an ox or horse; this is due to the higher temperature of the sheep (103°—104°), its smaller size, and therefore larger proportion of surface, and to the growth of wool, with its accompanying fat, which is always in progress.

*Labour Diet.*—If external work is to be performed, the body weight remaining unaltered, the quantity of food must be considerably increased. A man doing a moderate 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.

An agricultural horse weighing 1,100 lbs., doing regular work at a walking pace, will produce, according to Zuntz, about 771 foot-tons of work[1] for each pound of *available food*, reckoned as starch, consumed in the body over and above the quantity required for maintenance. By available food is to be understood the portion remaining for use in the animal after all the losses of matter and energy occurring during the processes of digestion and excretion. The quantity of food available for use in muscular exertion by the horse, supplied in 1,000 lbs. of ordinary foods, has been calculated by Zuntz from his experiments, and is shown in the table on p. 122.[2] Taking the figures

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[1] This amount of work is considerably less than that mentioned in previous editions of this book. In the experiments by Wolff, then quoted, the quantity of work performed by the experimental horse was over-estimated.

[2] Wolff taught that fibre is of no use for the production of external work, and obtained the amount of food available for work by deducting the fibre from the digested organic matter. Zuntz has shown

given in this table, the comparative values of these foods, and the amounts of work to be obtained from 1 lb. of each of them are as follows:—

| | Pounds of Food supplying 1 lb. available | Equivalent Quantities of Food | Foot-tons of Work from 1 lb. of Food |
|---|---|---|---|
| Maize .. .. | 1·42 | 1·00 | 542 |
| Beans.. .. .. | 1·64 | 1·15 | 470 |
| Linseed Cake .. | 1·77 | 1·24 | 436 |
| Oats .. .. .. | 2·04 | 1·43 | 379 |
| Lucerne hay.. .. | 4·27 | 3·01 | 180 |
| Potatoes .. .. | 5·02 | 3·54 | 153 |
| Meadow hay .. .. | 5·49 | 3·87 | 140 |
| Clover hay .. .. | 6·00 | 4·17 | 130 |
| Carrots .. .. | 10·87 | 7·63 | 71 |

Zuntz has determined the quantity of food which a horse requires to perform work under various conditions. One of the conditions having most influence on the result is pace. A horse, weighing with harness 1,144 lbs., will require 1·33 lbs. of available food to walk 10 miles at $2\frac{1}{2}$ miles per hour; 1·69 lbs. when walking at the speed of $3\frac{1}{3}$ miles per hour; and 2·53

that this correction is insufficient. The energy consumed in digesting fibrous foods varies according to the condition of the fibre, and often exceeds the whole value of the fibre digested. We must not, however, imagine that digestible cellulose cannot produce work, a large part of the digestible carbohydrates of hay consists indeed of cellulose (p. 133). The true view of the matter is simply that the harder kinds of cellulose require more energy for their digestion than they can produce when digested.

lbs. when trotting the same distance at 7 miles an hour. In the experiments of Grandeau and Leclerc, a horse walking $12\frac{1}{2}$ miles a day was kept in condition with a daily ration of 19·4 lbs. of hay, while a ration of 24 lbs. of hay was insufficient when the same distance was done trotting. A horse walking the above distance, and dragging a load (additional work 1,943 foot-tons), was sufficiently nourished by a ration of 26·4 lbs. of hay; but a daily ration of 32·6 lbs.—all that the horse would eat—was not enough to maintain the horse's weight when the same work was done trotting. When the horse is trotting, the internal work performed by the heart and by the respiratory muscles is much increased. The horse, when trotting or galloping, also lifts his own weight at each step, but allows it to fall again—the result appearing only as heat. The temperature of the horse rises with exertion, and much heat is lost by the evaporation of water through the skin and lungs. The horse at rest evaporated 6·4 lbs. of water, per day; when walking, 8·6 lbs.; at work walking, 12·7 lbs.; trotting, 13·4 lbs.; at work trotting, 20·6 lbs. It follows, of course, that a horse requires more water when at work. The Paris cab horse, on a mixed diet, consumed 2·1 of water to 1 of dry matter when at rest, and 3·6 : 1 when in the cab. When fed with hay alone the proportion was 3·3 : 1 at rest, and 4·3 : 1 when with the cab. Horses of different disposition, and different action when working, may require different amounts of food to accomplish the same task.

In order to calculate the quantity of food needed by a horse performing a certain daily task, we need to know the weight of the horse with harness, the draft of the load which he has to move, the distance he has to travel, the inclination of the road, and the time given for the accomplishment of the task. From these data the quantity of available food needed for the production of the required work can be calculated. To this amount must be added an amount of available food sufficient for the internal work of the body (digestion labour excepted) when the animal is at rest. This amount we have already seen (p. 182) is about 2·4 lbs. (one-third of 7 lbs.) for a horse of 1,100 lbs. live weight. We thus arrive at the total quantity of available food required for muscular exertion. The ration must besides this include an amount of digestible matter sufficient to provide for the labour of digestion: this is not a fixed quantity, but will vary according to the description of food used, and will be greatest when straw chaff is employed. The total amount of food must, of course, produce sufficient heat to maintain the temperature of the body.

One of Zuntz's examples is that of a horse ploughing eight hours a day. The horse with harness is assumed to weigh 1,144 lbs.; he walks at the rate of 2½ miles per hour, drawing a plough the draft of which is 147·4 lbs. The total work accomplished is 8,967 foot-tons, requiring 11·63 lbs. of available food. Adding 2·4 lbs. for other work (excluding digestion), we have a total requirement of 14·03 lbs. of available food for the day's ration during this heavy work. The table on p. 184 shows that this amount of available food would be supplied by 20 lbs. of maize, which would at the same time supply enough energy for its own digestion. A diet of maize only is, of course, impracticable; but the same table shows at once what quantities of other foods will replace 1 lb. of maize. If wheat straw chaff is introduced into the ration to supply the fibrous matter needed for the horse's health, it must be recollected that for each pound of straw 0·116 lb. must be deducted from the total of available food supplied from other sources. In calculating the above ration no mention has been made of the heat requirements of the horse; these we have seen (p. 182) are equivalent to 7 lbs. of digestible organic matter. As, however, only 31 per cent. of the food available for work actually produces a mechanical effect, and the whole of the rest of the ration appears as heat, the requirements for heat are fully met; and when, as in practice, fibrous foods are employed to a considerable extent, the proportion of the food producing heat is still further increased.

Wolff and Lehmann, as already mentioned, reckon a labour ration more simply, but less accurately, in terms of digestible organic matter, excluding fibre. Of such matter they state that a horse of 1,000 lbs. live weight will require 8 lbs. per day for light labour; 11 lbs. for average labour; and 13 lbs., or more, for severe labour.

A diet of meadow or clover hay does not supply sufficient available food for a full day's work, even at a walking pace; but the young grass of a good pasture, and green vetches or lucerne, are sufficiently nutritious for this purpose. Whenever severe labour has to be performed, food of high quality and easy digestibility must be given.

As already remarked, food containing a large proportion of albuminoids is not essential for a labour diet; rations supplying only a small proportion of albuminoids have been used successfully for agricultural horses doing full work at a moderate pace. In Fiji the horses in the sugar plantations receive 15 lbs. of molasses per day, and the ratio of nitrogenous to non-nitrogenous digestible matter in their diet is 1 : 11·8. It is generally recognised, however, that for quick movement, and to promote activity of disposition, a fairly good proportion of albuminoids is advisable. The albuminoid ratio of the diet employed by our tramway companies is about 1 : 7.

**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, carbohydrates and albuminoids is stored up in the form of fat. In the case of a young animal taking free exercise in the field, the increase appears as a general growth of the body; in the case of an animal at rest, the increase consists chiefly in the deposition of fat in the tissues.

The disposition of an animal to fatten depends much on breed and temperament. It is almost impossible to fatten a wild animal, while its domesticated descendants, especially if bred with the object of obtaining rapid increase, may be readily fattened. The changes in organisation produced by long-continued systematic breeding are most strikingly shown in the case of the pig. In the wild boar the intestines are six times the length of the body; in modern domesticated breeds the intestines may be more than twenty times the length of the body. Different individuals have different appetites, different powers of digestion, and different rates of fattening.

Rest and quietness are essential for rapid fattening; the production of work must be suspended if the production of fat is to proceed actively. An animal at rest in a stall will increase in weight far more than an animal taking active exercise on the same diet. A moderate degree of warmth is also favourable to the fattening process; the economy of feeding animals under cover in winter time is generally recognised. In Danish experiments, pigs of about 150 lbs. weight required 516 lbs. of corn meal in winter time to produce 100 lbs. of increase, while in summer 457 lbs. sufficed to produce the same result. If, however, the temperature becomes so high as to considerably increase the perspiration, a waste of food will occur. The temperature most favourable to animal increase is apparently about 60° Fahr. Freedom from excitement is essential to rapid fattening; the absence of strong light is therefore desirable.

As only that part of the food which is in excess of the bodily requirements is converted into increase, liberal feeding is, within certain limits, the most economical. If an ox can be brought by liberal treatment to 1,000 lbs. live weight at one year old, the amount of food consumed will be far smaller than if two years are spent in attaining the same weight, for the food required for animal heat and work during the second year is clearly saved.

We have already considered the rations required by an animal for maintenance only (p. 178), and have also seen that certain kinds of food may be used for maintenance which are quite inappropriate for the production of increase. The relative values of various cattle foods for the production of increase have been given in the table on p. 160. We have also partly discussed the composition and amount of the increase obtained when an excess of food is supplied over that needed for maintenance. We have seen (p. 127) that 100 parts of starch may yield in the ox 23·3 of fat; we may say, therefore, that, in round numbers, 4 of starch, or its equivalent in other food constituents, can produce about 1 of pure fat.

The increase in live weight actually obtained when animals are fattening contains, on an average, according to Lawes and Gilbert's estimate, 66 per cent. of fat, the rest being nitrogenous matter, water, and ash constituents (p. 110). If we calculate the calorific value of this increase by means of the factors given on p. 119, we find that 1 gram has the value of 6·64 Calories. As 1 gram of starch has a production value for the ox of 2·2 Calories, it appears that 3 of starch, or its equivalent in other food constituents, should produce 1 of fattening increase. The production values of different cattle foods have been given in the table on p. 160 in terms of starch; it is easy, therefore, to calculate what amount of fattening increase each food is capable of producing. Thus we see that 1·36 lbs. of linseed cake is equivalent to 1 lb. of starch; it follows, therefore, that $1·36 \times 3 = 4·08$ lbs. of linseed cake can produce 1 lb. of fattening increase. In the same way we find that about 9 lbs. of average meadow hay, 15 lbs. of potatoes, and 30 lbs. of small mangels, can also produce 1 lb. of increase in live weight when used to the best advantage. This does not, of course, mean that if a fattening ox is fed on hay and mangels it will gain 1 lb. in weight for each 9 lbs. of hay, or 30 lbs. of mangel consumed; the amount of food required for the animal's maintenance must be deducted from the total food supplied, and the *excess* of food alone must be credited to increase. Nor must it be forgotten that the maintenance food of an animal in a fattening condition is considerably greater in quantity than that required by a lean animal of the same weight (p. 180), and that the demand for maintenance increases as the process of fattening advances.

In the examples we now proceed to give of the results obtained when fattening oxen, sheep and pigs, the quantities of food mentioned are the total amounts consumed by the animal, no distinction being attempted between the maintaining and the producing portions of the ration; this is inevitable in the case of the sheep and pig, as the requirements of these animals for maintenance are not as yet accurately known. In the case of the ox, the amount of food required for maintenance has been most carefully determined; but even in this case we do not exactly know what portion of the maintenance ration must in any given case be deducted from a liberal diet to obtain the amount available for production.[1] Kellner's production values of food were,

[1] We have already seen that the fibre in the food of an ox only provides the animal with sufficient energy for its own mastication and digestion; the digested fibre thus contributes to the heat of the animal, but takes no share in the production of increase. A part of the maintenance ration must not consist of fibre, as internal work

however, obtained by giving a known quantity of food to an ox which was already receiving somewhat more than a maintenance ration; we are therefore apparently justified in deducting the whole, or nearly the whole, of the maintenance ration from the diet of a fattening ox, if we wish to ascertain the quantity of food available for increase in the sense understood by Kellner. Taking, as an example, the Rothamsted statistics for fattening oxen (p. 193), we see that an ox of 1,200 lbs. live weight received 106 lbs. of digested organic matter (including fibre) per week, and produced 13·6 lbs. of increase. Such an ox, in a fattening condition, would require, according to Kellner, about 9·63 lbs. per day of digested organic matter for maintenance only, or 67·4 lbs. per week, thus leaving 38·6 lbs. of digested food, reckoned as starch, for production. Now as 3 lbs. of starch can yield 1 lb. of increase, the 38·6 lbs. might yield 12·9 lbs.; the actually observed increase being 13·6 lbs. Calculating backwards, the 13·6 lbs. of increase would require 40·8 lbs. of productive food, leaving for

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besides that of digestion has to be provided for. What fraction of the maintenance ration must be non-fibrous is, in the case of the ox, unknown; in the case of the horse it must not fall below one-third of the digested matter. If we suppose an ox to receive a maximum amount of fibre in its maintenance ration, the amount of increase produced by the addition of any food will be strictly limited by the producing value of the food added. If, on the other hand, an ox is maintained on food poor in fibre, and additional food is then added for fattening, the waste heat produced during the deposition of increase may enable a part of the maintenance food, previously utilised for heat, to become productive, and the weight of increase obtained will then exceed that proper to the food added. The return from the additional fattening food thus depends, partly, on the character of the rest of the diet.

maintenance 65·2 lbs., or 9·3 lbs. per day. The results obtained by calculation thus nearly approximate to the facts observed, and the difference appears to indicate that a small portion of the maintenance food had, in the case in question, become available for production.

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, forty years ago, reckoned 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 3,500 lbs. swedes. Sheep will produce the same increase by the consumption of 250 lbs. oilcake, 300 lbs. clover hay, and 4,000 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 approximately as follows :—

COMPARISON OF FATTENING OXEN, SHEEP, AND PIGS.

| | Mean Live Weight | Per head per week | | | |
|---|---|---|---|---|---|
| | | Dry Food | Digested Organic Matter | Increase in Live Weight | Dry Manure* |
| | lbs. | lbs. | lbs. | lbs. | lbs. |
| Oxen .. | 1,200 | 151 | 106 | 13·6 | 60 |
| Sheep .. | 130 | 21 | 16 | 2·3 | 7 |
| Pigs .. | 175 | 48 | 40 | 11·3 | 11 |

* Dry matter of solid excrement and urine exclusive of litter.

| | Per 1,000 lbs. live weight per week | | | Required to produce 100 lbs. increase | |
|---|---|---|---|---|---|
| | Dry Food | Digested Organic Matter | Increase in Live Weight | Dry Food | Digested Organic Matter |
| | lbs. | lbs. | lbs. | lbs. | lbs. |
| Oxen .. | 125 | 88 | 11·3 | 1,109 | 777 |
| Sheep .. | 160 | 121 | 17·6 | 912 | 686 |
| Pigs .. | 270 | 227 | 64·3 | 420 | 353 |

The upper division of the table supplies some useful facts as to the quantities of food consumed, and the amounts of increase and manure obtained during the fattening stage of feeding.[1] In the lower division of the table, the consumption of food per 1,000 lbs. live weight, and the return in animal increase per live weight, and per food consumed, are given. It will be seen that in proportion to its weight the sheep eats more food and yields more increase than the ox, while the pig takes much more food and gives much more increase than either. 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

[1] Since these estimates were made the fattening capacity of English sheep and oxen has increased, owing to improvements in the breeds. It is probable that larger quantities of food are now successfully utilised by the animals in question.

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 assimilating large quantities of easily digested food.

The pig requires far less food to produce 100 lbs. of increase than either the ox or sheep. The pig, with its very large consumption of easily digested food, has, in fact, to spend a smaller proportion of it on heat and work, and has thus a larger surplus left for the production of increase. The pig, from its rapid feeding, and high rate of increase, is undoubtedly the most economical meat-making machine at the farmer's disposal.

We have as yet looked at the fattening period as a whole; the rates of consumption and of increase will generally, however, vary in different stages of this period.

In the case of a lean or growing animal, the quantity of food which the animal will eat increases during the earlier stages of fattening, the stomach and intestines becoming larger; in the case of full-grown animals this increase in consumption soon ceases. When the animal becomes very fat the consumption of food falls off somewhat, and the increase of weight at this point is much diminished.

As fattening advances the same amount of food will produce a steadily diminishing amount of increase. This is chiefly because the consumption of food for internal work steadily increases with the increasing size of the body. The increase during the later stages of fattening is also drier, and contains a larger proportion of fat than in the earlier stages of the process. 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 they had doubled in weight, their average weight being 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 | 67·5 | 36·7 | 17·4 | 9·4 | 388 |
| Third ,, | 66·4 | 30·9 | 13·2 | 6·2 | 502 |
| Fourth | 66·0 | 27·4 | 12·9 | 5·4 | 511 |
| Fifth ,, | 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 proportion of nitrogenous matter in the fattening increase is very small, the albuminoid ratio of the increase varying from 1 : 19 to 1 : 22 (p. 110). The proportion of lean to fat can be influenced to only a limited extent by the character of the feeding. In the case of a rapidly growing young animal, a diet supplying an abundance of albuminoids will produce a much larger increase of nitrogenous tissue (lean) than a diet rich in carbohydrates and fat. Very young pigs fed liberally on separated milk, with some barley meal and bran, will yield much leaner pork and bacon than similar pigs receiving barley meal and potatoes without milk. When, however, we are dealing with fully-grown animals, as oxen, the increase obtained during fattening is chiefly fat, whatever may be the albuminoid ratio of the diet.

Many years ago scientific men believed that albuminoids and fat were the only constituents of food which contributed to the formation of animal increase; the carbohydrates were supposed to produce heat in the body, but not fat. As a consequence of this belief the nutritive value of foods was supposed to be chiefly determined by the proportion of albuminoids, or "flesh formers," which they contained. This idea of the limited function of carbohydrates has been disproved by an abundance of experimental evidence. Nevertheless, the impression of the great preponderating value of albuminoids for the production of animal increase still remains in the minds of many agricultural writers. It may be well, therefore, to quote some of the results of the pig-feeding experiments at Rothamsted, in which the animals were intentionally supplied with very various proportions of nitrogenous matter in their food.

FATTENING PIGS ON FOODS RICH AND POOR IN ALBUMINOIDS.

| Food supplied | Consumed to produce 100 lbs. of Increase | | | Ratio of Nitrogenous to Non-Nitrogenous Substance |
|---|---|---|---|---|
| | Nitrogenous Substance | Non-nitrogenous Substance | Total Organic Matter | |
| | lbs. | lbs. | lbs. | |
| Bean and lentil meal .. | 137 | 291 | 428 | 1 : 2·1 |
| Bean, lentil and maize | 113 | 297 | 410 | 1 : 2·6 |
| Starch, sugar, lentil, bran | 81 | 329 | 410 | 1 : 4·1 |
| Starch, lentil, bran .. | 80 | 340 | 420 | 1 : 4·2 |
| Maize, bean, lentil, bran | 72 | 338 | 410 | 1 : 4·7 |
| Maize, bean and lentil.. | 72 | 366 | 438 | 1 : 5·1 |
| Maize and bran .. .. | 58 | 362 | 420 | 1 : 6·3 |

These results show in an unmistakable manner that the quantity of total organic matter needed to produce 100 lbs. of fat pork remained in all cases nearly the same, notwithstanding the great variations in the quantity of albuminoids supplied. The ratios of nitrogenous to non-nitrogenous substance given in the table are merely the ratios of these substances in the food supplied, the albuminoid ratios of the digested matter would be considerably wider.

Although an excess of albuminoids does not increase the nutritive value of a fattening diet, we have already seen (p. 153) that if the proportion falls too low the food is less thoroughly digested.

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 : 5·4, concluding with 1 : 4·5. For pigs, 1 : 5·9—1 : 7·0, as the age and weight increases. For oxen, 1 : 6·5 at the commencement of fattening, to be reduced to 1 : 5·4 when fattening in earnest has set in, and concluding with 1 : 6·2. In all these ratios, however, the amides have been reckoned as albuminoids; they are thus narrower than the truth, the error falling chiefly on those for sheep and oxen. Practical results show that very good rates of increase may be obtained with much smaller proportions of albuminoids than those recommended by Wolff, if cereal grains form a considerable part of the diet. In Kellner's experiments with oxen, the rates of increase were practically the same with ratios varying 1 : 4—1 : 10. A three years' trial at Woburn proved that a daily ration of 20 lbs. swedes, $\frac{1}{4}$ lb. hay, and $\frac{3}{4}$ lb. wheat for sheep (nitrogenous substance to non-nitrogenous 1 : 7—1 : 8, albuminoid ratio about 1 : 19) yields excellent results, generally equal to those obtained when oilcake is substituted for wheat. For another Woburn experiment illustrating the subject see p. 162. 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.

We cannot close this section without a word as to standard rations. In fattening it is clearly the farmer's object to supply the animal with the largest amount of food it can profitably make use of. So long as bulky foods, as hay, straw and roots are largely employed, the animal may safely be given as much as it can eat; the limits of profitable use must, however, be considered when concentrated foods, as cake and corn, are supplied. Few accurate experiments have been made as to the economy of supplying a more or less concentrated diet to sheep and oxen. The assimilating power of the pig is so great that there appears little danger of over-feeding in its case. The daily rations recommended in the German feeding standards for fattening animals by Wolff and Lehmann are as follows :—

DAILY FOOD PER 1,000 LBS. LIVE WEIGHT.

FATTENING OXEN.

| Stage of Fattening | Dry Food | Nitrogenous Substance | Non-nitrogenous Substance | Total Digestible Organic Matter | |
|---|---|---|---|---|---|
| | | | | Fibre included | Half Fibre included |
| | lbs. | lbs. | lbs. | lbs. | lbs. |
| First stage | 30 | 2·5 | 16·2 | 18·7 | 15·6 |
| Second stage | 30 | 3·0 | 16·2 | 19·2 | 17·0 |
| Third stage | 26 | 2·7 | 16·7 | 19·4 | 17·2 |

FATTENING SHEEP.

| | | | | | |
|---|---|---|---|---|---|
| First stage | 30 | 3·0 | 16·2 | 19·2 | 16·5 |
| Second stage | 28 | 3·5 | 15·9 | 19·4 | 16·9 |

FATTENING PIGS.

| | | | | |
|---|---|---|---|---|
| First stage | 36 | 4·5 | 26·7 | 31·2 |
| Second stage | 32 | 4·0 | 25·2 | 29·2 |
| Third stage | 25 | 2·7 | 19·3 | 22·0 |

These rations relate, of course, to German animals, and to the class of foods used in Germany. The quantities of food recommended for the ox and sheep, and especially the former, are considerably larger, while the rations for the pig are smaller than those mentioned in the estimates by Lawes and Gilbert, previously quoted. These differences are partly due to the fact that the live weight on which the food is reckoned in the German table is that of the animal at the commencement of the fattening period, while in Lawes and Gilbert's figures the standard live weight is the middle weight of the fattening period. As the daily quantity of food consumed by a full-grown ox or sheep does not seriously vary during fattening, the proportion of food to 1,000 lbs. live weight appears larger on the German mode of reckoning than on that employed by Lawes and Gilbert. Pigs, on the other hand, are frequently fattened before their growth is completed, and in their case there may be a rather considerable increase in the daily consumption of food during fattening.

Any real acquaintance with the subject must lead to the conclusion that the quantity of food required by a fattening ox or sheep must vary a good deal according to the class of diet employed. Sheep fattened at Rothamsted on swedes, with cake or corn, consumed

126 lbs. of dry organic matter per 1,000 lbs. live weight per week, and 802 lbs. of this food produced 100 lbs. of increase. When clover chaff took the place of roots, the sheep consumed 164 lbs. of dry organic matter per 1,000 lbs. live weight per week, and 1,521 lbs. of dry organic matter was needed to yield 100 lbs. of increase. The use of fibrous or non-fibrous foods had thus a great influence on the total quantity of food demanded by the animal, and on the return obtained from the food consumed.

It is also obvious from what has gone before that the weight of an animal is by no means a satisfactory datum for determining the quantity of food which it requires, and that, in fact, a great part of the demand for food is determined by the surface of the animal and not its weight. The fact that small animals require considerably more total food per unit of weight than large animals is generally recognised. Feeding standards are thus correct only under certain assumed conditions; they may, however, be of practical use by serving as the starting point for a more accurate determination of the best ration to be given.

**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 a nitrogenous organic acid. 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 in unwashed and in washed wool, is given on page 108.

A large proportion of the nitrogen of a sheep's body occurs in the wool; 20 per cent. of the whole nitrogen was found in the fleece in the case of the four Hampshire Down sheep analysed at Rothamsted.

The production of wool-hair and of wool-fat is practically no greater when a full-grown sheep receives 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 affected. With starvation, however, the yield of wool is considerably diminished. In the case of lambs, a liberal diet causes increased growth, and with this a bigger fleece. 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.**—Although milk is entirely derived from the food which has been supplied to the cow, yet the constant production of milk is of such great importance for the nourishment of the calf that it has been made as far as possible independent of the immediate supply of food. If the food of a fattening ox is suddenly reduced to a maintenance ration the increase of carcase will at once cease; but the food of a milking cow may be reduced to a maintenance ration without stopping the production of milk; this production may be long continued, but in greatly diminished quantity, the lack of food being supplied out of the body of the cow, which daily becomes thinner. As withholding food will not stop the production of milk, so neither by abundant feeding can milk production be pushed beyond a certain point. Each cow has a natural limit to its milk production; to feed beyond this requirement will merely fatten the animal.

The quantity of milk produced by a cow depends largely on the breed to which it belongs, and on its individual character. For profitable dairying it is before all things essential to start with a good cow. All the cows on a farm should have their yield in milk measured and registered at least once a week, and all unprofitable cows should be got rid of as soon as possible. If butter is made, the proportion of butter fat in the milk must also be regularly determined, as the quantity of the milk does not indicate its richness in butter fat. The most profitable cow is the one giving the largest return in milk or butter *per unit of food consumed.*

While abundant feeding will not turn a bad cow into a good one, a liberal diet is essential for a full supply of milk, and by sustaining the cow with proper food at the time of her greatest milk production, it is possible to prolong that profitable period very considerably. The supply of concentrated food (cake, bean meal, bran, &c.,) should rise and fall with the varying yield of milk as the period of lactation advances, the object being to obtain as large a produce as can be reached without fattening the animal.

The amount of produce yielded by a good cow is very large, and far exceeds that yielded in the same time by a growing or fattening ox. In the following table the constituents in the weekly increase of a fattening ox are compared with the constituents of the milk yielded by a cow.

| Fattening Ox | | | | | Milking Cow | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Gain per Day | In Weekly Increase | | | | Milk per Day | In Weekly Milk | | | |
| | Albuminoids | Fat | Ash | Total | | Albuminoids | Fat* | Ash | Total |
| lbs. | lbs. | lbs. | lbs. | lbs. | lbs. | lbs. | lbs. | lbs. | lbs. |
| 1 | 0·5 | 4·6 | 0·1 | 5·2 | 10 | 2·5 | 4·0 | 0·5 | 7·0 |
| 2 | 1·1 | 9·3 | 0·2 | 10·6 | 20 | 5·0 | 8·1 | 1·0 | 14·1 |
| 3 | 1·6 | 13·9 | 0·3 | 15·8 | 30 | 7·6 | 12·1 | 1·5 | 21·2 |
| | | | | | 40 | 10·1 | 16·2 | 2·0 | 28·3 |
| | | | | | 50 | 12·6 | 20·2 | 2·5 | 35·3 |

* The milk sugar has been calculated into its equivalent in fat, and is here included.

The quantity of albuminoids and ash constituents in the cow's milk thus always greatly exceeds the quantity yielded by a fattening ox as meat; and in the case of a first-class cow in full milk, the fat and sugar in the milk are also much more than equivalent to the largest produce of fat in the ox.

Notwithstanding the large amount of produce obtained from the cow, the quantity of food required is not correspondingly large. Thus in Wolff's rations, a cow yielding 27½ lbs. of milk daily is given 18·2 lbs.

of digestible food each day (reckoned as starch) per 1,000 lbs. live weight; while a fattening ox of the same weight receives 19·4 lbs. A good cow is thus an animal giving a very large return for the food consumed—a circumstance highly conducive to profit.

As milk is a highly nitrogenous substance, the albuminoid ratio in cows' milk being 1 : 3·7, the diet of a milking cow must contain a considerable supply of albuminoids, and the need for albuminoids will increase as the produce of milk increases. A cow giving abundant milk demands a more nitrogenous diet than a moderate milker; and a cow, if a heavy milker, will require more albuminoids when in full milk than afterwards. A small cow will also need a greater proportion of albuminoids in its food than a large cow, if both are giving the same yield of milk. This is because the maintenance food, which need only be poor in albuminoids, forms a smaller proportion of the diet of the little cow than of the big one. When the total quantity of food is sufficient, dairying statistics show that an albuminoid ratio of 1 : 7, or even 1 : 8, is adequate in the case of large cows or moderate milkers; while a ratio of 1 : 6 should be employed in the case of small cows or heavy milkers.

It has been taught by many that the whole of the fat in milk is formed from albuminoids. This, if true, would greatly intensify the demand for albuminoids in a cow's food; the theory in question is not, however, borne out by feeding statistics, or by experiments, and there is no doubt that in the cow, as in other animals, fat is largely produced from carbohydrates.

Science has not yet supplied us with all the facts necessary for establishing the ratio between food supplied and milk produced. One gram of cows' milk, containing 13 per cent. of dry matter, will have a heat value of 0·755 Calorie. If we might take food at the production value shown in the experiments with fattening oxen—1 gram of starch, for instance, as storing up increase equivalent to 2·2 Calories—then 1 lb. of starch, or rather its equivalent in digestible food containing a sufficient proportion of albuminoids, would produce nearly 3 lbs. of milk. The return obtained from a good cow is, however, more than this. The proportion of fat yielded by carbohydrates is probably nearly the same in the cow as in the ox, but the albuminoids of the food are used far more economically than in the ox, a large portion being stored up without undergoing any serious loss.

The return from the food supplied to the cow is also complicated by the fact that a part of the return appears as a young calf. Hagemann reckons a newly-born calf as weighing about 88 lbs., and as containing 22 lbs. of albuminoids, 3·3 lbs. of fat, the rest being water and ash constituents. In the first half of the lactation period the product of the food appears chiefly as milk; in the latter portion of the lactation the formation of the calf and the storing up of animal increase becomes more considerable, and the return in milk falls off.

An ample extent of good pasture furnishes sufficient food for a cow in full milk, and it is only on inferior land, in a dry season, or on a crowded pasture, that the addition of concentrated food becomes necessary. In winter feeding on hay, straw, roots, and silage, the addition of concentrated foods containing a considerable proportion of albuminoids is imperative if a good cow is to yield her best return. Oilcakes, bean-meal, bran, oats, and brewers' grains are recognised as excellent foods for a milking cow; most of those foods supply fat as well as albuminoids, and the cake and bran are also rich in phosphates. In the winter feeding of cows at Rothamsted, the general diet consisting of hay, oat straw, and mangels, $2\frac{1}{2}$ lbs. of decorticated cotton cake, and $2\frac{1}{2}$ lbs. of bran, were given daily to every cow yielding one gallon of milk, and an additional pound both of cotton cake and bran was given for every additional gallon of milk produced. The milk produced by each cow was registered, and the amount of concentrated food supplied rose or fell with the milk production.

The quality of the milk may be influenced to some extent by the character of the food. Thus a liberal diet of fresh brewers' grains, or a diet of watery grass (irrigated), will yield a moderate quantity of poor milk, and the addition of oil-cake will increase both the yield of milk and also its richness. The alteration in the composition of the milk by poor or liberal feeding is, however, often very small. The relative proportions of casein and sugar are scarcely affected by the character of the diet, the butter fat is somewhat more variable.

The quality of the butter may be a good deal influenced by the character of the food. The white, hard, tasteless character, which winter butter often possesses, is chiefly due to the foods employed. Pasture, whether grass or clover, yields butter of the lowest melting point, containing the highest percentage of volatile fatty acids, and best flavour. Silage appears to partake of the properties of green food, and is thus valuable for winter feeding when carefully used. Hay produces a harder butter, straw a still harder. Of the straws, oat straw is the best. The cereal grains yield a good percentage of volatile acids in the butter. Oat grain and wheat bran are the best of the cereal foods, and should form a considerable part of the cow's diet for butter production in winter. Leguminous grains and straw yield a hard butter. Oilcakes generally harden the butter and raise its melting point. This has been especially proved in the case of cotton cake. The addition of 1 or 2 lbs. of cotton cake to the daily ration of a cow on summer pasture helps to counteract the objectionable softness of the butter at this season of the year. Palm-nut cake and rape cake are favourite foods for winter feeding on the continent, and do not apparently produce a hard butter. Turnips, if used in considerable quantity, strongly flavour both milk and butter; mangels and cabbage are better foods for milking cows.

## CHAPTER X.

### 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 and their relative manure value.—The actual value of the manure under various circumstances—Economic use of manure.

**Quantity of the Manure.**—The quantity of manure furnished by an animal is plainly dependent to a considerable extent on the quantity and kind of food which it consumes. An animal on a maintenance diet will yield a minimum quantity of manure, an animal liberally fed will produce much more. The quantity of the solid excrement will be much influenced by the proportion of indigestible matter in the food. An ox fed on hay and straw will produce far more solid manure than one fed on roots, the former foods leaving 40 — 50 per cent. of their organic matter undigested, while of the roots only 12 per cent. is so left. The bulk of the urine is chiefly determined by the quantity of water in the diet, feeding with roots will thus greatly increase the volume of the urine. The solid matter in the urine, being the residue of the processes of oxidation in the animal body, will rise and fall in quantity according to the amount of nitrogenous matter and salts received into the circulation from the organs of digestion. The quantity of dry matter in the solid excrement of an animal may be calculated from the digestion coefficient of the dry matter in the food. The quantity of dry matter in the urine is, according to Wolff, about 6 per cent. of the dry food consumed.

The mixed excrements of pigs, and those of 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. An ox of 1,000 lbs. weight will furnish, according to Wolff, about 86 lbs. daily of fresh manure (including litter), and a horse of the same weight 53 lbs. Manure freshly made, with a minimum of litter, will contain 70—80 per cent. of water. The manure from stall-fed cattle and pigs ferments slowly, and is said to be "cold." The stable manure from horses ferments readily, and is termed "hot."

**The Litter.**—The worth of a litter depends partly on its powers of retaining water and ammonia, and partly upon the manurial constituents which itself supplies. A litter has the greatest power of absorption when it is finely divided; straw chaff is thus a better absorbent than long straw.

WATER RETAINED BY 1 PART OF LITTER.

| | | | |
|---|---|---|---|
| Dead leaves .. | 2·0 | Spent tan .. .. | 4·0—5·0 |
| Straw .. .. | 2·2—3·0 | Peat .. .. | 5·0—7·0 |
| Sawdust .. .. | 4·0—4·4 | Peat Moss.. .. | 10·0 |

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—1·0 |
| Peat Moss .. .. .. | 0·7 | 0·1 | 0·1 |
| Sawdust .. .. .. | 0·2—0·7 | 0·3 | 0·7 |
| Spent tan .. .. .. | 0·5—1·0 | — | — |
| Peat .. .. .. .. | 1·0—2·0 | — | — |

Müntz and Girard saturated different litters with a solution of carbonate of ammonium, and then allowed them to dry in the air. For 10 of ammonia retained by pine sawdust, 37 were retained by the same weight of wheat straw, 183 by peat moss, and 240 by powdered peat. These figures do not represent the relative retaining powers when wet, as under this condition the amount of water held by the litter would have great influence. Peat and peat moss are clearly the most efficient absorbents ; they decompose, however, but slowly in the soil.

**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 increase. 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. Ordinary labour does not increase the quantity of nitrogen and ash constituents voided.

The proportion of the nitrogen in the food which will appear in the solid excrement is determined by the digestion coefficient of the nitrogenous constituents. Thus 79 has been already given as the digestion coefficient of the nitrogenous matter of barley meal when consumed by a pig. It follows that, in this case, for 100 of nitrogen consumed, 21 will be voided in the solid excrement and 79 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, 21 appear in the solid excrement, and 64·3 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 p. 193. The relation of food to manure in the case of milking cows is calculated from 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 a daily ration of 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 | 21·0 | 64·3 | 85·3 |
| Milking cows .. .. | 24·5 | 18·1 | 57·4 | 75·5 |
| Calf fed on milk .. | 69·3 | 5·1 | 25·6 | 30·7 |

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

| | Obtained as Live Weight or Milk | Voided in Excrements and Perspiration |
|---|---|---|
| Horse at rest .. .. .. | None | 100 |
| Fattening oxen .. .. .. | 2·3 | 97·7 |
| Fattening sheep .. .. | 3·8 | 96·2 |
| Fattening pigs .. .. .. | 4·0 | 96·0 |
| Milking cows .. .. .. | 10·3 | 89·7 |
| Calf fed on milk .. .. | 54·3 | 45·7 |

The proportion of the ash constituents of the food which is stored up in the body of an animal 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; but with young growing animals the proportion retained in the body is much more considerable.

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 larger proportion of the nitrogen of its food, about 85 per cent. appearing in the manure. The milking cow gives a still better return in saleable produce for the nitrogen which it receives, only about 76 per cent. appearing in the manure. The best return is in the case of the young calf fed on milk, only 30 per cent. of the nitrogen consumed appearing as manure. These proportions are, of course, exactly true only in the case of the diets assumed to be given to each animal; with diets containing a smaller amount of albuminoids the proportion of nitrogen appearing as manure will 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 in the case of fattening animals it may be 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 horses are fed only on poor hay, the nitrogen in the solid excrement will somewhat exceed that contained in the urine. On the other hand, corn and cake 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 generally found nearly all the phosphoric acid, and the greater part of the lime and magnesia, while the urine contains the greater part of the potash. Horse urine is an exception to the above rule, as it contains a rather notable amount of lime. When animals receive food containing a considerable amount of alkali phosphates and but little lime, phosphoric acid will appear in the urine. Pigs fed on potatoes, peas, and milk yielded over 50 per cent. of the phosphoric acid in their urine. With sheep and horses, and probably more or less with other animals, a part of the potash is excreted in the perspiration.

The following table shows the distribution of nitrogen, phosphoric acid and potash in the milk, solid excrement, and urine of a cow. The experiment

| | Voided by Cow in 100 Days | | | Per cent. of each Constituent | | |
|---|---|---|---|---|---|---|
| | Nitrogen | Phosphoric Acid | Potash | Nitrogen | Phosphoric Acid | Potash |
| | lbs. | lbs. | lbs. | | | |
| Milk .. | 11·4 | 4·7 | 4·5 | 16·5 | 23·0 | 9·9 |
| Fæces .. | 21·5 | 15·5 | 7·1 | 31·2 | 75·6 | 15·6 |
| Urine .. | 36·1 | 0·3 | 34·2 | 52·3 | 1·4 | 74·5 |
| Total .. | 69·0 | 20·5 | 45·8 | 100·0 | 100·0 | 100·0 |

was made in Pennsylvania, and lasted fifty days. The cows received a nitrogenous diet of hay, cake and corn; no roots were given. The average yield of milk was 22·8 lbs. per day.

The immense loss of nitrogen and potash which must occur when the urine is not preserved is strikingly shown by these figures.

Some idea of the general composition of the solid excrement, and of the urine of various animals, receiving various diets, is supplied by the following tables. 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.

The immense influence of the character of the diet, both on the quantity and quality of the manure, is well

## PERCENTAGE COMPOSITION OF SOLID AND LIQUID EXCREMENTS.

(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 | 63·0 |
| 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.<br>42 | lbs.<br>88 | lbs.<br>48 | lbs.<br>14 |
| Water .. .. | Per cent.<br>83·00 | Per cent.<br>95·940 | Per cent.<br>79·70 | Per cent.<br>88·230 |
| Nitrogen .. .. | ·33 | ·124 | ·34 | 1·540 |
| Phosphoric acid .. | ·24 | ·011 | ·16 | ·006 |
| Potash .. .. | ·14 | ·597 | ·23 | 1·690 |

shown by the two experiments with cows. The difference appears chiefly in the urine, which is largely increased in quantity by the mangels.

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.** — (1) *Relative Value.* 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. The relative manure value of each food has been calculated from the market prices of the manure constituents; these prices are, of course, liable to variation.[1]

The manure value of different foods varies extremely. One ton of decorticated cotton cake has about four times the manure value of a ton of wheat, barley or oats, and thirty times as much as a ton of turnips. The practical importance of such facts is very great. We have already seen that decorticated cotton cake and wheat may yield almost the same increase in live weight when employed as food; they may also have the same price per ton. The farmer will, however, unhesitatingly prefer the cake in consequence of its far higher manure value.

The oilcakes 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 rather below

[1] In January, 1902, the wholesale price of nitrate of soda at Liverpool was £10 a ton; of kainite, £2 10s.; of 30 per cent. superphosphate, £2 12s. These prices work out to the following values: Nitrogen nearly 7d. per lb., phosphoric acid, 2d., and potash, 2d. per lb.

## MANURE CONSTITUENTS AND RELATIVE MANURE VALUES OF ORDINARY FOODS.

| | In 1,000 Parts of Food | | | | Relative Manure Value* |
|---|---|---|---|---|---|
| | Dry Matter | Nitrogen | Phosphoric Acid | Potash | |
| Cotton cake (decorticated) .. .. | 918 | 72·0 | 32·5 | 15·8 | 1,000 |
| Earthnut cake .. | 893 | 76·2 | 20·0 | 15·0 | 1,008 |
| Rape cake .. .. | 900 | 49·6 | 20·0 | 13·0 | 689 |
| Linseed cake .. .. | 883 | 44·8 | 16·2 | 12·5 | 620 |
| Cotton cake (undecort.) | 875 | 35·2 | 25·8 | 16·1 | 550 |
| Linseed .. .. | 908 | 36·1 | 13·9 | 10·3 | 503 |
| Palm-kernel meal .. | 896 | 26·9 | 11·0 | 5·0 | 366 |
| Beans .. .. .. | 857 | 40·7 | 12·0 | 12·9 | 561 |
| Peas .. .. .. | 860 | 36·0 | 8·4 | 10·1 | 485 |
| Malt dust .. .. | 900 | 37·9 | 18·2 | 20·8 | 578 |
| Brewers' grains (dried) | 905 | 33·0 | 16·1 | 2·0 | 441 |
| Wheat bran .. .. | 868 | 22·6 | 26·9 | 15·2 | 402 |
| Rice meal .. .. | 897 | 19·7 | 26·7 | 7·1 | 336 |
| Wheat .. .. .. | 866 | 18·7 | 8·0 | 5·3 | 263 |
| Rye .. .. .. | 866 | 18·3 | 8·6 | 5·8 | 262 |
| Oats .. .. .. | 870 | 18·1 | 6·9 | 4·8 | 251 |
| Barley .. .. .. | 857 | 17·0 | 7·9 | 4·8 | 241 |
| Maize .. .. .. | 890 | 16·6 | 5·7 | 3·7 | 225 |
| Brewers' grains (fresh) | 238 | 8·1 | 4·2 | 0·5 | 109 |
| Clover hay (medium) | 837 | 21·8 | 5·6 | 18·9 | 345 |
| Meadow hay (medium) | 863 | 14·7 | 4·1 | 13·2 | 235 |
| Bean straw .. .. | 816 | 13·0 | 2·7 | 18·7 | 232 |
| Oat straw .. .. | 855 | 6·4 | 2·8 | 17·7 | 152 |
| Barley straw .. .. | 858 | 5·6 | 2·0 | 10·6 | 112 |
| Wheat straw .. .. | 864 | 4·8 | 2·2 | 6·3 | 87 |
| Potatoes .. .. | 250 | 3·4 | 1·6 | 5·7 | 67 |
| Mangels .. .. | 120 | 2·0 | 0·8 | 4·8 | 44 |
| Carrots .. .. | 130 | 2·0 | 0·9 | 2·6 | 36 |
| Swedes .. .. | 107 | 2·2 | 0·6 | 2·0 | 35 |
| Turnips .. .. | 85 | 1·6 | 0·9 | 3·4 | 34 |

* These values have not been recalculated for the present edition, as the alterations which have taken place in market values do not seriously alter the values of the foods.

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. Potatoes stand below roots in manurial value when compared on the basis of their dry substance. Wheat straw takes the lowest place of all when foods are compared on the basis of their dry substance.

(2) *Actual Value.*—The nitrogen, phosphoric acid and potash in one ton of decorticated cotton cake, if reckoned at the market values of these substances in active manures already quoted, will have a total value of £5 12s. 1d.; the actual value to the farmer is, however, far below this. The actual value of the manure from a food depends partly, as we have already seen, on the amount of nitrogenous matter, phosphates and potash appropriated by the animal; these have in every case to be deducted from the constituents of the food before we can estimate its value as manure. The actual manure value depends also partly on the condition of the nitrogen, phosphates and potash present in the manure. It depends, finally, to a very considerable extent, on the changes which the manure undergoes before it reaches the land.

The potash in fresh manure is mostly in a readily soluble form, and may be reckoned as having a money value equal to the potash in commercial potash salts. The phosphates in manure can hardly be reckoned as equal in availability to the soluble phosphate of superphosphates, but it may probably be considered as similar in value to the phosphates in bone dust. The nitrogenous matter in fresh urine (chiefly urea) is perfectly soluble, and diffuses are readily in the soil as a nitrate; is is rapidly converted into carbonate of ammonium by the action of certain bacteria present in the atmosphere and the soil. The nitrogen of urea may apparently be reckoned as of equal value to that in ammonium salts. The nitrogenous matter of the solid excrements is certainly of far less value, consisting chiefly of vegetable matter which has already resisted the prolonged attacks of the digestive fluids and of the bacteria of the intestines; it will become available as plant food only by slow decomposition in the soil.

The constituents of animal excrements are in the condition of greatest value as manure at the time when they leave the animal; after mixing with litter and storage in heaps their manure value considerably diminishes. The manure from food thus yields its best return when the food is consumed upon the land, and the manure at once ploughed in; this happens when sheep receive oilcake while feeding off a crop of swedes. During the fermentation of the manure with litter the constituents enter into new combinations; the ammonia produced from the urine combines with the humic acids formed from the decomposing litter, insoluble amide compounds being produced. The potash also enters into combination with the humic matter. The constituents of farmyard manure are thus not so immediately available for plant food as the original animal excrements. The nitrogen of farmyard manure has been valued by Wagner, from its effect in producing crops, at 45 per cent. of the value of nitrogen in nitrate of sodium.

Besides the change in condition, we have further to take into account the serious losses in quantity which the constituents of animal manure may suffer before they reach the land. In the yard or stable much urine may run to waste. Ammonia will volatilise as gas in the stable during the decomposition of the urine. The mixed manure and litter may again suffer loss by drainage if exposed to rain. Considerable further loss of nitrogen may occur during the fermentation in the manure heap, free nitrogen being evolved. In the case of ordinary farmyard manure less, and sometimes much less, than one-half the nitrogen that left the animal is finally brought on to the land. Any loss of urine, or drainage from the heap, will also seriously diminish the supply of potash.

The results obtained by manuring barley crops at Rothamsted and Woburn illustrate the varying manure values of the nitrogen of oilcake when applied to the land in various stages of use. Rape cake ploughed into the land at Rothamsted before sowing barley has yielded an average return of about 80 per cent. of that yielded by a similar amount of nitrogen applied as nitrate of sodium.[1] Decorticated cotton cake is consumed at Woburn by sheep feeding off swedes. Its average effect on the following barley crop is about 46 per cent. of that yielded by the same quality of nitrogen as nitrate of sodium applied directly to the barley. Cake and other foods are consumed at Woburn by fattening bullocks in deep stalls or boxes. The manure is left undisturbed till the feeding is completed, then taken out and clamped, and finally applied as a top dressing to barley in a very well-rotted condition.

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[1] Applied to mangels, the average return from rape cake and nitrate of sodium is at Rothamsted very similar, though in individual seasons the differences are considerable.

Under these circumstances the return in barley from the nitrogen in the food is about 20 per cent. of that yielded by the nitrogen of nitrate of sodium. This return rises to 32 per cent. if the effect of the residue of the farmyard manure during fifteen subsequent years is taken into the account.

Lawes and Gilbert, in their estimates of the manure value of foods supplied to fattening animals, have first deducted the nitrogen, phosphates and potash which they estimate are retained by the animal, and then reckoned *one-half* of the remaining nitrogen, phosphates and potash at the current values of these substances in artificial manures. These estimates are more probably too high than two low.

The feeding of animals on the land is a plan which has many advantages, and if carried out under favourable circumstances will yield the best return from the manure constituents of the food; the distribution of the manure is apt, however, to be irregular, and in autumn or winter some loss may occur from rain and drainage. It is generally, however, not possible to consume more than a small part of the food of the farm in this way. The use of litter, and the preparation of farmyard manure, becomes, therefore, a necessity. Farmyard manure should always be prepared under cover. The precautions to be taken for diminishing the losses which it suffers have been already noticed on p. 51.

# CHAPTER XI.

## THE DAIRY.

*Milk.*—Its constituents—Conditions affecting its richness—Influence of breed. *Curdling.*—The action of bacteria. *Cream.*—The fat globules — Modes of raising cream — Composition of cream — Ripening of cream. *Skim and Separated Milk.*—Its composition under various conditions. *Butter.*—The operation of churning—Return for milk used — Composition of butter. *Butter Milk.*—Its composition. *Cheese.*—Rennet—Operation of cheese-making—Ripening of cheese — Composition of cheese. *Whey.*—Its com position. *Annatto.*—Its nature and use. *Necessity for Cleanliness.*

**Milk.**—The general composition of colostrum and of ordinary cows' milk has been already given on p. 170.

The milk from a herd of dairy cows has generally a *specific gravity* between 1·030 and 1·040. The solids other than fat tend to raise the specific gravity, while the fat tends to lower it. As cream may be removed and water added without altering the specific gravity, 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, casein[1] 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

[1] Some writers call the original, unprecipitated albuminoid in the milk, caseinogen.

coagulates on boiling. In ordinary cows' milk the albumin forms about 12 per cent. of the total albuminoids, but the proportion is somewhat variable.

The *fat* of milk differs considerably in composition from the fat of the animal body; it consists of the glycerides of at least nine fatty acids. Eight of these form a perfect chemical series, in which each differs from the preceding by the addition of $C_2H_4$ to the molecule. The lowest member of the series is butyric acid, $C_4H_8O_2$; the highest member is stearic acid, $C_{18}H_{36}O_2$. The average percentage composition of milk fat is about as follows.—

| | |
|---|---|
| Butyrin .. .. .. | 3.85 |
| Caproin .. .. .. | 3·60 |
| Caprylin .. .. .. | ·55 |
| Caprin .. .. .. | 1·90 |
| Laurin .. .. .. | 7·40 |
| Myristin .. .. .. | 20·20 |
| Palmitin .. .. .. | 25·70 |
| Stearin .. .. .. | 1·80 |
| Olein .. .. .. .. | 35·00 |
| | 100·00 |

Olein and the lower members of the series are liquid fats; the fats become more solid as they rise in the series, stearin being the hardest. About 7·0 per cent. of the fatty acids, chiefly consisting of the three lower members of the series, are soluble in water. The soluble acids have also a lower boiling point, and can be separated by distillation. These facts serve to distinguish butter fat from animal fats (as margarine) which contain no soluble and volatile fatty acids. The proportion of the various fats changes somewhat with the diet and condition of the animal; the influence of food on the composition of the fat has been already noticed, p. 208. Milk fat has a lower heat value than the fats of the animal body; 1 gram of milk fat has a heat value of 9·2 Calories.

The *sugar* contained in milk is known by chemists as lactose or lacton. This sugar is not present in the vegetable foods consumed by the cow; these foods, however, contain substances which yield galactose by hydrolysis, and others yielding dextrose by the same process. It is possible that these two sugars together form lactose in the animal, as lactose can be split up into these bodies.

Besides the three groups of constituents already mentioned, milk contains very small quantities of citrates, and traces of several other organic bodies.

The constituents of the *ash* have been already referred to, p. 108.

**Variations in Composition.**—The composition of cows' milk is affected by many circumstances; under extreme conditions it may contain 10—17 per cent. of dry matter. The percentage of sugar and ash varies very little, the percentage of albuminoids varies a little more, the fat varies most of all; rich milk may easily contain twice as much fat as poor milk. In the mixed milk of a herd of cows the non-fatty solids very seldom fall below 8·5 per cent., nor the fat below 3·0 per cent.: these facts become of great importance when adulteration with water has to be detected.

A cow in calf is usually in milk for ten months. The period of full milk is generally from the second to the seventh week; this period is more prolonged when the cow is on grass. As the milk falls off in quantity it increases somewhat in richness. The milk sent from the country to London, yielded for the most part by cows calving in the spring, is poorest from April to June, and richest in November, the total variation amounting to 0·5 per cent. of fat. The evening's milk is usually richer than the morning's milk; the average difference in the milk sent to London is 0·36 per cent. of fat, but in particular cases the difference may exceed 1·0 per cent. This difference is apparently connected with the times of supplying food and water, it is greatest during winter feeding, and may disappear altogether while a cow is on pasture. The first milk leaving a cow's udder is very poor in fat, sometimes but little superior to skim-milk; the last milk is extremely rich in fat. The whole of the milk yielded by a cow must thus be thoroughly mixed before its composition can be truly ascertained.

**Influence of Breed.**—The richness of milk depends much on the "race" of the cow, the fat being the constituent most affected. The Jersey breed gives the richest milk, the fat amounting to 5—6 per cent. Next to this stands the Guernsey. The Kerry, Welsh, and Red-polled follow with over 4 per cent. of fat. The milk of the Shorthorn and Ayrshire contains nearly 4 per cent. The Holstein, and some other Continental breeds, yield about 3·4 per cent. The Holstein and Shorthorn are remarkable for the large quantity of milk they yield. The difference between individual cows of the same breed may be very great. The milk of each cow in a dairy should be separately tested if economic production is desired.

It is quite obvious that a different cow is required when the sale of milk is intended, than for the economic production of butter or cheese. The average results obtained at three American stations as to the produce of milk and of milk fat, and as to cost of food, with various breeds of cows, were as follows :—

| | Produce in one Year | | Fat per cent. of Milk | Cost of Food for | |
|---|---|---|---|---|---|
| | Milk | Fat | | 100 lbs. Milk | 1 lb. Fat |
| | lbs. | lbs. | | Pence | Pence |
| Jersey .. .. .. | 5,579 | 301 | 5·4 | 47¼ | 8¾ |
| Guernsey .. .. | 6,210 | 323 | 5·2 | 41½ | 8 |
| Shorthorn .. .. | 8,696 | 345 | 4·0 | 39½ | 9¾ |
| Ayrshire .. .. | 6,909 | 248 | 3·6 | 39¼ | 10¾ |
| Holstein .. .. | 8,215 | 282 | 3·4 | 37¼ | 10¾ |

The Holstein cow thus produced the cheapest milk, and the Guernsey cow the cheapest butter. If ordinary cheese is to be manufactured, the presence of an exceptional amount of fat in the milk is not desired, and is, in fact, uneconomical, as the fat demands more food to produce it than any other constituent of the milk.

The influence of diet on the production of milk and butter has been already considered (p. 203).

**Curdling.**—Healthy milk as it occurs in the cow's udder is free from the organisms which produce change; but in the operation of milking, and during subsequent exposure to air, bacteria, moulds, and yeasts find admission. 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 enzyme. Other ferments (enzymes), altering the condition of the albuminoids in milk, are produced by other species of bacteria. The presence of these enzyme-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 also enables the required products to be obtained before change has occurred. All micro-organisms may be destroyed by a boiling heat, and many by prolonged exposure to a temperature of 140° Fahr. Milk that has been heated for some time to the temperature of boiling water in a closed vessel is said to be *sterilised*. Milk that has been heated for twenty minutes to 158° Fahr. is said to be *pasteurised*. In pasteurised milk all organisms, save spores, have been destroyed, while the character of the milk is little altered.

**Cream.**—The fat of milk occurs in the form of globules; the largest are about ·0005 inch in diameter, the smallest may be one-tenth this diameter. The average size of the globules is different with different breeds of cattle; thus, they are considerably larger in the milk of the Jersey and Guernsey than in the milk of the Ayrshire or Holstein breeds. The Devons and Shorthorns hold an intermediate position. The large globules diminish in number as the time from calving increases. The fat of the milk globules, in a solid state, has a specific gravity of ·930, and in a liquid state, ·912; the serum in which the globules float has a specific gravity of about 1·038. The globules thus tend to rise to the surface, where they form a layer of cream. The rapidity of rise is greatest while milk is cooling, as the globules then still contain liquid fat. The largest globules are the first to rise, the smallest may never rise at all. The smaller is the globule the larger is its surface in proportion to its volume, and the greater the resistance to its rise. Milk containing an abundance of large globules is best for butter-making, as the cream then quickly and perfectly separates; but milk with small globules is probably best for cheese-making, as a more even distribution of fat throughout the curd is then obtained.

*Methods of Separation.*—Milk, when it leaves the cow, will have a temperature of about 90° Fahr.; if set for cream it should be cooled as quickly as possible, as changes in composition would rapidly occur at a high temperature. Milk is often 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 risen. Under these conditions a large surface is exposed, the milk receives a great 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.

A much better plan is to place the milk in metal pails, 16 inches deep, surrounded by cold water or 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 (when, consequently, the fat globules are small), 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 serum, being the constituent of highest specific gravity, is thrown to the outer side of the revolving vessel, while the fat globules rise into the centre of the 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 from the middle of the top, the latter by another pipe at 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.

*Composition.*—Cream varies very greatly 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—25 per cent. of fat. Cream obtained by ordinary shallow setting may contain 15—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—60 per cent. of fat. Generally speaking, thin cream will contain 15—25 per cent. of fat, and thick cream 30—50 per cent. The scalded Devonshire cream contains about 58 per cent. fat.

In cream which has not been partially dried while rising, the constituents other than fat exist in the proportion proper to the quantity of milk serum present; in cream that has dried, as that made on the Devonshire plan, the proportion of solids not fat is considerably increased. The following analyses are quoted from Droop Richmond:—

| | Water | Fat | Albuminoids | Sugar | Ash |
|---|---|---|---|---|---|
| Thin cream .. .. | 67·50 | 25·67 | 2·60 | 3·66 | 0·57 |
| Thick cream .. | 39·37 | 56·09 | 1·57 | 2·29 | 0·38 |
| Devonshire cream .. | 34·26 | 58·16 | 6·92 | | 0·60 |

*Ripening.*—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; this is especially the case when the cream is thin. The flavour of the butter also is altered, and to popular taste improved, by ripening the cream. The change is due to the action of micro-organisms, and the thickening is probably brought about by the curdling of the casein.

**Skim and Separated Milk.**—Milk thoroughly skimmed after shallow setting will still contain about 0·8 per cent. of fat, and more than this quantity is frequently present. With deep setting and ice the percentage of fat left in the milk will be 0·5—0·7. When the centrifugal machine has been employed the percentage will be 0·05—0·3. In the experiments at Geneva, U.S., it was found that, with deep setting, twice as much fat remained in the skim milk from Holstein cows as in that of Guernseys and Jerseys, owing to the slower rising of the small fat globules in Holstein milk. With the centrifugal separator the results are very similar whatever the source of the milk; the size of the globules has in this case little influence.

Skim milk obtained by shallow setting will contain in 100 parts 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. Separated milk will average water, 90·5; albuminoids, 3·6; fat, 0·1; sugar, 5·0; ash, 0·8 per cent. Skim milk is a very nitrogenous food, the albuminoid ratio being 1 : 1·8. In separated milk the ratio will be 1 : 1·3.

**Butter.**—*Churning.* 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 does not, however, aim at 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 desirable 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 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°—55° Fahr., or lower for quick churning; and sour cream at 58°—63°. When sour milk is churned for butter the temperature must be about 65°. Thick cream can be churned at a lower temperature than thin cream. 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 by the experience gained in the last working. In the recently introduced high-speed churns, the work is done by centrifugal action, and is accomplished in a very short time, and with little regard for temperature.

The temperature will rise several degrees during churning, work being converted into heat. The rise in temperature causes an expansion of the air in the churn, and it is popularly supposed that gas is given off by the cream. The agitation with air displaces a little carbonic acid held by the cream, but no new gas is produced.

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 better than butter made from sour cream; the latter always contains somewhat more albuminoids, and the process of change which leads to rancidity has already commenced. 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. The loss of fat in the buttermilk is least when the cream contains

25 — 30 per cent. of fat. In the experiments at Geneva, U.S., 91·0 per cent. of the fat in milk was obtained as butter from Guernsey, 89·1 from Jersey, 83·6 from Holderness, 82·3 from Devon, 79·1 from Ayrshire, and 74·6 from Holstein cows.

*Composition.*—Good fresh butter will usually contain 12—15 per cent. of water, and salt butter 10—16 per cent. Fresh butter will contain 84—87 per cent. of butter fat; the other solid constituents will be about one-tenth of the water if the butter has been unwashed, or less when washing has taken place. Salted butter will usually contain 1—2 per cent. of salt, but in very salt butter 4—7 per cent. may be present.

The chemical characteristics of butter fat which distinguish it from animal fats, and thus allow of the detection of adulteration, have been already mentioned (p. 226). 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 more perfect is the churning the smaller will be the percentage of fat left in the buttermilk. With good churning of ripened cream the percentage of fat in the buttermilk may be 0·3, or even less. When sweet cream is churned 1·0 per cent. of fat may be expected. The average composition of buttermilk from ripened cream will be about—water, 90·9; albuminoids, 3·5; fat, 0·5; sugar and lactic acid, 4·4; ash, 0·7. The albuminoid ratio would be 1 : 1·5.

**Cheese.**—*Manufacture.* 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 an enzyme called rennin, 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,[1] 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 106° Fahr.; above this point the action rapidly declines, and ceases at about 130° Fahr. The rapidity of curdling is in a direct proportion to the quantity of rennet added. Slightly sour milk is more quickly curdled by rennet than sweet milk, but the presence of an acid (lactic acid) is not essential to the curdling.

The composition of cheese depends greatly upon 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.

As cheese is usually made in the morning from a mixture of the evening and morning milk, one-half of the milk has already become sufficiently old to

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[1] According to modern investigators the curdling of milk by an acid consists in the precipitation of the unaltered albuminoid, caseinogen, originally present in the milk; rennet, on the other hand, splits up the caseinogen, precipitating the greater part of it as casein in combination with a small quantity of a calcium salt, while a small part, termed lactalbumin, or caseose, remains in solution in the whey.

develop a slight acidity. Acidification may be accelerated by adding a little milk which has already become sour; or it may be retarded by cooling the evening milk.

The temperature at which the milk is curdled is of great importance. For soft cream cheese, the temperature may be 65°—76°. For hard cheese, the temperature chosen will be between 80°—90° Fahr. When 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.

To ensure the regular manufacture of cheese of the same quality, the acidity of the milk and the temperature of curdling must be kept uniform, and the strength of the rennet must be known, so that curdling may occupy always the same time. Rennet solutions diminish in power by keeping.

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 allowed to remain till it has developed a certain amount of acidity. 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 fat. 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 on a cloth or frame.

Reckoning the fresh cheese which goes into the cheese-room to contain about 36 per cent. of water, the products from 100 lbs. of normal milk will be as follows :—

| | Total Produce | Water | Albuminoids | Fat | Sugar, &c. | Ash |
|---|---|---|---|---|---|---|
| | lbs. | lbs. | lbs. | lbs. | lbs. | lbs. |
| Cheese .. | 10·40 | 3·94 | 2·57 | 3·59 | 0·17 | 0·13 |
| Whey .. | 89·60 | 83·16 | 0·83 | 0·31 | 4·68 | 0·62 |
| Milk .. | 100·00 | 87·10 | 3·40 | 3·90 | 4·85 | 0·75 |

As the period of lactation advances more cheese can be made from the same weight of milk, as the proportion of both casein and fat is increased. The loss of fat in the whey is no greater with rich milk than with poor if proper care is taken.

*Ripening.*—Cheese ripens quickest at a moderately warm 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. A considerable amount of chemical change takes place in the albuminoids, a part of the casein becoming soluble in water, albumose and peptone, with the amides, leucin and tyrosin, being formed ; in a later stage ammoniacal compounds may be produced. In experiments made at

Geneva, U.S., the fresh cheese, when placed in the cheese-room, had 6—7 per cent. of its albuminoids soluble in water; at the end of three weeks, at a somewhat high temperature, over 20 per cent. were found to be soluble. In another series of experiments the fresh cheese contained 4·2 per cent. of its albuminoids soluble in water, and at the end of five months 35·5 per cent. of the nitrogenous matter was in a soluble state. Of the total nitrogenous matter 89 per cent. was still albuminoid, while 11 per cent. had passed into the condition of amides or ammoniacal compounds.

The earlier changes which occur in the casein of cheese, before putrefaction sets in, are quite similar to those taking place in the process of animal digestion. It was at first supposed that these changes were brought about by bacteria, but it is now believed that they are due to an enzyme naturally present in milk; the presence of this enzyme was first ascertained by Messrs. Babcock and Russell. It has been shown that cheese will ripen at a temperature near freezing, and in the presence of substances which suspend the action of bacteria. When cheese is in an advanced stage of decomposition, fungi and bacteria become the chief chemical agents, and carbonic acid, water and ammonia the ultimate products.

The fat of cheese undergoes little change during ripening, but some of the neutral fat is decomposed and butyric and other fatty acids are liberated. It was once believed that fat was produced from albuminoids during the ripening process; this is not the case. The percentage of fat rises as the cheese gets older, owing to the loss of water and other products of

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decomposition, but the absolute weight of fatty acids remains the same. Young cheese contains a small quantity of lactic acid.

*Composition.*—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 cheese intended to ripen early and develop mould.

The chemical composition of cheese exhibits great variations, the differences, both in the original composition and in the alterations due to age, being very considerable. Soft cheese contains most water, usually 40—50 per cent. Skim milk cheese may also reach 40 per cent. of water. Ordinary Cheddar will contain 27—34 per cent. The percentage of fat depends, of course, on the materials employed. Cream cheese may contain 50—60 per cent.; Stilton, 35 per cent., or more; Cheddar and Cheshire, 24—33 per cent.; Gloucester (made from partly skimmed milk), 22—25 per cent.; Skim milk cheese, 17 per cent.; and cheese from separated milk, 1 per cent. The percentage of casein is determined by the percentages of water and fat present; in Cheddar and Cheshire it will be 24—36 per cent.; in skim milk cheese it may exceed 40 per cent. Cheese generally yields about 4 per cent. of ash; skim milk cheese, 6 per cent. A great part of the ash consists of common salt.

**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, considerable 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, 93·3; albuminoids, 0·9; fat, 0·3; sugar and lactic acid, 4·9; ash, 0·6. The albuminoid ratio is 1 : 5·7.

**Annatto.**—This is prepared from the pulpy coating of the seeds of *Bixa Orellana*. The orange colouring matter is soluble in alkalies 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 utensils should be washed with hot water as soon as done with, to destroy any adhering ferments. Every vessel containing milk, or its products, should be covered in order to protect it from dust. Without such precautions no good butter or cheese can be made.

# APPENDIX.

## NEW NITROGENOUS MANURES.

The manurial sources of nitrogen have during the last few years been supplemented by two methods of bringing the nitrogen gas of the atmosphere into combination, and the products are now becoming factors of importance in the fertilizer market. Speaking broadly, there are two ways of bringing nitrogen into combination: firstly, at extremely high temperatures, such as are attained in the electric arc or sparks, nitrogen will combine with the oxygen also in the air to produce oxides which yield nitric acid on absorption with water; secondly, nitrogen will combine with a few metals and allied bodies to yield compounds which under the action of water give rise to ammonia. It has been this latter method that has first been developed on a commercial scale by Frank and Caro, of Berlin; they started with the calcium carbide which is so well known as a source of acetylene gas for illumination, and found that it would combine with nitrogen gas at quite moderate temperatures. The resulting product is now on the market as nitrolim, or calcium cyanamide, and large factories have been established for its production on a vast scale in Italy, Norway, Savoy, America, &c., where cheap water-power for the electrical manufacture of calcium carbide is available.

Nitrolim is a very fine dark grey powder, smelling somewhat strongly of the acetylene which is given off from a trace of calcium carbide it still retains. The more recent improvements in its manufacture have eliminated this impurity and also have done much to remove the dustiness which made the earlier product somewhat difficult to handle in the field. When nitrolim is applied to the soil it is attacked by the water present and becomes converted into ammonia on the one hand and carbonate of lime on the other. Experiments have shown that the change goes on pretty quickly, so that the nitrogen is readily available to the plant; its value, nitrogen for nitrogen, appears to be but little below sulphate of ammonia. The composition of the output from the works is not quite uniform as yet, but as a rule it contains about 18 per cent. of nitrogen, and is in consequence almost as concentrated a fertilizer as sulphate of ammonia. In considering the value of nitrolim the carbonate of lime which it produces in the soil should be taken into account, as well as the 20 per cent. or so of free quicklime which it also contains. Nitrolim is therefore a basic manure and is well suited for soils that are sour or heavy and require lime—just the soils, in fact, on which sulphate of ammonia gives poor results. It is desirable to sow nitrolim some short time before the seed, so that it may get incorporated with the soil and decompose before coming in contact with the germinating seedlings. When used, therefore, for barley, turnips, or root crops it should be sown previous to the last working of the land preparatory to seeding. It should not be used as a top dressing for corn crops, but it can be successfully sown on grass land early in the year—

in February or early March. It can be mixed with superphosphate, and a mixture of about eight parts of superphosphate to one of nitrolim makes an excellent turnip manure which can be sown from the drill with the seed, but during the mixing a good deal of heat is developed. The mixing is, however, quite safe, and the heat can be diminished by sprinkling the mass with water.

The electrical method of bringing the nitrogen and oxygen in the air into combination by means of the intense temperature of the arc is now the basis of two or more working processes. In the Berkeland-Eyde process air is blown through an intensely heated flat flaming arc and the combined gases which issue are absorbed by water and lime, with the eventual production of a nitrate of lime containing rather more than 13 per cent. of nitrogen. This nitrate of lime is now being turned out on a large scale from a factory at Notodden in Norway, and other works are in contemplation. Nitrate of lime is a rather coarse white powder which absorbs water rapidly from the air, and if left lying loose in a damp place will take up so much moisture as to liquefy. As a source of nitrogen it behaves exactly like nitrate of soda; it can be used in the same way and for the same crops as nitrate of soda, and will, nitrogen for nitrogen, give the same returns. Being rather less rich in nitrogen (13·5 per cent. against 15·5 per cent.), about 8 lb. must be reckoned as the equivalent of 7 lb. of nitrate of soda, 128 lb. in place of a hundredweight of nitrate of soda. The fact that in the new fertilizer the nitric acid is combined with lime and not with soda will be of value on many soils, especially on those of a heavy and retentive nature where the use of nitrate of soda is apt to result in a bad texture of the surface. Nitrate of lime will undoubtedly become a very valuable fertilizer, one, again, which acts as a basic substance, and is therefore valuable on sour soils.

These new nitrogenous fertilizers, the number of which will certainly be soon increased, have been proved to be of real value; they belong to the active sources of nitrogen and are to be ranked with nitrate of soda and sulphate of ammonia and valued on the same basis. Which of the four the farmer should buy may be settled in the main by the price per unit of nitrogen, though the nature of the crop and the soil should also be considered. Barley and turnips answer better with nitrolim and sulphate of ammonia, though the latter should be avoided on soils short of lime or where finger and toe prevails. The nitrates are better for wheat, mangolds, and grass, and nitrate of lime should have the preference on very heavy working soils.

# INDEX.

See page 244 for Appendix.

THE END.