SCIENCE IN AGRICULTURE

A DISCUSSION OF SCIENTIFIC PRINCIPLES IN THEIR RELATION TO FARM PRACTICE (ADAPTED FOR THE USE OF SCHOOLS AND COLLEGES)

BY

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PREFACE

IN a recent address to teachers the Parliamentary Secretary to the Board of Education stressed the importance of maintaining the rural outlook in country schools. "While tariffs, subsidies, and marketing boards," he added, "were important, let them not forget that the basis of all true agricultural reconstruction was the intelligent human being, and the maintenance of a rural culture which made a prosperous agriculture so valuable to the country as a whole."

One must agree with this. He did not suggest, nor is it feasible, to attempt the teaching of practical agriculture in schools. But much could usefully be done to develop the rural outlook by *implication* while teaching ordinary subjects. In arithmetic, for example, sums might often be based on rural or farming problems without lowering the value of the lessons. But perhaps the widest opportunity for suggesting the importance and dignity of country life occurs in those schools which aim at giving some science training.

The opportunity to do this has improved because of modern doubt as to whether concentration on one single science in a school yields the best educational results. There is a growing tendency to broaden the basis of science teaching in the secondary schools of this country. Syllabuses of instruction in Nature Study, or in General Science, are frequently adopted, and well-planned courses of that kind can have high educational value. But abstract teaching of Nature's laws is apt to be dull. For many it seems to lack definite objective or point, and the enthusiasm of the pupil lags.

It is here that Agriculture comes in. Most of the pure sciences have a bearing upon farming pursuits, and there seems no reason why students at our secondary schools and colleges should not receive their mental training from the study of agricultural science as well as from, say, biology, or from "physics plus chemistry." Educationally, and when properly handled, it is as good as any of them, while the declared utilitarian purpose of its lessons broadens the outlook of its students and keeps its science alive. And it carries, in addition, two public advantages of no mean order. If the student subsequently goes on the land it will be of vocational advantage to him ; through those who will follow other pursuits it will help to augment public interest in, and respect for, what after all is our oldest and most important industry.

This book deals with the scientific basis of farming on lines intended to convey a fairly wide grounding in general science. It presupposes hardly more knowledge of farming than what is common property. Its teaching is concerned *not with how* things are done *but with why* they are done. This line of treatment has been followed deliberately. If the text is carefully followed, then previous study of agricultural science is not required by the teacher. The lessons should be accompanied by appropriate laboratory exercises which any science teacher can easily plan. Not too much time should be occupied with garden plots or pot cultures, because the educational gain is liable to be incommensurate with the time required.

It may reassure the reader to know that in recommending agricultural science as a basic subject for secondary-school work the writer is not without experience. While in Australia thousands of examination papers for the University Public and Matriculation examinations passed through his hands, while his book there, entitled " Nature in Farming," which was adapted for the rural conditions in that country and New Zealand, is now in a fourth large edition.

This is an English book, and the writer farmed in this country for seven years before going abroad. It is hoped that the book, from its division into so many chapters, may also serve as a handy book of reference to farmers. As a rule each chapter begins a new subject from the beginning. There are many isolated points in theory which the practical man will often wish to understand, and as a rule he will easily find them from the Index.

J. W. P.

LONDON, 1938.

NOTE TO SECOND EDITION

The text has been carefully revised and necessary minor adjustments have been made.

J. W. P.

September 1944.

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SCIENCE IN AGRICULTURE

CHAPTER I

THE ATMOSPHERE

THE atmosphere has "**weight.**" If a thin glass flask furnished with a stop-cock be partially exhausted by lung suction it will weigh appreciably less than it did before. Under normal conditions, 5 gals. of air weigh just over 1 oz. A building measuring about 70 ft. by 40 ft. and 10 ft. high contains 1 ton of air.

Owing to its weight the atmosphere presses upon the earth's surface. It extends to a height of several hundred miles. If we ascend vertically the pressure of the air becomes less, because the weight of air at lower levels does not affect us. At a height of 18,000 ft. the atmospheric pressure is only abont one-half as great as it is at sea-level.

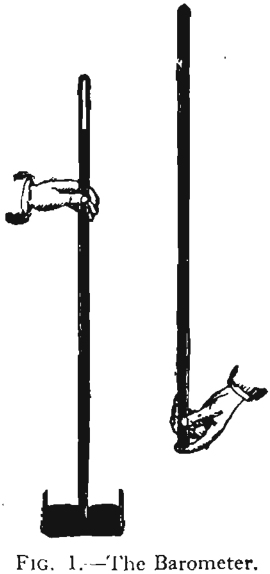


FIG. 1.—The Barometer.

Atmospheric pressure is measured by the **barometer.** Fig. 1 shows a simple form of barometer. It consists of a stout glass tube about 36 in. long, and closed at one end. The tube is filled with mercury (quicksilver) and is then inverted in a vessel containing the same liquid while keeping the open end closed. On releasing the open end the mercury does not all run down, because the pressure of the air outside the tube prevents this. If there were no air, the mercury would reach the same level outside and inside the tube. At sea-level the pressure of the atmosphere gives a difference of about 30 in. between the levels of the mercury outside and inside the barometer tube.

The empty space above the mercury in the barometer tube contains no air. It is named the *Torricellian vacuum*—after Torricelli, who invented the barometer. If air be freely admitted to the Torricellian vacuum the mercury immediately takes the same level outside and inside the barometer tube.

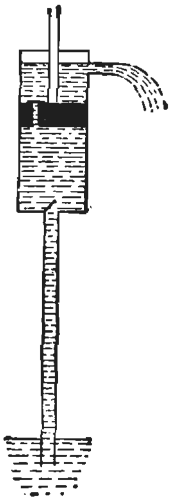


FIG. 2.—Suction Pump.

A column of mercury 1 sq. in. in section and 30 in. high weighs 14·75 lbs. The pressure of the atmosphere, therefore, when it can support a mercury column of 30 in. in height, equals 14·75 lbs. per sq. in. This equals 14·75 lbs. × 144, or 19 cwt. (nearly) per sq. ft. This pressure, however, is not inconvenient, because it is exerted equally on all sides of us and also from the inside.

Bulk for bulk, mercury is 13·6 times heavier than water, and hence the atmosphere can support a column of water in a closed tube which is 13·6 times higher than 30 in. The water barometer, therefore, would stand at 34 ft. when the mercury barometer stood at 30 in., and 34 ft., therefore, should be the height to which water will rise in a closed tube when all the air has been pumped out. In an ordinary **suction pump** (Fig. 2), owing to imperfect exhaustion of air and other reasons which it is not necessary to discuss, the water cannot be raised to the full height of 34 ft., but good results are easily obtained up to 20 ft.

The **siphon** is another device for raising water which takes advantage of atmospheric pressure. In the siphon (Fig. 3) the tube must first be filled with water in order to exclude the air, and the outer limb of the tube must stand at a lower level than the surface of the water supply inside. Animals take advantage of air pressure in drinking, and most artificial milking machines depend upon

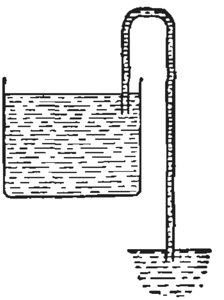


FIG. 3.—The Siphon.

atmospheric pressure, which in their case is exerted from inside the udder of the cow.

As the atmosphere has weight it can be investigated by the chemist. The **chief constituents** are free oxygen and free nitrogen gas, which are present in approximately the following proportions :—

TABLE I

Chief Constituents of the Atmosphere (per Cent.)

	By Weight.	By Volume.
Free oxygen gas . .	23	21
,, nitrogen gas[1] . .	77	79
Total . .	100	100

The oxygen gas forms a rather higher percentage by weight than by volume, because bulk for bulk it is a somewhat heavier gas when weighed under similar conditions.

Water dissolves many substances. Generally speaking, solids dissolve better in hot water and gases dissolve better in cold water. The oxygen and nitrogen of the atmosphere are slightly soluble in water. At the ordinary temperature, 100 gals. of water can dissolve 3 gals. of oxygen and 1½ gals. of nitrogen gas. When the water is boiled the gases are expelled and may be collected. The mixture collected will contain more oxygen than ordinary air. The fact that water does not dissolve the oxygen and nitrogen in the same proportions in which they are present in air gives us one of the proofs that in the air these gases are not chemically combined with each other, but are free gases.

Free **oxygen** is a colourless gas, and has no smell. The free oxygen of the atmosphere is necessary for combustion, as in fires and in the respiration of both plants and animals.

Free **nitrogen** is also a colourless gas without smell. In the atmosphere it serves to dilute the oxygen, and thus prevents a fire from burning away too quickly, or animals from becoming too vivacious. Free nitrogen, indeed, does not enter readily into chemical combination, and while free oxygen is very ready

[1] This "nitrogen" includes a little *argon*—here unimportant.

to unite with other things, free nitrogen has not this property. Plants require nitrogen in their food, but although the air contains so much nitrogen, they cannot use it because it is free nitrogen. They can use only nitrogen which had already become combined with other things, and this they get from the rotting remains of dead plants which contained combined nitrogen. Farmers often gladly pay 4d. per lb. for combined nitrogen in fertilisers, although there are thousands of tons of free nitrogen in the atmosphere resting upon their farms. Combined nitrogen is so expensive because the free nitrogen of air is very unwilling to combine with other things, and plants require combined nitrogen.

Besides free oxygen and free nitrogen, the atmosphere always contains small quantities of a number of other things not included in Table I. Important among these are the:

Carbon dioxide;
Water vapour;
Dust particles.

The **carbon dioxide,** or carbonic acid gas, is present to the extent of only 3 or 4 vols. per 10,000 of air. Nevertheless, from this source crops form by far the greater portion of their dry substance. Although the free nitrogen of air does not contribute to the feeding of ordinary crop plants, the carbon dioxide is very important indeed. It is always present in air, and its presence there can be shown by exposing a vessel containing clear lime water; a white skin of carbonate of lime will be formed. Carbon dioxide is produced from ordinary fires and in respiration, but these matters will be considered in another chapter.

The **water vapour** varies more in amount than the other constituents—sometimes it may form 2 to 3 per cent.; at other times there is very little indeed. Warm air is able to hold more water vapour than is cold air, and the presence of water vapour can always be shown by placing a glass of chilled water in a warm room. Water condenses on the outside of the glass. The atmosphere rarely contains as much water vapour as it could hold at the existing temperature; when it does there is no use in hanging out articles to dry.

The **dust particles** are solid, and include both living and dead particles. Both kinds are always present in large numbers over land surfaces, and particularly in inhabited places. The living particles include bacteria and their spores—some of which cause infectious diseases in man and the lower animals; others cause putrefaction and decay in dead matter like meat and milk. The dead particles of dust are important in the formation of fog and cloud from the water vapour of the atmosphere, and without suitable dust particles there would be no rain as we know it. The dust particles are mostly very small, and usually number several hundred millions per gallon of air.

CHAPTER II

COMBUSTION AND RESPIRATION

IN the previous chapter we saw that the atmosphere contains over 20 per cent. of free **oxygen** gas. This oxygen plays a necessary part in the burning of fires and the respiration of animals. It is available for this purpose because it is free oxygen.

Free oxygen is not united to any other element. There are about ninety different chemical elements—such as hydrogen, nitrogen, carbon, sulphur, phosphorus, magnesium, iron, copper, etc. Free oxygen can unite with almost any one of the other elements, and then an **oxide** of the other element is formed. In this way oxide of hydrogen (water), oxide of carbon, oxide of iron, etc., are produced. When this occurs the other element is said to undergo *oxidation*. Oxidation is an instance of chemical change.

When oxidation of another element takes place there is, as a rule, a considerable amount of **heat** evolved. This is always the same for the same element, but different for different elements. Thus when 1 lb. of carbon is fully oxidised, sufficient heat is produced to raise 14,550 lbs. of cold water through 1° F. The same amount of heat is produced whether the oxidation be slow or rapid. In the former case a lower temperature will prevail for a long time; in the latter, owing to the more rapid evolution of heat, a higher temperature will prevail for a short time. An example is seen in the blacksmith's forge.

Combustion is a form of oxidation. In combustion, rapid oxidation takes place—the high temperature attained producing light and intense heat.

Oxidation usually takes place most quickly when the substances are hot. When phosphorus is exposed to air, the oxygen of the air at the ordinary temperature slowly begins to oxidise the phosphorus. As the oxidation proceeds, the unburnt phosphorus may melt and finally catch fire owing to the heat produced from the earlier oxidation. As a rule, however, it is necessary to apply external heat to a substance before combustion will start.

Coal and charcoal are fairly pure forms of carbon. Before these will begin to burn in air, their temperature must be raised. The fire must be lighted. The same is true for most of the other elements. Each of them has a **temperature of ignition,** or a temperature above which alone it will begin to burn in air.

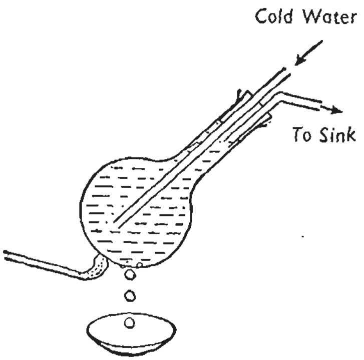


FIG. 4.—Burning Hydrogen to form Water.

When carbon, hydrogen, or sulphur has once been raised above its temperature of ignition in air, then the heat produced from the burning is sufficient to raise the next unburnt portion of the substance past its temperature of ignition. In these cases the combustion is continued until the raw material is exhausted, and the combustion process in the matter of temperature is thus self-supporting. Iron will burn in air when its temperature has been sufficiently raised, but the heat from the burning is here insufficient to maintain the temperature of the unburnt iron above ignition point. In order to burn iron in air it is necessary to keep "lighting" it.

The free nitrogen gas of the atmosphere takes no part in the burning of fires. It passes through the fire unchanged except that it becomes heated in the process. The effect, therefore, is to cool the fire by taking heat from it. As would be expected, a much higher temperature can be reached by burning in pure oxygen. A glowing wood splinter will burst into flame in pure oxygen, and a piece of iron will go on burning without the application of external heat.

As oxygen unites during combustion with the substance burnt, it may be said that the oxygen is burnt equally with the other substance. This is true. In an *ordinary* fire, however, attention is drawn rather to the coal or wood than to the atmospheric oxygen, because while the coal has to be carried, the air comes of its own accord.

Organic substances include things like wood, starch, sugar, fat, alcohol, etc.—the class of substances which are formed by plants and animals. These are not elements, but are compounds of carbon with hydrogen and only a little oxygen. They contain too little oxygen to oxidise fully their carbon and hydrogen, and they can therefore unite with more oxygen from the air. This happens when they are burnt.

Any of the organic substances named will go on burning in air after being raised to its *temperature of ignition*. In each case a definite amount of heat will be liberated for each 1 lb. of the material burnt. Each of them might not be an economical fuel, but that does not alter the facts.

Combustion is a rapid oxidation, and it proceeds from a purely chemical motive. In the case of organic substances, the motive is the tendency of the carbon and hydrogen of the materials to become more fully oxidised.

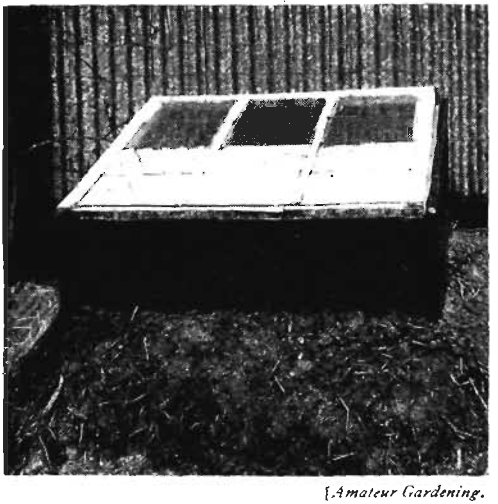
Respiration is a slow form of oxidation. *Respiration* is a vital necessity for plants and animals. In respiration, the sugars, fats, etc., are slowly oxidised—their carbon forming oxide of carbon, and their hydrogen forming oxide of hydrogen. From such changes the animal heat is maintained. In respiration, exactly the same amount of heat is produced from 1 lb. of sugar which the animal had eaten, as if the material had been burnt on a fire.

While the final results of respiration are identical with those of combustion, the slower form of oxidation has a *different* motive. This is seen from the fact that it continues in a living organism at a temperature far below the temperature of ignition of the same substance in air. Respiration is a vital phenomenon and ceases when the *plant or animal* dies.

Fishes and water-plants are able to respire because oxygen is slightly soluble in water.

Fermentation and decay are oxidation processes somewhat similar to respiration. As a result sugar, starch, or vegetable residues as in soils, gradually disappear, forming an oxide of carbon and oxide of hydrogen. To attain this result atmospheric oxygen is generally required. Heat is evolved from the decay of organic substances, and for each to the same extent as in combustion and respiration. The heat in a manure heap is the result of oxidation (Fig. 5) as the materials decay.

Decay of wood, starch, and organic rubbish generally, occurs below the temperature of ignition of these substances in air. In this respect it resembles respiration. Decay and putrefaction of organic materials are indeed caused by bacteria or other low forms of life which attack the materials for their own use in



[*Amateur Gardening*.

FIG. 5.—Gardener's Hotbed.

order to feed upon them. If the materials are sterilised by boiling, or by disinfectants, then those living things are killed, and, of course, decay at once stops. An example is seen in tinned meat.

The oxide of carbon formed during combustion, respiration, and the various processes of decay is termed **carbon dioxide** or carbonic acid gas. Faraday long ago estimated the total production of carbon dioxide from the sources named at 3½ million tons per day. In this way fresh supplies are continually added to the atmosphere. Its presence there has already been noted (Chap. I.), and its importance in the life of the plant we shall consider at another time.

CHAPTER III

THE PLANT: STRUCTURE

THE ordinary crop plants of the farmer all form seeds. They belong to the large group of plants known as Seed Plants or *Spermaphyta*. Ferns, mosses, and the fungus group of plants do not form true seeds, but they have other methods of propagation.

A typical seed plant is made up of root, stem, and leaves. The roots grow downward into the soil, whence they abstract water and certain food materials, while the stems and leaves are usually borne above-ground, and serve in various processes of nutrition and reproduction.

A **seed** consists of the outside coats, and contains inside an *embryo* or baby plant. The root, stem, and leaf of the mature plant are already distinguishable in the embryo within the seed, but naturally in a diminutive form.

The first leaf of the young plant within the seed is termed the **cotyledon.** There may be either one or two of these cotyledons, according to what particular plant we are dealing with. The number of cotyledons borne on the embryo is used to separate the main division of Seed Plants into two great classes. In *Monocotyledons* only one seed leaf is present, and in *Dicotyledons* there are two. To the former belong the cereals, grasses, onion, lily, etc., while mangels, rape, and beans are dicotyledonous plants.

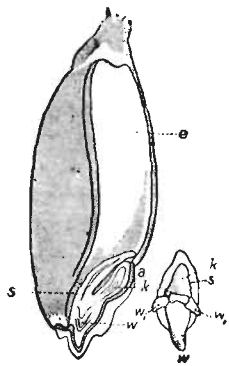


FIG. 6.—Section of Wheat Grain (Enlarged).

e, food material; *k*, embryo (on the right, the embryo *k*, removed from the grain); *w*, *w'*, primary roots, and *a*, the stem—all covered by sheathing leaves; *s*, the single cotyledon (scutellum).

In seeds, besides the embryo there is always contained a store of **foodstuffs** to sustain the young plant when it begins to grow. In wheat (Fig. 6) and other monocotyledons this food supply lies outside the embryo but in contact with it, and on germination it is absorbed through the single cotyledon which acts here as a sucking organ. In dicotyledons the food supply

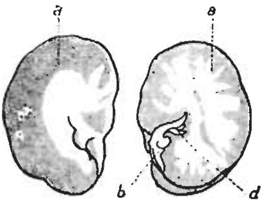


FIG. 7.—Seed of Bean (Dissected).

a, *a*, the two fleshy cotyledons ; *d*, the young stem ; *b*, the radicle or root of the embryo.

is often contained in the fleshy leaves of the embryo itself, which then occupies the whole cavity of the seed. This happens (Fig. 7) in the bean. The difference, however, is chiefly one of form, and in both cases the food supply of the seed is available to nourish the young plants, or when required, to serve as the food of animals.

In a dry seed the life is dormant. For **germination** to take place there is required a suitable degree of—

(1) Moisture. (2) Air.
(3) Warmth.

Under these conditions the food materials are dissolved and absorbed by the living embryo, which then awakens to active life. The root and shoot protrude through the seed coat—the former bending downwards in obedience to gravity, while the shoot grows upwards in opposition to it.

The Root.—In roots, growth takes place just behind the tip. In order to protect the growing point from mechanical injury while forcing its way through the soil, there is formed just in front of it a *root-cap* (Fig. 8), which undergoes constant renewal as it gets worn off. As a rule roots are furnished with numerous *root-hairs*, which arise from the surface of the root at some little distance behind its tip. It is through those hairs that the plant draws water (Chap. XXV.) and nourishment from the soil.

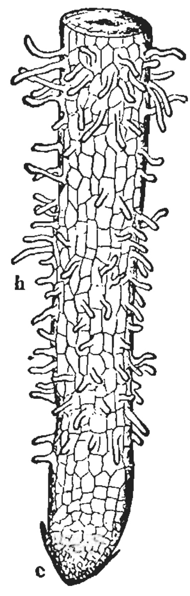


FIG. 8.—End of a Root (Enlarged).

c, root-cap ; *h*, root-hairs.

The first root which emerges from the seed is called the primary root, or *tap-root*. In dicotyledons such as the bean, the tap-root often attains a considerable size and sends out branches. In monocotyledons—*e.g.*, wheat—the tap-root does not persist, but, as substitute, a large number of fine *adventitious roots* are developed from the nodes or knots at the base of the stem.

These fine roots branch freely, and in suitable soil may reach to a depth of 5 or 6 ft. In one case measured, the aggregate length of the roots from a single wheat plant is said to have totalled 1,704 ft.

Functions.—Roots serve to *fix the plant* in the soil, and also enable it to *draw nourishment* therefrom. But sometimes they perform *other duties*. In the turnip, carrot, and other "root crops," the root is thickened to serve as a storehouse of food for future use (Chap. XXXV.).

The Stem may be defined as an axis bearing leaves. The leaves arise at the *nodes*. Stems usually grow upwards, and

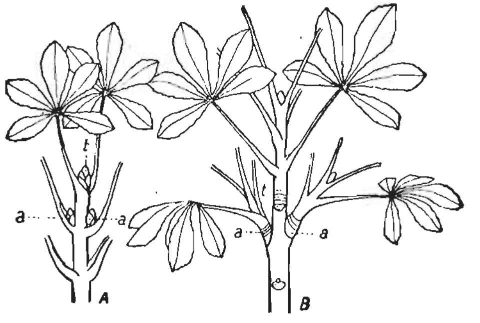


FIG. 9.—Branch Bearing Leaves.

A, the first; *B*, the following year of development. In *A*, the lateral buds (*a*), formed in the axils of leaves, have by next year (*B*) developed into branches, while also a new terminal shoot has arisen at *t*.

only the base of the stem is buried in the soil. When branches are formed on a stem these usually spring from *buds* (Fig. 9) in the *axils* or angles formed between the leaf and the *internode* of the stem above it. Buds, however, do not necessarily develop into branches, and many remain dormant for years unless excited to growth by the destruction of other buds. This is well seen in street trees which have been lopped or pollarded. In the tillering of wheat or oats, side shoots may be developed from any node covered with soil. As a rule the thinner the seeding and the better the soil, the more new stalks will be thrown out from the lower nodes of a young cereal plant.

The chief **functions** of the stem are to *support the leaves*, and to act as a *channel of communication* between the roots and the leaves. This communication is carried on through the *fibro-vascular bundles*. These bundles consist of elongated vessels of various shapes and of two distinct kinds—those conducting upwards being the *xylem* or wood portion of the bundle, while those conducting downwards form the *phloëm* or bast. In monocotyledons the bundles have a scattered arrangement (Fig. 10), while in dicotyledons they form a ring.

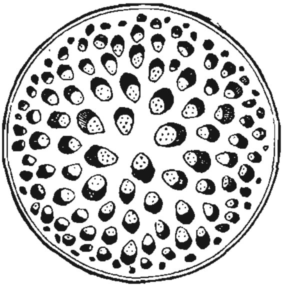


FIG. 10.—Transverse Section of Stem of Maize (Enlarged), showing scattered arrangement of fibro-vascular bundles.

Sometimes stems are **altered** for a special purpose. The potato *tuber* is a thickened underground stem (Chap. XXXV.) formed for food storage, and as a stem it forms buds (" eyes ") in the axils of small leaves,

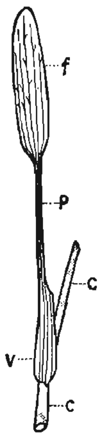


FIG. 11.—A Complete Foliage Leaf.

f, lamina or blade ; *p*, petiole or stalk ; *v*, vagina or sheath ; *c*, *c*, portion of stem.

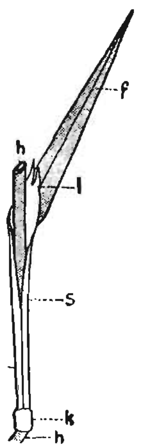


FIG. 12.—Leaf of Grass.

h, *h*, portion of stem ; *k*, node ; *s*, leaf sheath ; *f*, lamina ; *l*, ligule.

which, however, are inconspicuous. The underground stems or *rhizomes* (Fig. 14) of couch grass enable the plant to spread vigorously on open ground.

The Leaf.—The typical leaf consists of three parts as indicated in Fig. 11. The three parts are not, however, developed in all leaves. Thus in cereals and grasses, the stalk or *petiole* is wanting. In many plants—*e.g.*, pea—flat leaf-like growths called

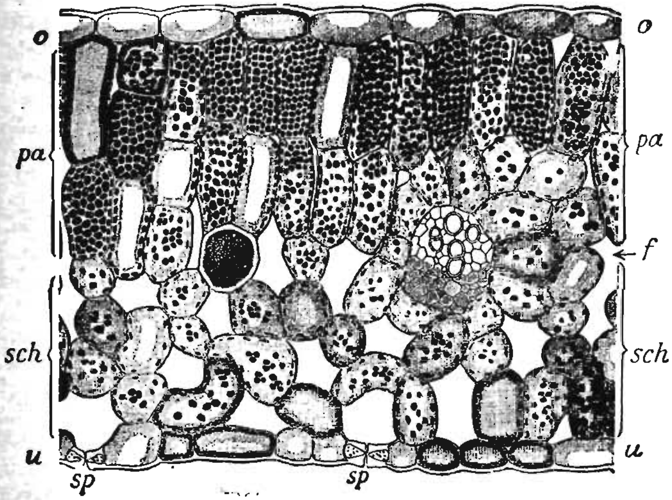


FIG. 13.—Transverse Section of Leaf of Sugar Beet (Highly Magnified).

o, epidermis of upper surface; *u*, of under surface; *pa*, long cells containing chlorophyll; *sch*, loose tissue with air spaces; *f*, points to a vascular bundle; *sp*, stomata.

stipules are formed at the base of the leaf stalk. The *ligule* is a white membranous growth formed at the junction of the *lamina* and *sheath* in many species of grasses (Fig. 12). Leaves may either be *simple* as in grasses, or *compound* as in clover or vetches. The compound leaf of clover is composed usually of three *leaflets*.

The vascular bundles from root and stem are continued into the leaf where they form the *veins*. There are two principal kinds of *venation*. In dicotyledons the veins form a network pattern, while in monocotyledons, such as grasses, they are arranged in parallel lines.

The internal structure of the **leaf** is adapted to **its use** as the chief centre of the plant's manufactures. It has been described as the chemical laboratory of the plant. Fig. 13 is a photograph, highly magnified, of the interior of a leaf. It is sufficient to notice generally the parts at this time ; their uses will be referred to more fully later on.

Leaves may be **modified** for some special purpose. In the *bulb* (Fig. 16) there is a short underground stem which bears a number of white fleshy leaves whose function it is to store up food for future use.

In the *flower* special leaves are developed for the purpose of reproduction.

CHAPTER IV

THE PLANT: REPRODUCTION

THE production of new individuals among the higher plants commonly takes place by one of two methods. In the one case there is reproduction by vegetative parts, and in the other reproduction by the formation of seeds. The former is a non-sexual, and the latter a sexual process.

Vegetative reproduction is notably common both among wild and cultivated plants. In this case a shoot, or any part of the old individual which will develop root and shoot under favourable conditions, gives rise to a new plant. The method is followed in striking cuttings, *e.g.*, of geraniums, which throw out adventitious roots at the nodes which have been planted in the ground. In growing potatoes we have another instance of vegetative reproduction—roots and shoots being developed from the buds of a thickened underground stem. The potato tuber is in no sense a seed. Couch grass (Fig. 14) propagates itself, giving rise to new individuals by *underground* stems (rhizomes), and the strawberry (Fig. 15) develops *surface* stems or runners (stolons) which take root at some distance from the parent plant. Bulbs (Fig. 16) furnish examples of vegetative reproduction common in the Lily order of plants. The operations of budding and grafting in fruit trees are methods of producing new individuals from the old without having recourse to seed.

FIG. 14.—Underground Stems or "Rhizomes" of Couch Grass (Reduced), showing production of roots and shoots from the nodes within the soil.

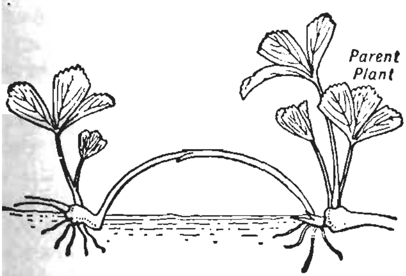


FIG. 15.—"Runner" of Strawberry.

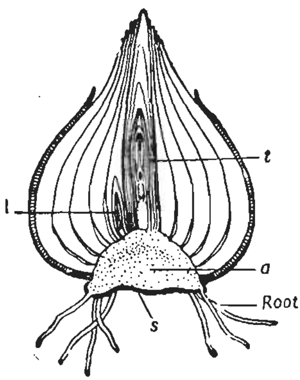


FIG. 16.—Section of Bulb.

a, short stem bearing numerous fleshy leaves and adventitious roots from *s*, its undersurface; *t*, terminal bud which will subsequently elongate, forming a green shoot; *l*, lateral bud.

In vegetative reproduction the new plant is simply a continuation of a single parent, and, apart from stray instances of bud variation, the grower knows exactly what he has got. There is no danger of hybridisation or the development of undesired characters as may result from crossing. Nor does there always appear to be any deterioration involved where vegetative reproduction has been repeated through many generations. The date and fig have not been grown from seed for centuries. Moreover, the vegetative method affords with many plants a considerable saving of time, *e.g.*, in favourable damp situations willow poles 20 ft. long will produce fine trees in a few years.

Reproduction by Seed.—Here an entirely new individual is formed by the fusion of the sexual cells of two parent plants.

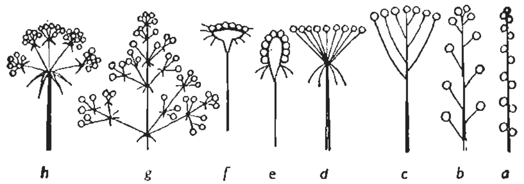


FIG. 17.—Forms of Inflorescence.

a, spike ; *b*, raceme ; *c*, corymb ; *d*, umbel ; *e* and *f*, capitula ; *g*, panicle ; *h*, compound umbel.

The *flower* is the part of the plant which is formed for seed production.

A seed is always preceded by a flower. The flower may arise as a single flower upon a stalk as in the snowdrop or lily. In many cases, however, a number of flowers spring from a common stalk giving an **inflorescence.** The form of inflorescence varies in different plants, and Fig. 17 illustrates some of the chief forms found in farm plants. In rape and turnips the inflorescence is a *raceme*, and in the plantain—a *spike*. Similarly, the head of the dandelion and sunflower is not a single flower but a *capitulum* containing a great number of small flowers. Compound forms of inflorescence are also found—wheat gives a *compound spike* (Chap. XXXIII.), and oats a kind of raceme which is often termed a *panicle*.

A **flower** may form part of an inflorescence, or it may occur on an independent stalk. In either case the typical flower contains four sets of leaves. Working towards centre these are the

(*a*) Sepals. (*c*) Stamens.
(*b*) Petals. (*d*) Carpels.

The position of the parts of a flower is represented in Fig. 18.

The *sepals* and *petals* are not directly concerned with reproduction and form the **non-essential parts,** or *perianth*. Taken together the sepals form the *calyx*, and the petals form the *corolla* of the flower. The corolla is usually coloured, while the calyx is often green and firm in texture, remaining on the flower-stalk after the petals have fallen away. The number and position of the parts of the flower varies in different orders of plants, and forms the chief basis of their identification and classification.

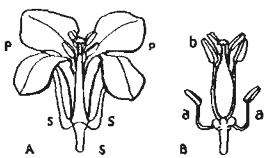


FIG. 18.—Flower of Rape.

A, whole flower; *B*, with perianth removed. *s*, sepals; *p*, petals; *a*, stamens (six in this case, two short) bearing *b* anthers. The carpels in the centre.

It frequently happens that certain of the floral parts are absent in a plant species, and the corolla is not in every case brightly coloured. This is so in grasses, including the common cereals (Chap. XXXIII.).

The *stamens* and *carpels* form the **reproductive** organs of the flower. The stamen consists of a stalk or *filament*, bearing the *anther*, and in this the *pollen* or male fertilising element is formed. The carpels, of which there may be one or more, form the *pistil*, and in this the female or *egg-cell* is produced. When pollen from the stamens is transferred to the sticky upper surface or *stigma* of the carpel it germinates, and the egg-cell is later fertilised.

In the majority of plant species, stamens and pistil are present in the same flower, which is then termed *hermaphrodite*, being both male and female. In other species of plants, however, while both stamens and pistil are produced on the same plant they are borne upon separate flowers, as in maize, melons, etc., in which cases the flowers are *unisexual*, being either male or female. Still another arrangement is that in which one set of plants in a species bears staminate flowers only, while another set bears pistillate flowers only, as in hemp and nettles, and here one may speak of male and female plants.

Transference of pollen to the flower stigma is termed **pollination.** In some cases pollination occurs before the flower opens, as in most of the cereals and in some grasses ; a more general rule, however, is for flowers to be pollinated from *other* flowers of the same species, which may either be on the same or on another plant. The latter is often an advantage—giving greater vigour, and in some instances it is a necessity. It has recently been shown, further, that in certain kinds of pears and other fruits, fertilisation is more effective when pollen is available from trees of another variety, and on this account orchardists now mix their varieties. Certain varieties of tree, indeed, are apparently quite sterile to pollen from their own variety, and the fruit consequently does not " set."

Pollination is effected in some plants by *wind*, while others have *insect* pollination. Where insects are required to carry pollen the flowers are usually brightly coloured, possess attractive odours, and secrete honey. Orchardists sometimes keep bees to assist pollination, and it is said that clover seed could not be produced in New Zealand before the introduction of bumble bees.

Artificial crossing is performed by removing pollen from one plant, which is then called the male, and transferring it to another plant, which is then called the female. The object is to combine the best qualities of both parents in the character of the offspring. Careful cultivation tests with the new offspring are necessary in subsequent years to find which of them are worth keeping. The majority are not, but agriculture has benefited enormously from the successful few. Artificial crossing is possible only when the parent plants are closely allied, as, for example, different varieties of the same species, or it may be different species belonging to the same genus. Outside of this instances of crossing are extremely rare.

After fertilisation, **seed** is developed inside the carpels, which remain attached to the parent plant and draw nourishment from it. When the walls of the carpels *open* at maturity the seed may be handled ; this is seen in shelling peas. When the carpels continue to *envelop* the ripe seed within it we have a **fruit.** This happens in wheat, buckwheat, mangels, etc. Strictly speaking, therefore, wheat is the fruit and peas are the seed of the respective plants. Green pea-pods are the unripe fruit. Sometimes the walls of the carpels become *succulent* and juicy as the seed ripens, as in berry and stone fruits generally. Such fruits also contain the seed inside.

Chapter V

THE PLANT: NUTRITION

The feeding of plants seems entirely different from the feeding of animals. The animal may live on a bag of barley meal or a truss of hay, and at any rate both the quantity of the food and the

[*Farmer and Stockbreeder.*

Fig. 19.—A Good Crop of Wheat at Harvest—near Guildford.

nature of it can be examined by the eye. Whence, however, does the plant derive its food, and what does the food consist of? Barley meal is not entirely unlike the bacon which can be obtained from it, but there is apparently nothing in a garden soil to resemble the material found in a cabbage.

The main business of the arable farmer is to provide suitable feeding conditions for his crops. He can do this most economically when he has considered exactly what the crop requires. How does the crop grow? It is proposed in the present chapter to deal with the general principles of this subject.

Every plant, and every part of a plant, contains water. Ripe seeds contain about 15 per cent. of water, timber 40 per cent., green forage and potatoes 75 per cent., turnips and cabbage 90 per cent. When clothes are wet they may be dried by placing near a fire, and the natural water in plants may be dried off in the same way. In order to avoid burning, a drying oven heated by steam is usually employed by chemists to expel the water from plants. When the water has been expelled by heat, the actual *dry matter* of the crop remains behind.

A ton of potatoes will yield about 5 cwt. of dry matter, and a ton of wheat grain will yield about 17 cwt.

The dry matter of a crop is formed **chiefly from the atmosphere.** About 5 per cent. of it only is derived from the soil. The figures apply generally to all crops, but the wheat crop may be taken as an example. The accompanying statement (Table II.) shows the approximate composition of a 30-bushel crop of wheat, and the demands which it makes upon the soil for its support.

TABLE II

Composition and Requirements of a Wheat Crop

Thirty-bushel Crop.	Grain.	Straw.	Total Crop.	One Acre-Foot Soil Contained.
	Lbs.	Lbs.	Lbs.	Lbs.
Natural weight	1,890	3,360	5,250	...
Dry matter	1,606	2,856	4,462	3,500,000
Necessary soil constituents	166	113	279	...
Comprising—				
Nitrogen (=nitric acid)	131·0	62·0	193·0	15,255
Phosphoric acid	15·0	6·0	21·0	1,925
Potash	9·0	20·0	29·0	19,075
Lime	1·0	8·0	9·0	56,770
Magnesia	3·6	3·0	6·6	14,525
Iron oxide	0·4	1·0	1·4	99,785
Sulphuric acid	6·0	13·0	19·0	2,660

It is not intended that the data should be committed to memory, but the *names* of the seven necessary soil constituents should be noted.

Taking the grain at 63 lbs. per bushel, and allowing 112 lbs. of straw for each bushel of grain, the weight of the crop at harvest would be 5,250 lbs. This will contain about 15 per cent. of moisture, so that after drying, the weight is reduced to 4,462 lbs. Of this weight only some 279 lbs. will require to be drawn from the soil, so that the balance of the crop—equalling 4,183 lbs.—will have been formed from the air and not from the soil at all.[1]

Although a crop does not draw much of its raw materials from the soil, still the soil materials are highly important, because unless these are available the crop cannot feed from the air. The air is as good over barren sand as over the richest fields, but it is only the latter which can produce large crops.

The **soil materials** required by a crop always contain **seven** different **constituents.** If any one of these seven be wanting, the other six will not enable a crop to feed out of the atmosphere. The accompanying photograph of cultures of barley (Fig. 20) shows the effect of leaving out any one of the constituents in turn, even when all of the other six were present in suitable amounts.

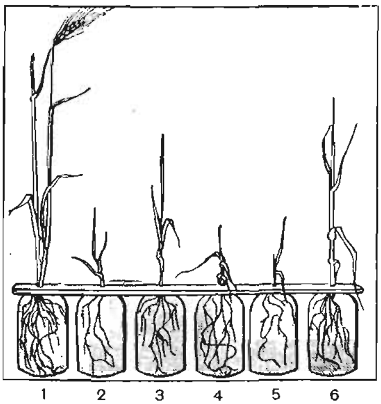


FIG. 20.—Cultures of Barley. (After Hall.)

1, all seven soil constituents; 2, nitric acid wanting; 3, phosphoric acid wanting; 4, potash wanting; 5, lime wanting; 6, magnesia wanting.

Not only must each of the seven soil constituents be present, but each must be present in an amount which is not less than the crop requires. For example, most farm and orchard crops require about 22 lbs. of phosphoric acid per acre. If only 11 lbs. be available, then the crop can use only about one-half of the other soil constituents even although the supply be large. In consequence the crop will be able to feed from the atmosphere only to about one-half the required amount, and the yield in consequence will be reduced by about one-half.

It is that soil constituent, therefore, which is scarcest, relatively to the crop's requirement, which determines the smallness of the yield. This principle is known as the "**Law**

[1] How crops feed from air is discussed in next chapter.

of the minimum," and is the foundation of modern methods of applying manures. Such manures are intended to make good the deficiencies in one or other of the seven essential constituents of plant food which are drawn from the soil.

Manner of Absorption.—How are the seven soil constituents which form about 5 per cent. of the dry matter of crops taken in? A boy can take sugar either in solution as in tea, or he can take it dry with a spoon. A crop cannot take any of the seven soil constituents in the dry form, because there are no mouths or openings in the roots through which they can pass. The soil constituents must therefore in each case be taken into the plant **in solution.**

The last column of Table II. shows the average amount of each of the seven necessary constituents found in 1 acre of different wheat soils to a depth of 1 ft. It is only necessary to refer to them generally. When we compare the amount of each constituent present in the soil with the amount of the same constituent required to produce one crop, it is seen that there is nearly 100 times more than enough in each case to produce one crop. Taking phosphoric acid, for example, the figures show that 1,925 ÷ 21, being equal to 91, there should be enough phosphoric acid to produce 91 crops. This is quite characteristic for ordinary farm soils in any part of the world. Why, then, should crops frequently be unable to get all the soil constituents which they want? The reason is that they can take them through the roots only when they are in solution, and in soils the great bulk of the food materials are present in insoluble forms which the crop cannot utilise.

Chemical analysis shows more or less the total food constituents in a soil. A crop, however, is less concerned with the total amount present in a soil then with the amount which is soluble in water, and which consequently it can use. In this respect it might be likened to the commercial man who is less concerned about the total amount of money in his bank than with the amount standing to his private account because it is only the latter which he can draw upon.

In soils the various necessary food materials for crops gradually become soluble as a result of various agencies. This matter will be more fully dealt with in the chapters on soils.

Of the seven necessary soil constituents required by crops there are commonly only **three** which at one time or another fall short so far as their available supplies are concerned. These three are **nitric acid, phosphoric acid,** and **potash.** This part of the subject is connected with the use of manures.

The soil food materials of crops are taken in with the water, which they absorb by the roots. As we shall see later, a very large amount of water is absorbed by growing crops.

Besides the seven constituents essential for its growth, a crop may absorb **other soil constituents** which are not essential. Silica, soda, and chlorine are always present, and in cereals the first named is usually present in large amount. It has no special significance. The fact seems to be that a crop absorbs all soluble soil constituents in the first place, and then decides whether or not it can use them afterwards.[1]

For the same reason that a crop may absorb constituents which it does not want, it may also absorb an excess of those seven constituents which it does want. In practice the results of such excess are seldom serious, but a deficiency in any one of the essentials leads directly to a reduction of crop yield.

When a wheat stack gets burnt, the ash of the crop remains behind. This ash represents practically all that the crop had taken out of the soil with the exception of the nitric acid which it required. The part which is lost in burning returns to the air whence it came. Such a fire reminds us that a crop draws its main supplies from the atmosphere, and that a comparatively small amount of soil constituents only is necessary to enable it to do this.

Chapter VI

CARBON ASSIMILATION BY PLANTS

Plants and animals alike require food. They require in general **the same kinds of food.** These include the starches, sugars, fats, and the other substances which we commonly recognise as

[1] Altogether from thirty to forty chemical elements drawn from the soil have at different times been actually found in plant ash in small amounts. It is found that a few of these, *e.g.*, boron, copper, manganese, zinc, may be useful or even essential in *very small* amounts, and such are therefore known as "**trace elements.**" Soils normally supply enough of the trace elements for ordinary crops, but cases arise where "Grey Leaf" disease of oats is caused by manganese deficiency in the soil, while lack of boron in trace amounts is a not uncommon cause of trouble with sugar beet and swedes.

essential for animals. But there is an important difference in the manner in which they obtain these things. While animals receive their food ready-made, plants make their own food for themselves.

The **manufacture of food** by plants is, in its extent, one of the most important processes in nature. The materials formed—the starches, sugars, etc.—contain carbon in addition to the elements of water. The plant obtains this carbon by decomposing the carbon dioxide of the atmosphere. On this account the process of food manufacture is often referred to as **carbon assimilation.**

" Analysis " means the breaking down of a chemical compound, or taking it to pieces. When starch or sugar is gently heated over a flame it is partly broken down. The carbon, which was present in combination in the starch, becomes evident when the starch is broken down. It appears as carbon, which is black, and the starch is said to be charred. Water is formed at the same time.[1]

" Synthesis " is the opposite of analysis. It is a process of building up. When starch is formed by plants from water and the carbon dioxide of the atmosphere we have a building-up process. Light is necessary for this building-up process. On this account, carbon assimilation is often referred to as **photosynthesis.**

Starch, then, is formed from carbon dioxide and water. There are a number of intermediate steps,[2] but the final changes can be represented thus:

Carbon dioxide and water give starch and free oxygen gas.

$$(6CO_2 + 5H_2O = C_6H_{10}O_5 + 6O_2.)$$

Besides starch, it will be observed that photosynthesis also results in producing **free oxygen gas.** It appears probable that

[1] If strongly heated for long enough, and in sufficient air, the carbon escapes as carbon dioxide gas along with the water formed.

[2] Formaldehyd is apparently one of the first products of photosynthesis: $CO_2 + H_2O = CH_2O + O_2$. This (present in " formalin ") is very toxic, and is quickly polymerised within the plant to yield various harmless sugars, *e.g.*, glucose: $6CH_2O = C_6H_{12}O_6$. Accumulation of such sugars would, however, increase osmotic pressure (Chap. XXV.) to a dangerous degree, and in most plants refuge is found by further conversion of soluble sugar into insoluble starch: $nC_6H_{12}O_6 = (C_6H_{10}O_5)_n + nH_2O$. The latter changes are the work (Chap. XLIV.) of special enzymes.

all the free oxygen of the atmosphere has been formed at some time by plants.

In combustion and respiration, starch is caused to unite with free oxygen (Chap. II.), giving carbon dioxide and water. In that change, not only is the starch destroyed but oxygen of the air is used up. The action can be shown thus :

Free oxygen gas and starch give water and carbon dioxide.

$$(6O_2 + C_6H_{10}O_5 = 5H_2O + 6CO_2.)$$

In combustion and respiration the change is of the same kind as in photosynthesis, but it goes in exactly the *opposite direction*. In respiration starch and oxygen are used up, while carbon dioxide and water are formed. The importance of photosynthesis lies in the fact that by reversing the respiration process it renews the supplies of starch and oxygen, and enables the animal to live.

Like animals, plants also require oxygen for respiration, and they also require starch and similar materials as fuel to support the respiration. In photosynthesis plants form starch for their own use as well as oxygen. They are thus self-supporting. Animals are not self-supporting in this way and must steal from plants. Indeed, they have no option in the matter, because animals cannot form for themselves either the food, or the oxygen, required to support life.

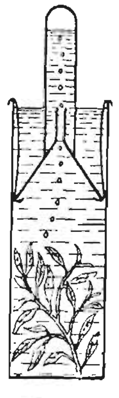


FIG. 21.—Oxygen is formed by Green Plants.

The formation of oxygen during photosynthesis can be shown by placing some fresh sprigs of water-cress, or mint, etc., under water (Fig. 21) which was first saturated with carbon dioxide gas. The apparatus (glass) should then be exposed to direct sunlight. As the oxygen produced is less soluble in water (Chap. I.) than carbon dioxide, most of it can be collected in the manner shown.

It is only *green* plants which can build up food by the process of photosynthesis. The green colouring matter of plants is called **chlorophyll**. This colouring matter may be extracted from young leaves of bean, grass, etc., by treating with warm alcohol. After extraction the leaves will appear white. Chlorophyll is essential to photosynthesis. It appears to play an intricate in-and-out part in a series of chemical changes induced by the living plant. A solution of chlorophyll cannot of itself form starch from carbon dioxide and water. Chlorophyll is concentrated chiefly in the leaves, which are generally adapted so as to expose as large a green surface as possible to sun and air.

Plants which do not form chlorophyll cannot build up food by photosynthesis. *Fungi* form a large class of plants which cannot build up their own food because they have no chlorophyll. Such plants must subsist either on dead plants or on other living plants which have the power. Fungi must steal (Chap. XL.) from other plants.

Light is necessary for the formation of chlorophyll in the first instance, and in darkness plants remain pale or *etiolated.* Plants grown from seed cannot produce chlorophyll until they come above-ground. On this account seeds, such as wheat or bean, contain as much ready-formed starch and other materials as will enable the young plant to grow and breathe until it can build up food for itself.[1]

Effect of Light.—In cycling, a person may run downhill without effort, but if he wishes to return he must work his way while going uphill. When starch is burned, heat is given out; the action goes on after it is started, and it is a downhill process. Photosynthesis is the reverse of burning. To make it go on, therefore, *energy* must be expended because it is an uphill process. The energy required is the energy of light. Photosynthesis will not proceed in darkness.[2]

The amount of starch formed in green plants is, within wide limits, proportional to the intensity of the light. A season with plenty of sunshine is thus favourable to crop growth. In England, during the winter months, electric light has been used to supplement the daylight in the production of forced vegetables. Some

[1] Besides light, a little iron from the soil is necessary for chlorophyll formation and in its rather rare absence plants also remain pale. This kind of paleness is known as *chlorosis*, and chlorotic plants are most likely to be found on chalky or calcareous soils.

[2] Certain low forms of plant life, such as the bacteria of nitrification, can carry on carbon assimilation using CO_2 and water, in the absence of light and without having chlorophyll. They, of course, require energy to make it go, and those mentioned get it from the simultaneous oxidation of ammonia (Chap. XIV.), which is a downhill process. In other cases, necessary energy may be obtained from oxidation of sulphides, ferrous salts, etc. As green plants came later in the scheme of evolution, such forms of carbon assimilation are of considerable scientific interest.

plants, however, can succeed with a lower intensity of light than others, and this faculty gives an advantage in the struggle for existence in mixed herbage or forest growths. Of the various rays of the solar spectrum, the orange and red appear to be the most active in promoting photosynthesis, while the blue and violet rays, which are most active in photography, have relatively little effect.

From the atmosphere, the carbon dioxide gas enters the leaf through the little openings or *stomata* (Fig. 13) which are present chiefly on the underside of the leaf. Photosynthesis is much hindered when a crop is *not* receiving sufficient **moisture.** This is partly owing to an automatic narrowing of the openings under such conditions. Another reason is that, while a small quantity of water only is chemically decomposed in the building up of starch, a large excess must be present to enable the action to go on.

The volume of **carbon dioxide** in the atmosphere is only about 3 parts in 10,000 of air—or 0·03 per cent. In practice it is impossible to increase this amount. It appears, however, that under optimum conditions of moisture, light intensity, and temperature, the building up of starch is hindered in practice by the small supply of the gas. In experimental cultures an artificial atmosphere containing from 30 to 100 parts of the gas, and in some cases even 1,000 parts per 10,000 of air, gave larger and more rapid growth—at least for a time—than did the ordinary atmosphere.

A suitable **temperature** promotes food-making, and for most crops one of 75° to 85° F. gives the best results. In cold weather the action is greatly hindered.

The effect of **electricity** on crops has been studied by eminent workers, but results have been elusive and often contradictory. The subject is not well understood.

About one-half of the dry matter of plants is combined carbon ; oxygen and hydrogen, the other constituents of starch, make up most of the balance. As the carbon is derived wholly from air, a growing crop makes heavy demands upon the atmosphere. An acre of wheat will take in four months about 1 ton of carbon, or the quantity contained in a column of air of nearly 1 mile in height.

Photosynthesis cannot proceed unless the crop receives through its roots the **seven soil constituents** (Chap. V.) necessary for it growth.

CHAPTER VII

MATTER AND ENERGY

OUR experience in the physical world deals with two great realities, which for most practical purposes are treated as distinct. One of these is Matter ; the other is Energy.

Matter has a certain size, a certain form, and two pieces of matter cannot exist at the same spot. Matter attracts and is attracted by gravity, and thus all kinds of matter have " weight." This is a familiar property of matter.

Matter can neither be created nor destroyed. We thus speak of the **conservation of matter.** One kind of matter, however, can be *transformed* into another kind of matter as in combustion (Chap. II.), but there is no loss, and the new products have the same weight as the original materials.

Energy is " capacity for doing work." It has no weight. A revolving flywheel has energy and can do work, but it is no heavier than the same wheel at rest. Heat is another form of energy and can be made to do work. But a hot body is no heavier than the same body when cold.

Matter consists of very small bodies called **molecules.** A molecule is the smallest particle of any substance that can exist by itself. A pound of peas is made up of a number of similar peas, and a speck, *e.g.*, of chalk, is made up of a number of similar molecules of chalk. Each molecule is chalk, and each one is exactly alike. When the chemist knows what goes to make up one molecule of chalk, he knows all about the composition of chalk that he wants to know. The molecules are very small indeed.

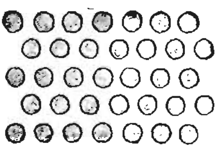


FIG. 22.—To Illustrate the Molecular Composition of Matter.

The arrangement of the molecules in a piece of chalk or other substance may for convenience be represented as in Fig. 22. The molecules of a substance are never touching, but there are always *spaces* between the molecules.[1] When the molecules are fairly close they attract each other strongly, and do not readily move about in the mass. This happens in **solids.** When the

[1] The spaces are relatively much larger than here shown, but this is immaterial.

spaces between the molecules are wider, then the mutual attraction of the molecules is weaker, and this happens in **liquids.** A liquid can be stirred about, although it is still able to hang together in drops. When the spaces are still wider, then the molecules instead of attracting actually repel each other. This happens in **gases,** and gases can only be retained in a closed vessel.

When a substance is **heated** it expands. When this occurs the molecules do not become larger, but the spaces between the molecules do. When a substance is cooled the spaces become smaller again. By heating a solid, the spaces may become wider until the liquid condition is reached, when the substance is said to fuse or **melt.** Similarly in a liquid the spaces may become wider until the gaseous condition is taken. The substance is then said to evaporate or **volatilise.**

When some solids are heated, the molecules themselves break down before the liquid stage is reached—thus giving a new substance. These are **infusible** substances, because they could not be melted without decomposition. If we try to melt chalk, its molecules are broken down into lime and carbon dioxide gas, and we cannot get liquid chalk. Chalk is infusible. When a pure substance is fusible it always melts at a certain definite temperature called its **melting point.**

In the same way some liquids cannot evaporate because their molecules break down when we try to do it. This happens with melted sugar. Sugar is a fusible but not a volatile substance.

Volatile substances volatilise more quickly as the temperature rises. The vapour produced exercises a pressure which may be measured by the barometer.[1] When the temperature is sufficient to give the vapour a pressure, which is equal to the atmospheric pressure at the place, the evaporation becomes much more rapid. The liquid is then said to *boil.* Volatile liquids will obviously boil at a lower temperature when the barometer is low; cold water may be made to boil just by reducing the pressure over it with an air-pump. The **boiling point** of a liquid is always determined when the barometer shows the normal pressure of 30 in.

Heat is a form of energy. Energy can exist only where there

[1] A little water introduced to the Torricellian vacuum (Chap. I.) will depress the mercury more and more as the apparatus is warmed. At 212° F. a barometer originally reading about 30 in. will have fallen to zero, owing to the water-vapour pressure inside the tube being then equal to 1 atmos.

is matter. All matter contains a certain amount of heat. Cold means the absence of heat, just as emptiness means the absence of matter. But matter is never perfectly cold, and it seems probable that no space is quite empty of matter. It is calculated that at a temperature of $-460°$ F. there would be no heat in matter, but this **Absolute Zero** of temperature has never quite been reached.

Heat affects the molecules of matter (Fig. 22) in two ways. The molecules of a substance are never at rest, but are always vibrating or rebounding towards each other like rubber balls. One effect of heat is to make the molecules vibrate faster, and rate of vibration is heat that can be felt by the senses, and is called **sensible heat.** This is what the thermometer measures. The other effect of heating a substance is to increase the size of the spaces between its molecules. This effect of heat cannot be felt, nor measured by the thermometer, and it is called **latent heat.**

When a substance is gradually heated, one part of the heat goes to raise the temperature—sensible heat; the other part goes to increase the size of the spaces—latent heat. Most heat becomes latent during changes of state, as in the melting of solids and the evaporation of liquids.

Water at 32° F. contains much more heat than does an equal weight of ice at the same temperature. This may be ascertained by experiment:

Mix 1 lb. water at 32° F. with 1 lb. water at 212° F.	Mix 1 lb. ice at 32° F. with 1 lb. water at 212° F.
Get 2 lbs. water at 122° F.	Get 2 lbs. water at 50° F.

Deducting from 2 lbs. water at 122° F.
the heat in 2 lbs. water at 50° F.

We get the heat in 2 lbs. water at 72° F.

But the heat required to heat 2 lbs. of water through 72° F. equals the heat required to heat 1 lb. of water through (72×2) or 144° F. It had taken, therefore, as much heat to melt 1 lb. of ice at 32° F. and convert it into 1 lb. of water at 32° F. as would raise 1 lb. of water through 144° F. This heat was latent in the water but not in the ice, and therefore the latent heat of water equals 144 thermal units.[1]

Steam contains more heat than boiling water at the same temperature. It requires as much heat to evaporate 1 lb. of boiling

[1] The British thermal unit is the amount of heat required to raise 1 lb. of cold water through 1° F. See also p. 152.

water at 212° F. and convert it into steam at the same temperature as would raise 5·39 lbs. of cold water from the freezing to the boiling point. *Where the molecules become wider apart heat always becomes latent.* The latent heat of steam is 970 units.

When steam is condensed to water the latent heat becomes free again. This happens when steam is led into cold water to heat it. Similarly when water freezes, the latent heat of the water is set free, and this tends to heat up the next layer of water, so that much heat must be taken from water at 32° F. to convert it into ice at the same temperature. This prevents ice from forming rapidly on ponds in a single night.

The fact of heat becoming latent when water evaporates makes a person cold when wearing wet clothes, as heat is taken from the body to become latent in the evaporated water. For the same reason wet soils are cold. Similarly when ice is placed in drinking water, the heat which becomes latent when the ice is melted is taken from the drinking water, which in consequence is cooled down.

Heat can **move** from one place to another. It can travel in different ways, viz., by

Conduction ;
Convection ;
Radiation.

In **conduction,** the heat is handed on from molecule to molecule. In this way a poker hot at one end soon becomes hot at the other. Solids are the best conductors, and among these the metals.[1] In liquids the spaces between the molecules are wider, and partly for this reason liquids are much worse conductors than solids. One may picture it that with them increased rate of vibration is with more difficulty handed on. As would be expected, gases are very bad conductors of heat indeed.

In **convection,** the heat is *carried* along in moving crowds of the heated molecules. Convection is possible only in *fluids*, *i.e.*, liquids and gases. When water is heated from below (Fig. 23) the heated portion expands, and as it is then lighter than the colder water higher up, it ascends, while the colder water

[1] On a frosty morning iron handles on a plough feel colder than wooden ones but are not really colder ; they only *conduct* heat away more rapidly from the hands. Clothing is a bad conductor and prevents heat passing *out* from the body, but it may also be wrapped round ice to prevent heat passing *in*, and thus delay melting.

passes down to take its place. In an ordinary fire the hot air, being lighter, passes up the chimney—carrying heat upwards by convection. It is impracticable to boil a kettle properly if hung below a fire, because water is a bad conductor; when hung over the fire, convection currents in the kettle carry the heat uniformly through the whole mass of water.

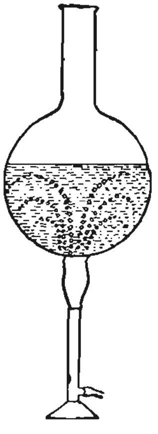


FIG. 23. — Heat Travelling by Convection.

Radiation.—Here heat travels as little oscillations or waves. In this way heat travels from the Sun. The Sun is the principal source of radiant heat (Chap. XXIX.), but every hot body radiates heat all the time. Every body is also absorbing radiant heat all the time. Radiant heat travels at the rate of 186,000 miles per sec. Light is radiant energy of a similar kind to radiant heat, but the rays of light have a shorter wave-length than the dark heat rays.

Conservation of Energy.—Energy is like matter in that it can neither be created nor destroyed (conservation of energy). But one form of energy can be *transformed* into another form of energy. Thus we have seen that in photosynthesis (Chap. VI.), carbon dioxide and water are formed into starch. Starch contains chemical energy, and in photosynthesis light energy is transformed into chemical energy. In combustion and respiration, again (Chap. II.), the chemical energy is transformed into heat. These are examples of the transformation of energy.

CHAPTER VIII

HUMIDITY AND RAINFALL

WATER can exist in a state of **vapour**. When a vessel of water is exposed to ordinary air it gradually evaporates. If this occurs in a closed room the water will be present in the air of the room. The water vapour will add to the weight of air if the room be airtight.

There is a **limit** to the amount of water vapour which the air of the room *can* hold. It will be greater the higher the temperature. The following table states in grams per cubic metre of air space at normal pressure the largest amount of water vapour which can be held at different temperatures :–

TABLE III

Water Vapour Possible at Different Temperatures

Temperature (Fahrenheit).	Grams per Cubic Metre.
32°	4·84
40°	6·51
50°	9·33
60°	13·13
70°	18·25
100°	45·26

The hotter the room the more water can it hold in a state of vapour.

The amounts stated are the maximum amounts which can be held at each temperature. If the room were a vacuum and contained no air to begin with, the final results would be just the same but the evaporation would occur very much more rapidly.

When air holds as much water vapour as it can at the particular temperature it is said to be **saturated.** If the temperature be then caused to fall, some of the vapour will condense as little drops of water. It will not all condense to liquid water, but an amount of water will remain as vapour corresponding to the new and lower temperature.

The air we breathe is seldom fully saturated. It could usually hold a good deal more water vapour than it does at the particular temperature. If we gradually cool such air down, however, it will sooner or later reach the temperature at which it will be fully saturated, and any further loss of heat will cause a portion of the vapour to separate as liquid water. This temperature is called the **dew-point.**

Suppose we get a glass of water with a thermometer in it. If we add some ice to the water it will be cooled down. As it gradually cools, the time will come when vapour from the air will begin to condense on the outside of the glass. Immediately this occurs, the temperature of the glass of water should be read off. We thus find the dew-point, or the temperature at which on that day the air begins to deposit its moisture. An instrument acting on this principle to tell the dew-point is called a *hygrometer*.

Let us again refer to Table III. Suppose the temperature of a room were 60° F., and the dew-point were found to be at 50° F. At 60° the air could have held 13·13 grm. weight of water vapour in each cubic metre, but a dew-point of 50° shows that it held only 9·33 grm. It was thus only partially saturated, and held $\frac{100 \times 9{\cdot}33}{13{\cdot}13}$, or 71 per cent. of the vapour which it could have held at the higher temperature. This figure gives what is called the **relative humidity** of the air.

The rate at which things dry depends upon the relative humidity of the air. When the relative humidity is below 40 per cent. the air is popularly described as " dry " ; over 80 per cent. it is " damp." It will be observed that the relative humidity may be increased in two ways. One way is to add more water vapour without changing the temperature ; the other is to lower the temperature towards the dew-point without adding more water vapour.

In a dry atmosphere there is rapid evaporation of perspiration from the skin, and the heat which becomes latent during evaporation tends to cool the body. On this account a damp or muggy atmosphere in hot weather may be more oppressive than a dry one where the thermometer stands perhaps 20° higher.

The *wet and dry bulb thermometer* (Fig. 24) gives an alternative but indirect method of calculating the relative humidity of the air. The wet bulb shows a lower reading than the dry bulb, and the difference is greater the faster water is evaporated from the wet bulb. In an atmosphere saturated with water vapour no evaporation could take place, and both thermometers would then show the same reading.[1]

[1] " *Absolute humidity* " refers to the actual amount of water vapour in the air without reference to temperature. Air containing actually little water vapour allows the *Sun's rays to pass* through with small loss. This occurs over high mountains, and in centres of great land masses remote from the ocean ; it leads to extreme temperature variations at the ground as between day and night. Absolute humidity affects this property ; it likewise affects the *conducting power of air* for heat from bodies with which it comes in contact—*cf.* the colder feeling often experienced in England when a frost is succeeded by a thaw ; with more vapour it becomes a better conductor. These effects are to be distinguished from those arising from relative humidity, and which we have here specially to consider.

The atmosphere always contains a certain amount of water vapour. When it is cooled part of this **vapour** may be **condensed,** forming dew, fog, mist, cloud, rain, hail, or snow. These are different phases of the same thing.

Dew is formed when the surface of the ground is cooled at night by radiating heat into a clear sky. Water is then deposited from the atmosphere upon the cooled ground in the same way as upon the glass in our previous experiment. The dew may be water condensed from the air above it; or it may largely consist of water which was previously in the soil, but was condensed on the cooled surface just as it was about to leave it in the vapour form.

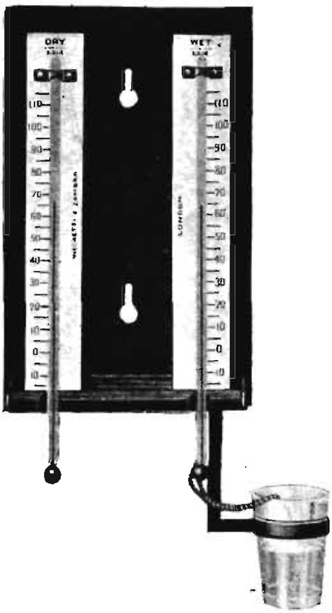


Fig. 24.—Wet and Dry Bulb Thermometer.

Mist and **fog** occur where the water vapour in the atmosphere is condensed at some little distance above the surface of the ground. They consist of innumerable fine pellets or globules of condensed water.[1] As cold air is heavier than warm air it tends to flow down into the hollows along the cooled surface of the ground, and thus low-lying situations most frequently experience fogs. Fogs are of different kinds, but are all formed from a supersaturated atmosphere.

Clouds are formed at higher elevation. When air is compressed it is heated as in an ordinary cycle pump. When allowed to expand it is correspondingly cooled. This matter is related to latent heat and the spaces between the molecules (Chap. VII.).

[1] When water is condensed from moist air, suitable dust particles must be present (Chap. I.) to act as nuclei, and upon them the little drops of water form. Such nuclei-free air has been prepared artificially, but has never been found to occur naturally at any altitude, and need not be further considered.

As we ascend a mountain the atmospheric pressure becomes less. If air is forced by winds up the side of a mountain it expands by coming under diminished pressure, and is consequently cooled. A rise of 100 ft. causes a fall in temperature of about 0·54° F. At the top of the mountain it may be cold enough to form clouds and **rain.** Where the prevailing winds (Fig. 25)

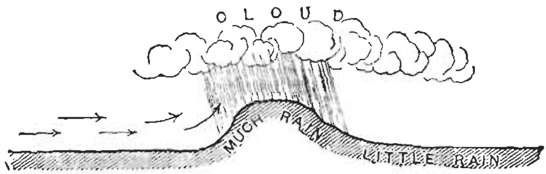


FIG. 25.—Effect of Mountain in Forming Cloud.

pass over a mountain the atmosphere may be robbed of a large part of its moisture in this way, and the country to the back is then much drier. The mountainous west of England is far wetter than the eastern counties because most of our moisture-laden winds come from the Atlantic.

Clouds and rain are produced in other ways. When the air over a given region is heated more than over the surrounding

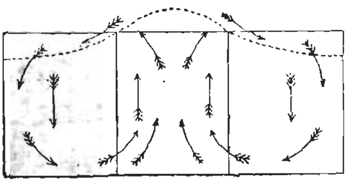


FIG. 26.—Ascending Air Currents in Low-pressure (Cyclonic) Area. (After King.)

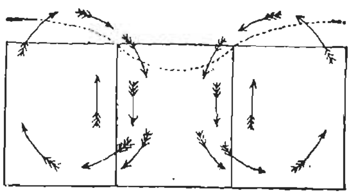


FIG. 27.—Descending Air Currents in High-pressure (Anticyclonic) Area. (After King.)

districts it becomes lighter and tends to rise, while colder air comes in below to take its place. In rising, the air is cooled as explained above, and deposits part of its moisture as clouds. Such an area of low pressure with ascending currents (Fig. 26) is called a **cyclone** or "**Low.**" Owing to the Earth's rotation the winds blow obliquely into the cyclonic system at the base, and pass out obliquely at the top. A cyclonic area is characterised by a low barometric reading, and is often visited by rain. The vortical action of winds entering and leaving a cyclone keeps it going long after the original cause of its formation (a difference of temperature) has disappeared.

An **anticyclone** or "**High**" is an area of high pressure, and here the winds pass out below into areas of lower pressure round about. If the air over an anticyclonic area (Fig. 27) is passing downwards, this will tend to warm it. This condition is unfavourable to cloud formation, and an anticyclone is typically characterised by dry weather.

The **Meteorological Office** in London receives barometric readings daily by telegraph from about fifty recording stations scattered over Britain and the adjacent territories. These readings, after certain necessary corrections, are then marked upon the regional map. Lines are then drawn connecting those adjacent stations which show (Fig. 28) the same barometric reading.

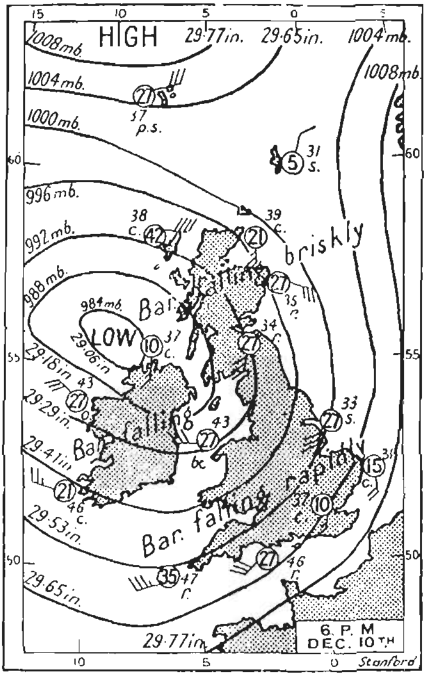


FIG. 28.—Specimen of Daily Weather Chart (*Daily Telegraph, London*, 1937), showing isobars and the presence of low (cyclonic) and high (anticyclonic) systems. Wind direction by arrows flying with the wind ; its velocity in miles per hour by figures in circles, and by the number of feathers on arrow shafts. Temperatures (not in circles) show F.° Small letters indicate— *b*, blue sky *c*, cloudy ; *f*, fog ; *m*, rain ; *s*, snow ; etc.

The lines so drawn are called **isobars**. In the specimen chart we have the distribution of pressure on a particular day.[1] The isobaric lines lead *up* to an anticyclonic or "high" pressure system north of the Faeroes. Similarly the lines lead *down* to a cyclonic or "low" pressure system north of Ireland. The direction of the winds will be noted; in the Northern Hemisphere they blow in an anti-clockwise direction round the centre of a depression. Thus by standing with our back to the wind, *the centre of a cyclone will be towards the left hand*; to be more exact it will be a little in front of it. While a "high" is often accompanied by clear weather, a "low" is typically accompanied by rain.

Comparison of the weather charts from day to day shows that the "highs" and "lows" do not remain stationary, but **travel across the map.** The general path is from west to east—with a tendency towards north. Were this direction invariable, then the task of *forecasting* the approach of "lows" with their accompanying rains and winds would be greatly simplified. Unfortunately, disturbances are liable to deviate from the straight course, or even to loiter for an appreciable period over one spot. The average *rate of passage* of a storm centre is 20 to 30 miles per hour. In Britain, forecasting is more difficult than in eastern Europe, owing to lack of enough barometric readings from the west, whence most storms come.

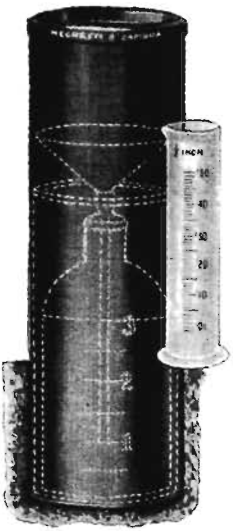


FIG. 29.—Rain-gauge.

The amount of rainfall is measured by a **rain-gauge.** The rain-gauge must be placed on level ground, and not nearer to trees than twice the height of the trees. It should stand quite level, and usually at a height of 1 ft. above the ground. One inch of rain is equal to nearly 101 tons of water per acre.

[1] Daily weather charts now state pressures both in inches and in millibars for each isobar. In the metric system 1,000,000 dynes (per sq. cm.) equals 1 bar or 1,000 millibars, and this equals 29·531 in. of mercury at 32° F. and 45° latitude N. or S.

Chapter IX

CLIMATE

Climate depends upon the average conditions of the atmosphere, and weather is a single occurrence in the conditions which make up climate. Of particular importance in agriculture are the conditions in regard to rainfall and temperature.

Rainfall.—The differences in rainfall at different parts of the world are remarkable. At Aden there may be no rain for several years, while at Cherra Pungi, in Assam, the mean annual rainfall is given as 471 in. Fortunately our home experience does not run to such extremes.

Within the *British Isles* the heaviest annual falls occur at high elevations in the west. This would be expected from the relations of mountains to rainfall already discussed. Local variations are considerable (Fig. 30). A large part of the Scottish Highlands receives over 80 in. per annum, while the Lake District of Cumberland, and the mountainous regions of Wales, Devon, and Cornwall also receive very heavy rainfalls. Some places receive over 100 in. each year. The eastern counties are the driest. These seldom register over 30 in., and the low lands near the Thames estuary, and around the Wash, even average less than 25. Between the extremes, extensive areas stretching through the centre of England and into Scotland receive from 30 to 40 in. per annum. Typical rainfalls down the east coast include—Edinburgh 24, Yarmouth 25, London 23 ; and down the west coast—Fort William 80, Glasgow 35, Manchester 37, Bristol 34. Along the south coast, Dover receives 28 and Falmouth 44 in. While the drier eastern counties are the best adapted for wheat and barley, and for seed crops, yet a heavier rainfall is desirable for roots, forage, and pasture. Thus it comes that dairying and grazing are particularly prominent in the west country.

In the agriculture *of other countries*, annual rainfall is important ; but not less important often is its **distribution throughout the year.** In some tropical and sub-tropical lands there is a " rainy season " which is followed by a " dry season " with great regularity. Whether this rainy season occurs in the local summer, or in the local winter, depends among other things on latitude. The latter is the " *Mediterranean* " type of climate,

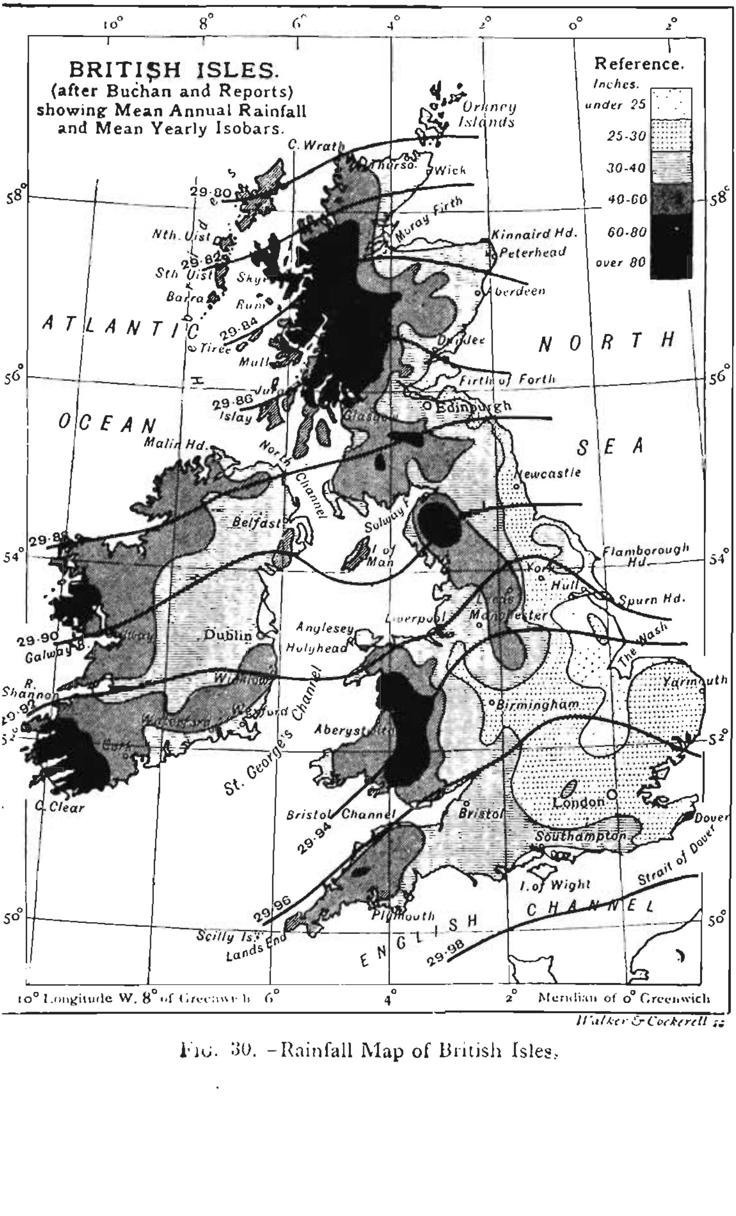


FIG. 30.—Rainfall Map of British Isles.

and examples are seen in California, South Africa, and on the shores of the Mediterranean itself. Needless to say the long dry summer of the Mediterranean climate restricts choice in crops, and is unfavourable to establishment of the best pastures.

Fortunately the seasonal variations in rainfall of the Mediterranean climate do not extend north to this country in any important degree, even although the western coastal districts usually do receive their heaviest falls in autumn and winter. Our rainfall, as a whole, is well distributed throughout the year, and there are no dry months. In Britain, seed-time and harvest are regulated rather by temperatures than by rainfall; in many other countries the case is exactly reversed.

Temperature.—The temperature of a place is the temperature of the air taken inside a louvred screen, and at a few feet from the ground. Lines drawn on a map through places showing the same mean temperature are called *isotherms*. Figs. 31 and 32 show the position of isotherms over England in January, and in July, as calculated from the average mean temperatures of those months.

The temperature of any locality is affected by several conditions. Thus higher *latitude*, or increased distance from the Equator, naturally tends to lower temperatures. Then *season of year* obviously affects the results. In Britain, July is usually the hottest month, and January the coldest. The average difference of these two may be taken as "the mean annual range." This may amount to 24° F. in England, but locally it varies considerably—being least towards the north-west and highest towards the south-east. Then again, *altitude* has an effect—the mean temperature of a place falling at higher elevations. As, however, the isotherms are drawn from local temperatures which have been calculated to sea-level, the effect of altitude upon the isotherms does not show in the charts.

Finally temperature is affected by the *prevailing winds*. In the British Isles the south-west winds from the Atlantic greatly regulate temperatures. In winter the sea is warmer than the land, and in summer colder. For this reason sea winds bring heat in winter and coolness in summer. As shown in Fig. 31, the result is to make winter temperatures higher along the whole west coast. In January it appears, indeed, that the sea winds are a more important source of heat than the Sun, because the effect of latitude is overcome to the extent that the general trend of the winter isotherms runs north and south. In July (Fig. 32) the Sun reasserts himself, and the prevailing tendency is east and west in obedience to latitude. The higher temperatures over the land than over the sea in the summer month are also clearly marked.

There are many **effects** of temperature seen **on** British

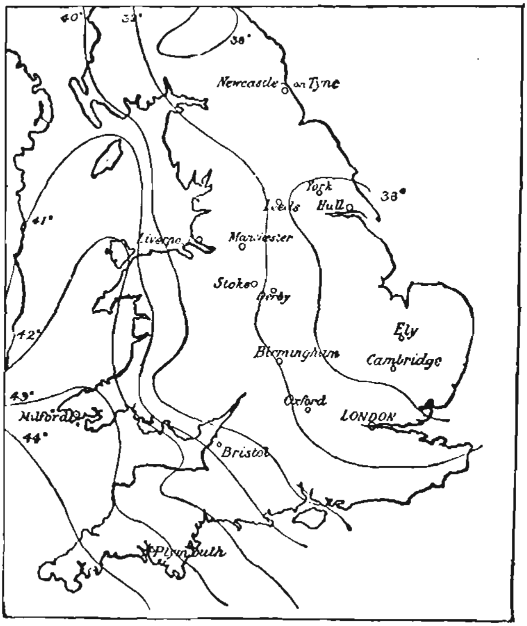


FIG. 31.—Isotherms for January.

farming. The mangold crop succeeds better in England than in colder Scotland. Wheat takes longer to ripen in the north country, and thus suffers in quality. Oats and turnips are more productive and of better quality in Scotland ; under a warmer climate oats develop a thickness of husk. Valuable forage crops like lucerne and sainfoin require the warmer conditions of southern England. The more delicate fruit and market-garden crops fail to thrive north of the Tweed, while with others the cultivation becomes risky. In any locality, those lands with a southern exposure are "earlier" in spring (Chap. XXIX.), because they receive more heat from the Sun.

Frost.—On clear nights the surface of the ground loses heat by radiation into space, and air in contact with it becomes cooled. It may be cooled below 32° F. If clouds be present, these radiate heat back again to the earth ; therefore in cloudy

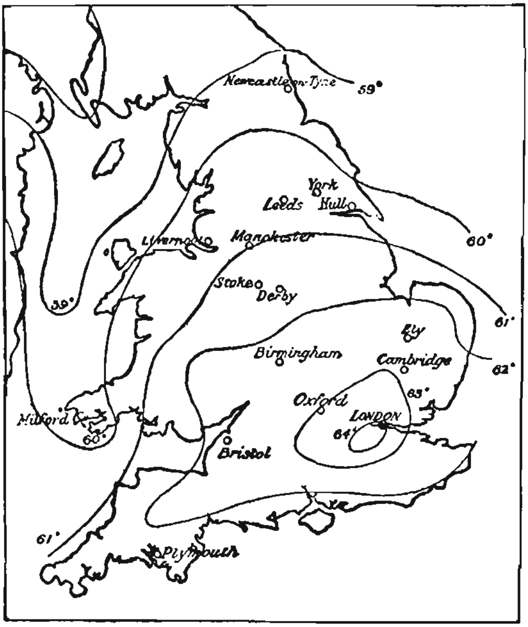


FIG. 32.—Isotherms for July.

weather frost is less likely. Sometimes in America "*smudging*" is practised to protect crops. This consists in building smoky fires to windward of the crop—the smoke acting like a cloud in preventing rapid cooling at the ground.

Frost is worst in *low situations*. Air cooled by contact with cold ground contracts, and is then heavier than warm air. As water would do, this heavier air flows downhill and fills the valleys. To reduce frost danger, tender crops should occupy the higher grounds.

When air is cooled the dew-point is eventually reached. Water vapour then condenses. When this occurs latent heat is set free, which tends to retard the further fall of temperature. If the dew-point, therefore, in early evening stands above the freezing point there is thus going to be some check after sundown to a further fall of temperature; if the dew-point, however, is below freezing, there is not. Frost is therefore more *likely* with a *low* relative humidity. When dew forms below 32° F. it is frozen, being then known as *hoar-frost* or rime.

Evaporation.—Hardly less important to the farmer than local rainfall is the rate at which water evaporates again into the atmosphere. For him evaporation may be viewed as the converse of rainfall, and in countries where power of evaporation is low a much-reduced rainfall may satisfy his needs.

Evaporation is *increased* by low relative humidity of the air, by high temperatures, and by winds, and it varies much in different parts of the world. Table IV. shows the average evaporation recorded during twelve months from an exposed surface of water at various places.

TABLE IV

Annual Evaporation from a Free Water Surface

Observation Station.	Inches of Evaporation.
London	20·7
Munich	24·0
Demerara	35·1
New York	50·2
Bombay	82·3
Coolgardie	86·4

The figures may serve as examples. In different parts of Britain the evaporation from a *lake* will equal from 25 to 75 per cent. of the total rainfall registered—according to district; at Coolgardie it would equal 988 per cent. of the local rainfall—a figure suggesting very dry soil conditions.

Naturally, rainfall and evaporation do not keep pace from day to day, and during considerable rains much of it percolates into the ground. It is interesting, therefore, to inquire how much of the rain falling *on land* is actually evaporated, and how much of it **sinks into the ground** under local conditions. Observations have been taken at Rothamsted, on the heavy loam there, during a period of sixty-six years. With an average annual rainfall of 29·158 in. it was found that 50·6 per cent. drained away through 20 in. of soil during that period, while the balance of 49·4 per cent. was evaporated into the air.

Owing to greater evaporation, less of the rainfall is lost by drainage during the *warmer months*. Thus in the half-year of October to March 71·5 per cent. of the rainfall received was lost by drainage, while in the warmer April to September period only 27·9 per cent. drained away. This land was never under crop.

Sunshine.—Light is necessary for the growth of crops (Chap. VI.), and if a bright warm summer often gives smaller

FIG. 33.—Campbell-Stokes' Sunshine Recorder.

yields, the cause may be sought in accompanying lack of rain. Hours of bright sunshine each day can be automatically recorded by an instrument (Fig. 33) which burns a tracing on prepared paper. In this country rather over 1,600 hours per annum is the average for the south coast, while in the north-east of England there is just under 1,300 hours ; in Italy, perhaps 2,600. Not only does sunshine promote ripening and better quality in cereal and fruit crops, but " roots " and forage are of higher feeding value in the brighter seasons. The reasons for this are not wholly understood.

CHAPTER X

CHEMICAL CONSTITUTION

A PIECE of matter is made up of extremely small particles called **molecules,** and there are always spaces between the molecules. Physical changes like melting and evaporation (Chap. VII.) are concerned with an alteration in the size or shape of the spaces between the molecules. Chemistry has to do with the constitution of the molecules themselves.

In a **pure substance** the molecules (Fig. 34) are all alike, but in a **mixture,** *e.g.*, of sugar and chalk, there is more than one kind of molecule. The different kinds of molecules in a mixture can be separated in various ways. Thus water will dissolve out sugar from chalk which is insoluble, and by pouring off the sugar solution and drying, the separate substances may be obtained pure. In determining chemical composition it is first necessary to obtain the substances pure.

A molecule of any substance is built up of small **atoms.** There are about ninety different kinds of atoms known to chemists, and practically speaking, one kind of atom cannot be changed into another kind of atom. The business of chemistry is to find out how many and what kind of atoms enter into the composition of one molecule of any particular substance.

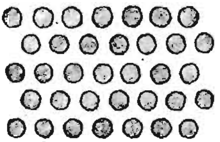


FIG. 34.—Pure Substances Consist of Similar Molecules.

In Table V. (page 47) is given for reference a list of the more important kinds of atoms.

The chemical symbol is usually the first letter of the Latin name. It is important to recollect that the symbol denotes not only the kind of atom, but it denotes only *one* atom of it.

The molecule is built up of atoms. In an **element,** the atoms composing the molecule are of the same kind. Thus free oxygen gas has each molecule composed of two atoms of oxygen, and any molecule of free oxygen may be written (O=O), or more easily as O_2. Similarly, free nitrogen gas has two atoms of nitrogen in every molecule, *i.e.*, N_2. These are elements. In **a compound** there is more than one kind of atom in a molecule. Thus carbon dioxide gas has two atoms of oxygen and one of carbon, and may be written (O=C=O), or more commonly as CO_2. In the same way water is a compound, and every molecule of water has the formula (H—O—H), usually written H_2O.

TABLE V

Some of the More Important Chemical Atoms

Name.	Symbol.	Atomic Weight.	Name.	Symbol.	Atomic Weight.
Metals.			*Non-metals.*		
Hydrogen .	H	1·0	Oxygen .	O	16·0
Sodium .	Na	23·0	Sulphur .	S	32·0
Potassium .	K	39·0	Nitrogen .	N	14·0
Magnesium .	Mg	24·0	Phosphorus .	P	31·0
Calcium .	Ca	40·0	Carbon .	C	12·0
Aluminium .	Al	27·0	Silicon .	Si	28·0
Iron . .	Fe	56·0	Chlorine .	Cl	35·5
Copper .	Cu	63·5			

The atoms which make up a molecule may be supposed to **hold together** by hands or bonds. Some kinds of atoms have more hands than others. See above. Oxygen has always two hands—it may be likened to a wheel-barrow. Hydrogen has only one hand—it may be likened to a man with one arm. How many one-armed men would be required to wheel a barrow? It would take two. Therefore when hydrogen unites with oxygen the molecule formed is H_2O (water), and never HO or HO_2. Similarly an atom of carbon has four hands. One may imagine that a four-handed man could wheel two barrows. When carbon is joined to oxygen, therefore, the new substance produced is CO_2, or carbon dioxide gas. The other kinds of atoms mentioned in the list have each a characteristic number of hands. Thus lime is the oxide of a metal called calcium, and a molecule of lime is represented by CaO. Calcium is obviously a two-handed element, because one atom of it can take the two hands of oxygen. It is unnecessary to delay over the varying combining power or **valency** of the different atoms; it is sufficient to know that it can account for the definite propor tion of the atoms to be found in a molecule of each different substance.

Table V. also gives the **atomic weights** of different kinds of atoms. There are *no artificial* weights small enough to weigh the atoms, so they are weighed against one of themselves. The hydrogen atom is the lightest in weight, so they are weighed against 1 atom of hydrogen. Carbon has an atomic weight of 12, which means that 1 atom of carbon has the same weight as 12 atoms of hydrogen. The atomic weights of the others mean the same thing.

The weight of a bushel of apples is the sum of the weights of each apple in the measure. So also the weight of a molecule is the sum of the weights of all the atoms composing it. Water has the formula H_2O. Referring to Table V. it seems that 2 atoms of hydrogen weigh $2 \times 1 = 2$, and 1 atom of oxygen $= 1 \times 16 = 16$. Adding together $2 + 16$ we get 18, which is the weight of all the atoms in a molecule of water. The **molecular weight** of water is thus 18, *i.e.*, it is 18 times heavier than 1 atom of hydrogen. In the same way it may be calculated that carbon dioxide (CO_2) has a molecular weight of 44, and lime (CaO) a molecular weight of 56.

A simple example may be given of the **use** of atomic weights. When carbon is burnt in oxygen (Chap. II.), a change takes place which may be shown by a chemical equation :

(Carbon) and (oxygen) give (carbon dioxide gas).

$$\underset{(12)}{C} + \underset{(16 \times 2)}{O_2} = \underset{(12+32)}{CO_2}.$$

Applying the atomic weights from the table as shown, it appears that 12 of carbon by weight, and 32 of oxygen, yield 44 of carbon dioxide gas. It is immaterial whether it is grains, or lbs., or tons—the figures are relative. How much carbon must be burnt to yield, say, 120 lbs. of carbon dioxide ? According to the equation 12 lbs. can yield 44 lbs., therefore $\frac{12 \times 120}{44}$, or 32·73 lbs., is the amount of carbon required.

There are about ninety different chemical elements. An important classification of these breaks them up into the two groups of **metals,** and **non-metals,** and most elements belong distinctly to one or other of those groups. The metals are not necessarily hard, nor are they all heavy. Generally, however, they are very opaque and possess a metallic lustre, and they conduct heat and electricity better than the non-metals.

Another important difference between the metals and non-metals is in the character of their **oxides.** All of the elements mentioned in Table V. form oxides—sometimes by burning in air, and sometimes in roundabout ways. Oxides of metals are known as **bases.** Oxides *of non-metals* when dissolved in water yield **acids.**

FIG. 35.—Chemical Laboratory at South-Eastern Agricultural College, Wye.

The following are the more important oxides of non-metals mentioned in the table, and the **acids** which are formed when they are dissolved in water :—

	Oxide.	Acid. Dualistic Formula.	Acid. Empirical Formula.	Name.
Sulphur	. SO_3	H_2O, SO_3	$=H_2SO_4$	= Sulphuric Acid.
Nitrogen	. N_2O_5	H_2O, N_2O_5	$=(2)\ HNO_3$	= Nitric Acid.
Phosphorus	. P_2O_5	$3H_2O, P_2O_5$	$(2)\ H_3PO_4$	= Phosphoric Acid.
Carbon	. CO_2	H_2O, CO_2	H_2CO_3	Carbonic Acid.
Silicon	. SiO_2	$H_2O. SiO_2$	$=H_2SiO_3$	= Silicic Acid.
Chlorine	. (Acid derived in different way)		HCl	= Hydrochloric Acid.

The empirical formula is the arithmetically simplest, but in following chapters the dualistic formula is often used where it seems to express facts more clearly. Students should be familiar with both.

Sometimes an element forms more than one oxide. For example, sulphur forms SO_2 as well as SO_3. In the former it may be said to keep some of its " hands " in its pockets. The name of SO_2 is sulphur*ous* oxide, and of SO_3—sulphur*ic* oxide. In such cases *-ous* in the name always means less oxygen. We thus have other acids from the three elements first named in the above list :—

	Oxide.	Acid. Dualistic Formula.	Acid. Empirical Formula.	Name.
Sulphur	. SO_2 . . .	H_2O, SO_2	$= H_2SO_3$	= Sulphurous Acid.
Nitrogen	. N_2O_3 . . .	H_2O, N_2O_3	$= (2)\ HNO_2$	= Nitrous Acid.
Phosphorus	. P_2O_3 . . .	$3H_2O, P_2O_3$	$= (2)\ H_3PO_3$	= Phosphorous Acid.

In each case the -ic acid is a stronger acid than the corresponding -ous acid. The additional " oxygen " increases the acid character of the compound.

Acids are sour substances, and set the teeth on edge. Acids are often tested for by blue *litmus* colouring matter which they change to red.

Only oxides of metals yield **bases.** If they are soluble, bases have a soapy taste and feel, and they turn red litmus blue. They are not acid but *alkaline.* The following are the principal bases formed from the metals quoted in Table V. :—

	Oxide.	Name.		Oxide.	Name.
Sodium .	Na_2O	= Soda.	Aluminium	Al_2O_3	= Alumina.
Potassium .	K_2O	= Potash.	Iron . .	Fe_2O_3	= Ferric oxide.
Magnesium .	MgO	= Magnesia.	,, . .	FeO	= Ferrous oxide.
Calcium .	CaO	= Lime.	Copper .	CuO	= Cupric oxide.

If a metal forms two basic oxides (*e.g.*, iron) the one with least oxygen is the stronger base (contrast acids).

It is useful to **memorise** the names and empirical formulæ of the commoner acids and bases.

Acids act upon bases to form **salts.** When this happens the hydrogens of the acid go to form water with the oxygens of the base, and *everything left* in both together unite to make up the salt. Acid and base must be used in proportions necessary to form water. This will be more clearly understood from a study of the following equations which are only given as examples and should *not* be memorised. In forming salts the -ic acids give -ate salts, and -ous acids give -ite salts. Salts of hydrochloric acid, however, are known simply as chlorides :—

Sulphuric acid and soda yield water and sulphate of soda.

$$H_2SO_4 + Na_2O = H_2O + Na_2SO_4.$$

Carbonic acid and potash yield water and carbonate of potash.

$$H_2CO_3 + K_2O = H_2O + K_2CO_3.$$

Nitric acid and lime yield water and nitrate of lime.

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

Phosphoric acid and magnesia] yield water and phosphate of magnesia.

$$2H_3PO_4 + 3MgO = 3H_2O + Mg_3(PO_4)_2.$$

Sulphuric acid and alumina yield water and sulphate of alumina.

$$3H_2SO_4 + Al_2O_3 = 3H_2O + Al_2(SO_4)_3.$$

Hydrochloric acid and ferric oxide yield water and ferric chloride.

$$6HCl + Fe_2O_3 = 3H_2O + 2FeCl_3.$$

Nitrous acid and lime yield water and nitrite of lime.

$$2HNO_2 + CaO = H_2O + Ca(NO_2)_2.$$

Another important base, which may be called ammonium oxide, is present when ammonia gas (NH_3) is dissolved in water :—

$$2NH_3 + H_2O = (NH_4)_2O.$$

This base also forms salts with acids, *e.g.*, sulphate of ammonia $(NH_4)_2SO_4$. The (NH_4) group behaves just like one K or one Na ; it acts like a business company as compared to the private trader.

When acids unite with bases to form salts, as in the above examples, they always unite in **definite proportions,** and if unlimited acid be used it depends upon the supply of base how much of the salt can be formed, and *vice versa.*

Salts may also be viewed as acids in which the hydrogen has been replaced by a metal atom (or atoms) of equal valency. Thus we get HNO_3—KNO_3—$Ca(NO_3)_2$. Also H_2SO_4—K_2SO_4—$CaSO_4$—$Al_2(SO_4)_3$, etc.

The salts we have considered are called "*normal salts*" because all the hydrogens of the acids have been replaced. Such salts are typically, but not always, neutral to litmus. There are, however, other kinds of salts. "Acid salts" have had only *part* of the hydrogens of the acid replaced by metal atoms— thus

$KHSO_4$ and $NaHCO_3$ (sodium bicarbonate) are acid salts. tain acid salts of phosphoric acid, *e.g.*, $CaHPO_4$, occur in m: Nitric acid (HNO_3) and hydrochloric acid (HCl) canno acid salts. Why ? " Basic salts " may also be formed.

But let us confine ourselves to the more important salts. If a salt formed from one acid and one base be with another acid, sometimes the new acid drives out t acid from the salt and forms a new salt. Thus when car of lime is treated with sulphuric acid, the carbonic acid is out with effervescence and sulphate of lime is formed in p the carbonate :—

$$CaCO_3 + H_2SO_4 = CaSO_4 + H_2O + CO_2.$$

This is an example of what is called **chemical displace** In the same way one base may drive out another base salt. Thus when ferric sulphate is treated with soda th phate of soda is formed, and the base (ferric oxide) is driv This may be shown here as follows :—

$$Fe_2(SO_4)_3 + 3Na_2O = 3Na_2SO_4 + Fe_2O_3,$$

or using the dualistic formulæ –

$$Fe_2O_3,\ 3SO_3 + 3Na_2O = 3(Na_2O,\ SO_3) + Fe_2O_3.$$

These equations mean the same thing. Chemical di: ments tend to be complete either when (*a*) one of the sub: formed happens to be volatile (like CO_2) and goes away, when it is insoluble (like Fe_2O_3) and retires from the comp In such changes an acid can never drive out a base from it in a salt, nor can a base drive out an acid.

A **hydrate** is a compound of water with a basic oxid sodium hydrate or caustic soda (Na_2O, H_2O), or more sim $NaOH$. Calcium hydrate is (CaO, H_2O) or $Ca(OH)_2$. hydrates are readily acted on by acids to form salts, an water is then set free, *e.g.* :—

$$Ca(OH)_2 + H_2SO_4 = CaSO_4 + 2H_2O.$$

Later chapters will at times give opportunity to exte knowledge of **chemistry** to particular branches of fa and for this the present brief notes will serve as an introd Separate study of chemistry, especially if accompanied by l tory practice, will be of undoubted advantage to the stude this is not always easy and the sections have been treate that difficulty in mind.

CHAPTER XI

ROCKS AND THEIR FORMATION

CARBON is an element. It occurs very pure in the diamond and in graphite, which are crystalline forms of carbon. It also occurs in lamp-black and charcoal, and in coal, which are more or less pure forms of carbon. In those cases the carbon is free. Carbon occurs in combination in all living things. Sugar, starch, fat, and albumin are formed in living things. They are *organic* substances. Organic substances always contain carbon. Carbon is thus of great importance in the organic world—the world of plants and animals.

Silicon is an element. In many ways it resembles carbon. There are crystalline forms of silicon which correspond to the diamond form of carbon, and also to graphite. Silicon also occurs in non-crystalline forms which may be compared to lamp-black. It is a dark brown powder. In those cases the silicon is free, but free silicon must be prepared by the chemist. Silicon occurs in combination in the great majority of rocks, which thus contain silicon as an essential constituent. The place of silicon in the *mineral* world, indeed, is in many ways comparable to the place of carbon in the organic.

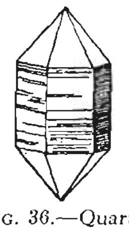


FIG. 36.—Quartz, or Rock Crystal.

When carbon is burnt in air, carbon dioxide (CO_2) is formed. This is a gas. Similarly when silicon is burnt in air, silicon dioxide (SiO_2) is formed. The latter, as it happens, is not a gas but a solid substance. Chemically speaking this is a detail. Silicon dioxide is usually known as **silica.**

Silica occurs nearly pure in flint, and in ordinary sea sand. There is no occasion to burn silicon in order to obtain silica, because the latter is very abundant in nature. Quartz or rock crystal (Fig. 36) is chemically pure silica.

When carbon dioxide is dissolved in water, carbonic acid is produced. With bases this forms carbonates, *e.g.*, with lime carbonate of lime, or with soda, carbonate of soda, and so on.

In the same way, when silica is dissolved in water, silicic acid is formed. Silica or sand, it is true, will not directly dissolve in water, but there are roundabout ways of dissolving silica in water, Silicic acid is then formed. With lime it forms **silicates** of lime. and with soda—silicates of soda. A large part of the existing rock masses is built up of naturally occurring silicates and of free silica.

When substances solidify they usually take a definite geometric shape and form **crystals.** The shape of crystal depends on the kind of solid. Calc spar is crystallised carbonate of lime, and the form is that of an obtuse rhombohedron (Fig. 37) whose terminal edges make an angle of 105°. All crystals of calc spar form this figure, and if the angle is not 105° the substance is not calc spar. Similarly common salt has one definite form of crystal and cane sugar has another. Examine some crystals of coarse sugar and observe that, while they may vary in size, all have the same shape. Sugar cannot be made to crystallise like salt, nor salt like sugar. Some substances have no definite or crystalline form at all, *e.g.*, glue, and such substances are termed *amorphous*.

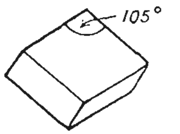


FIG. 37. — Crystal of Calc Spar.

Crystals can be formed when the solution of a crystalline solid is evaporated down. If a solution contain two dissolved solids, then, in general, separate crystals will be obtained of each. Thus if a mixed solution of sugar and salt be dried up, the crystals formed could be sorted out into two heaps and the sugar and salt separated from each other. The more slowly a solution is dried up the *larger* will be the crystals, but their shape will be the same.

Crystals can also be formed when a melted solid is gradually cooled. This is well seen in the cooling of melted sulphur, or in cooling water when crystals of ice are formed. With slow cooling, large crystals are produced, but with rapid cooling it might be difficult to see them.

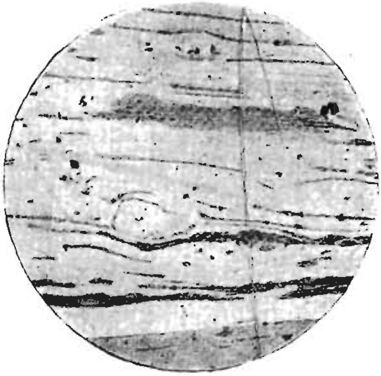
Rocks are generally classified into—

(1) Igneous rocks ;
(2) Derivative rocks ;
(3) Metamorphic rocks.

1. The **igneous rocks** have consolidated by cooling of the molten matter of the earth's substance. Where the cooling was slow—being deep down from the surface—the igneous rocks exhibit a well-defined crystalline character (Fig. 38), as in granite. Where the cooling was rapid the same separation of constituents

was not obtained, and the appearance is more glassy or vitreous (**Fig.** 39), as in obsidian.

FIG. 38.—Microphotograph of Granite.



[*Photos, Geol. Survey (Crown Copyright Reserved*).

FIG. 39.—Microphotograph of Obsidian.

In crystalline igneous rocks definite **minerals** can usually be identified by their shape. Thus granite contains crystals of quartz, felspar, and mica. The composition of a rock depends upon which minerals it contains. The following are some of the *principal minerals* occurring in igneous rocks, and it is sufficient to refer to them :—

Quartz—Silica (SiO_2).
Felspars—
- (*a*) Orthoclase felspar—Silicate of alumina and potash (Al_2O_3, K_2O, $6SiO_2$).
- (*b*) Plagioclase felspars—
  - (1) Albite — Silicate of alumina and soda (Al_2O_3, Na_2O, $6SiO_2$).
  - (2) Anorthite — Silicate of alumina and lime (Al_2O_3, CaO, $2SiO_2$).

Micas—Silicates of alumina and potash (or soda), some kinds containing magnesia and iron.

Amphiboles—Silicates of lime and magnesia—often with alumina and iron ; example—hornblende.

Pyroxenes—Much similar to amphiboles, and containing silicates of lime and magnesia ; example—augite.
Olivine—Silicates of magnesia and iron.

The mineral composition of granite has already been given. Basalt, another widely occurring rock, contains as crystalline minerals plagioclase felspar, augite, and usually olivine. Sufficient has been said to **indicate generally** that the primitive or igneous rocks consist of a complex mixture of silica and silicates, and may supply potash, soda, lime, magnesia, and oxides of iron.

Besides the chief minerals named above, small quantities of the following are widely distributed in rock masses as chance or *accessory minerals* :—

Magnetite—an oxide of iron.
Apatite—phosphate and fluoride (or chloride) of lime.
Pyrite—disulphide of iron (FeS_2).

These can supply iron, phosphoric acid, and sulphuric acid, which all play an essential part in crop nutrition.

2. The **derivative rocks** have been formed from the breaking down of the primitive igneous rocks, or it may be of other derivative rocks which in an earlier epoch had themselves been formed from igneous rocks. The products from such breaking down of older rocks were often laid down subsequently in water, and hence many of them are referred to as *sedimentary* rocks. Important among these are—

(*a*) Sandstones.
(*b*) Clay Shales.
(*c*) Limestones.

(*a*) *Sandstones*, *grits*, and *conglomerates* have as their main constituent sand, but usually mixed with small portions of the original silicates and other minerals. The sandstones vary in colour according to the cementing material which binds the grains together. In white sandstone it is often lime, and in red it is oxide of iron (rust) ; sometimes there is no cementing material, and the material has become consolidated by pressure alone.

(*b*) *Shales* or *clays* are also decomposition products of older rocks, but were laid down from deeper and quieter water than were the sandstones. In them the clay is usually mixed with fine particles of undecomposed felspars and other minerals. Shales are clays which have become hardened through pressure.

Boulder clay has been produced and transported by moving masses of ice (glaciers), and was not laid down in water.

(*c*) *Limestones* contain principally carbonate of lime, but a large variety of constituents is usually present as impurities. Limestones were formed from the remains of marine and sometimes fresh-water life.

The derivative rocks typically contain **fossils** -the long-dead remains of prehistoric animals and plants. The relative ages of rocks can be told by biologists who have made a study of the ancient life on the Earth ; this study is known as *palaeontology*. It would not be expected that igneous rocks could contain any fossils.

3. **Metamorphic rocks** were formed either from the igneous or from the derivative rocks. Heat, as from an intrusion of molten lava, or extreme pressure owing to cooling and contraction of the Earth's crust, induced changes in the earlier rock. In these ways granite was changed into gneiss, limestone into marble, and clay shales into clay slates. Such rocks are often very hard.

Chapter XII

ROCK WEATHERING AND SOILS

Before rocks can be used for the growth of crops they must be broken down into soil. This work is effected by various natural agents in the process known as "*weathering*." Weathering causes both mechanical and chemical changes in the material of hard rocks.

The changes caused by weathering are not only of historical interest ; they are slowly going on to-day, and have their influence on soil fertility. The following are the principal agents concerned in the weathering of rocks :—

Changes of Temperature.—Substances expand when they are heated. Rocks are not good conductors of heat like the metals, and during daytime the surface may become much hotter than the mass of rock underneath. The effect of this is unequal expansion, setting up strains in the rock which may cause it to fracture. A similar effect may be produced by pouring boiling water into a thick glass bottle. In dry tropical countries, with their greater daily range of temperature, the effect is naturally greatest, and rocks may be shattered to a depth of several inches. For various reasons the rocks showing well-marked crystalline structure are particularly vulnerable, and tiny fissures are produced at the surface scarcely visible to the eye. Fissures and cracks so formed admit the entrance of other weathering agents, and greatly increase the amount of surface exposed to their action.

Freezing Water.—Most liquids contract when they solidify. For certain reasons, water behaves in an anomalous fashion when it *crystallises* as ice ; on freezing it expands by about one-eleventh of its original volume.[1] The pressure exerted by freezing water is enormous, and a pressure of 75 atmos. is required to lower the freezing point by 1° F. In the higher latitudes of the Earth, frost is a powerful means of breaking down rocks where water has gained entrance by any means. The more porous rocks naturally break down more quickly, while cracks and fissures allow entrance to water which on freezing makes the cracks wider. On clay soils in England it is of great benefit to plough before the winter frosts ; these break down the furrow slices by freezing the contained water. When the ice subsequently melts it contracts and the water runs out or dries up, leaving the soil loose for the harrows.

Moving water and ice have a mechanical action. The wearing action of water is seen from the rounded stones of a modern stream ; the extent of this action in times past can be inferred from the water-worn appearance of ordinary gravel. The worn-off corners of the stones have largely gone to form sand and silt which are insoluble. The waves of the sea in many places rapidly wear away the coast-line, and rocks fall among the breakers. Glaciers or rivers of ice do not grind quickly, but " they grind exceeding small." The result is deposited as boulder clay or till. Closely connected with moving water and ice is the action of wind. In wind-swept country the wind often carries dust and grit, which act upon the rock surface like a sand-blast ; bathers on sandy beaches during high winds can realise this.

[1] In crystals the molecules always occur in definite placings which may also involve irregular spacings—like a few bricks which are spaced so as to provide ventilation through a wall. The development of such spacings in ice would explain the expansion of water on freezing, even although the molecules at their nearest points had come closer as required (Chap. VII.) for solidification. Amorphous substances *always* contract on solidification.

Air.—Dry air has no weathering effect upon dry rocks. When dissolved in water, however, the oxygen and carbon dioxide of air are potent factors in bringing about their decomposition. The action is chemical.

The action of *oxygen* is naturally confined to those rocks which are capable of further oxidation. Iron when fully oxidised is like iron rust ; the presence of fully oxidised iron then gives a yellow, brown or red colour to a soil or rock. Iron may also be present in rocks in a form which is not fully oxidised, and then the colour due to iron is often dark green to black. Many dark-coloured rocks, such as basalt, contain this partially oxidised iron, and when these are exposed to moist air the colour changes gradually to red—the original composition of the rock being altered. Oxidisable iron is a weakness so far as the rock is concerned, and it is partly on this account that dark basaltic rocks rich in iron yield soils of high agricultural value, and of the "red" colour which the practical farmer tacitly recognises as a good sign.

The action of carbon dioxide in water (*carbonic acid*) is also important, and unlike oxygen it operates upon almost all kinds of rocks. It dissolves certain constituents from them, the carbonic acid then forming carbonates. A characteristic action is that upon felspars which so often are present in igneous rocks. Felspars are silicates of alumina and potash, but sometimes soda or lime substitutes for the potash in felspar (Chap. XI.). From potash felspar, carbonic acid takes away the potash forming carbonate of potash which is a soluble substance, while the remainder of the felspar combining with some water is converted into *clay*. Clay is just silicate of alumina with some combined water. With soda felspar, carbonic acid gives carbonate of soda and clay ; with lime felspar it gives carbonate of lime and clay. Other silicate minerals are more or less slowly decomposed by carbonic acid, which dissolves out part of the mineral forming a carbonate.

Granite contains quartz, felspar, and mica. The felspar is the most easily attacked by carbonic acid, the mica with difficulty, and the quartz not at all. When the felspar is thus destroyed the granite falls to pieces. The quartz which is mechanically liberated from the minerals surrounding it (Fig. 32) appears as sand, and the as yet undecomposed mica can often be seen as glistening plates.

Sand and clay are thus common products of the weathering of rocks, and of the undecomposed rock particles present in ordinary soils.

Animals play a certain part in the weathering of rock particles. In temperate climates *earthworms* help to grind up the smaller particles, which they pass through their bodies and deposit on the surface. Darwin estimated the amount might reach 10 tons per acre per annum. In tropical countries white ants probably carry on the same kind of work. The part played by larger animals may be left to the imagination.

Plants help in the breaking down of rocks in three ways. The roots force their way down through rock crevices and through soil, and when they decay, a passage is left for the movement of air and water. Again, the roots of living plants develop a slight acidity, which slowly eats away the soil minerals. Not the least important effect of plants is obtained after they die—in their decay carbonic acid is produced and is available to attack the soil minerals. The full effect here is only reached when the plant is buried, and the farmer does this by " ploughing-in " stable manure or green crops grown for the purpose. The effect of bacteria—the smallest of all plants—needs only to be acknowledged at this time.

Kinds of Soil.—The weathering of rocks, by the various agents described, results then in the formation of a soil. The soil may remain where it was formed, or it may be carried away by moving water or by wind and deposited at some other place. In the former case we have what are called *sedentary* or bed-rock soils ; in the latter *transported* or drift soils. In a sedentary soil the character of the soil must be related to the rocks which underlie it, but in a transported soil there is no such relationship.

Sedentary soils are usually found on rock plateaux and level country where the surface drainage is not sufficient to carry off the products of weathering. On digging down, the upper layer to a depth of from 3 to 9 in. will be found to consist of finer or coarser particles, and, owing to decaying plant remains, will usually be rather dark in colour. This constitutes the *soil* proper. As we proceed downwards, the soil is at first somewhat finer grained—more particularly in humid districts, and is also lighter in colour. This is the *subsoil*. At greater depths fragments of loose bed-rock will be scattered through the subsoil in increasing numbers and size, until the solid rock is (Fig. 40) reached. The surface of the bed-rock is often much fissured, but as the fissures are followed downwards they gradually close up. In those changes it will be seen that the passage from soil down to rock is a gradual one.

Transported soils were carried from the parent rocks by moving ice or water or by wind. From moving ice, deposits of *boulder clay* were laid down. Soils which were deposited by rivers are termed *alluvial*; these contain chiefly silt, sand, or still coarser material, according to the velocity of the water at the time they were laid down. Owing to the variety of their constituents, their depth, and their fine texture, such alluvial soils are often extremely fertile. Typical examples are seen on the banks, flood plains, and deltas of great rivers. Soil transported by wind include the *sand-dunes* of maritime and certain inland districts of dry countries.

[*Photo, Geol. Survey (Crown Copyright Reserved)*.

FIG. 40.—Sedentary Soil Merging Downward into Rock.

CHAPTER XIII

COMPOSITION OF SOILS

IT is a matter of common knowledge that no two soils are exactly alike. Soils vary in character according to the rocks from which they were formed, the extent to which weathering has taken place, the amount of washing or leaching to which they have been subjected, and to the suitability of the climate for producing a vigorous plant growth. In lands under cultivation, the character of the soil also depends upon the treatment it has received from the farmer. The variability of soils is one of the main reasons why we should understand them, because in farming more than in the manufacturing industries it is impossible to conduct the management by rule of thumb.

In its natural state a **soil contains:**

Mineral matter.
Organic matter.
Water.
Gases.
Bacteria.

The mineral matter is derived from rocks, and forms by far the largest constituent in ordinary soils. The organic matter represents the remains chiefly of decaying vegetable matter, and is referred to as "humus." The water is received from the clouds as rain, or by drainage from higher lands. The gases enter by diffusion from the air above, or are partly manufactured within the soil (carbon dioxide). All healthy soils contain bacteria or plant germs.

The first three of these constituents are practically responsible for the total weight of any soil. To find the **percentage** of each of them the soil is first well mixed. Then about one-sixth of an ounce is weighed out in a small tared dish and thoroughly dried at steam heat (212° F.); on again weighing, the loss of weight equals *water* and can be calculated as percentage on the soil taken. The dry soil remains. This may then be heated to low redness over an open flame to burn out all the organic matter and weighed again. The loss of weight this time includes the *organic matter*, and it also may be calculated to a percentage. What is left in the dish represents the *mineral matter* of the soil.

The **mineral matter** of soils contains a great variety of substances. Some of these are required for the nourishment of crops. Crops absorb their mineral substances in solution (Chap. V.). Some of the mineral substances in soils are so extremely insoluble that it is not worth while to consider their composition. Others of them are insoluble, but not so insoluble but that they may become available for crops within a reasonable period. In practice, hot strong hydrochloric acid (spirits of salt) is often employed by chemists to extract the mineral ingredients of soils--the part remaining undissolved by the acid being then classed as " insoluble."

In Table VI. (page 64) are given the analyses of two soils *for purposes of illustration only.* Soils may vary within wide limits and the figures indicate this. Soil A here is a good one and Soil B is not. The results have been calculated on the dry soils.

The **insoluble matter** forms the main bulk of both samples. Generally speaking, it may be said that the amount of a soil which

[*C. Reid, Lanarkshire.*

FIG. 41.—Good Land is required for Expensive Crops.

is insoluble in the hot concentrated acid used for its extraction varies from 65 to 95 per cent. of its whole weight ; occasionally there is less. This insoluble matter always comprises sand, undecomposed silicates, clay, and other intractable materials which cannot be reckoned on to provide soluble plant food for crops. Sometimes the insoluble matter is very fine-grained material, and at others it is much coarser. If composed chiefly of sand it may be very coarse ; when composed of clay particles it is much finer. This would be expected when we recollect that clay was formed by chemical action from the parent rocks, while the sand grains had only been mechanically freed when the cementing material (felspar, etc.) was dissolved away. Soils, therefore, which contain much clay are always fine-grained, while sandy soils may be very coarse. Clay is a compound of alumina, and soils which yield much alumina on ordinary analysis are sure to be fine in texture.

But the main object of a chemical analysis is to get information as to the probable supply of **plant food materials** within the soil. Crops demand from soil seven essential constituents—nitrogen,

TABLE VI

Chemical Composition of Two Soils (per Cent.)

Soil Constituents.	Soil A.	Soil B.
Insoluble matter	70·87	95·15
Soluble silica	0·05	0·04
Potash	0·36	0·06
Soda	0·13	0·02
Lime	0·33	0·03
Magnesia	0·03	0·01
Manganese oxide	0·05	0·07
Ferric (iron) oxide	4·37	1·06
Alumina	9·13	0·66
Phosphoric acid	0·09	0·02
Sulphuric acid	0·21	0·02
Carbonic acid	0·03	0·02
Organic matter, etc.[1]	14·16	2·56
	99·81	99·77
[1] *Containing nitrogen*	0·17	0·04

phosphoric acid, potash, lime, magnesia, iron oxide, and sulphuric acid. Varying amounts of each of these are present in all soils, but the supply of each of them always appears insignificant when stated as a percentage of the whole soil.

Bulk for bulk some soils are rather heavier than others, but 1 acre of soil to a depth of 9 in. generally weighs about 3 million lbs. (1,340 tons). If a soil contains 0·075 per cent. of any constituent this will be equal to 1 ton per acre, so that even a small percentage of any plant food material means a considerable actual amount. Referring to the table it will be seen that " Soil B " contains less than 1 ton per acre of the principal ingredients of plant food ; the " Soil A " is better, and contains usually from

1 to 4 tons. These amounts are typical of what may be expected under ordinary conditions.

Besides the plant food constituents, soils always yield on extraction with acids certain **other constituents** which are not essential to crops, but may have a limited use. These are not as a rule important, and include soda, manganese, and soluble silica. Carbonic acid is, however, important, as its presence in

[*Photo. J. Dixon-Scott.*

Fig. 42.—Poorer Land is adapted only for Grazing. On Leithen Water, Peeblesshire.

considerable amount implies a sufficiency of carbonate of lime (Chap. XXII.), or other base.

Nature of the Soil Compounds.—A salt is composed of an acid and a base. In the table, phosphoric acid and lime are both stated, but there is no reference to phosphate of lime. The reason is that other bases besides lime are also present, *e.g.*, magnesia, iron oxide, and alumina, and it is impossible to say from ordinary analysis to which of the bases the acid was united. In the soils referred to, the phosphoric acid may have existed chiefly as phosphate of iron. To get over this difficulty the acids and bases are always stated separately, it being understood that they did not exist separately within the soil.

The particular bases with which an acid is united has an intimate bearing, however, upon the rate at which it becomes available to crops. In the same way the particular acids with which a base is united has a bearing upon its solubility. The rate, indeed, at which the various acids and bases become available for plant nutrition depends in very large measure upon the nature of the compounds in which they exist within the soil. This matter will be discussed more fully in another chapter.

Value of Soil Analysis.—An ordinary chemical analysis can only show that the materials are present, and it does not indicate the rate at which these will become available for the use of crops. On this account it cannot be used as a guide to the manurial requirements of the land. It can only indicate probabilities. If one soil, for example, contains twice as much potash as another, there is a chance that the first soil will each year yield about twice as much potash as the second as a result of weathering. *There is, however, no certainty.* Analysis, indeed, is more useful in indicating the deficiencies than the sufficiencies of a soil. If a soil shows an abnormally low percentage of phosphoric acid or of potash it is highly likely to be infertile.

The **organic matter** of soils is estimated from the loss of weight on burning. It is known as *humus.* Some soils, and especially clay soils, contain combined water which had not been lost at the temperature previously used for drying the sample, but which is lost at the higher temperature used for ignition. In such cases the loss of weight on burning is not wholly due to organic matter, and on this account the humus content of clay soils is apt to be overstated.

The **nitrogen** of soils is almost wholly contained in the organic matter. All of the other plant food materials mentioned in the table were derived more or less directly from the weathering of rocks.

CHAPTER XIV

NITRIFICATION AND HUMUS

Humus is the name given to the decaying vegetable matter of soils. Unless the supply is renewed by an addition of new vegetable matter as in crop residues or farmyard manure, the quantity of humus in a soil will gradually decrease.

The best part of a farm is usually the farm garden. The result is brought about by frequent applications of farmyard manure, coupled with deep and thorough cultivation. Almost any kind of loose soil material can be rendered fertile in this way. The manure forms humus in the soil. Humus changes a dead soil into a living one, and by its presence a sand-pit or a brick-field may be gradually converted into a garden.

In a state of nature the humus supply of soils is maintained by the roots of decaying vegetation, and the dead leaves falling upon the surface. Where the soil is well furnished with phosphoric acid, potash, and the other essential minerals, the next crop is better than the one before it, and a good pasture goes from good to better. A suitable climate is necessary to this self-improvement of a good soil. With a poor soil or climate the annual residues of one season are barely sufficient to restore the natural wastage of humus, the next crop is poorer than the one before, and the poor soil goes from bad to worse. Deterioration proceeds until a balance is reached at which only an inferior class of herbage can hold the ground.

Humus confers a variety of **physical benefits** upon the soil. It improves it for holding moisture between rains ; it loosens up stiff clay soils, allowing air and water to enter ; and it binds the particles of coarse sands. These matters will be considered in detail at another time. Humus, especially when wet, gives the darker colour to soil. There is little humus in the subsoil, and the change from soil down to subsoil is usually marked by a lighter colour.

Chemical Changes in Humus.—The transformation of vegetable matters to form humus, and the further changes in humus within the soil, are brought about by various low forms of life, and especially by bacteria (Chap. L.). The number of these may amount to several millions per cubic inch of soil. Some kinds of bacteria can decompose the humus in wet soil and in the *absence of air*, but under those conditions the decomposition stops before it is complete. The products are an acid form of humus containing " humic acid," which renders the soil sour. Such acid humus accumulates in wet swamps and in peat bogs, and it accumulates there not because the water makes them wet but because the water shuts out the supply of air.

When *air can penetrate* the soil, the decay of humus does not stop at the production of humic and similar acids within the soil. By the aid of atmospheric oxygen the bacterial changes go further, a milder form of humus is produced, and the oxidation goes on to the end. Carbon dioxide and water are final oxidation products (Chap. II.) of the humus. These final changes involve the disappearance of humus from the soil, but they are necessary. The value of acid humus is not realised in the crop. A soil not only requires humus, but it requires that it shall decay.

Vegetable matter **decays** within the soil to form humus **gradually**. In the later stages of decay the valuable nitrogen, phosphoric acid, and potash of the humus become available for crops. Rotted farmyard manure is immediately effective. Where, however, fresh vegetable residues like straw are ploughed in *shortly before planting* a crop, the initial effect of the fresh straw is to cause a temporary lowering of fertility. The bacteria causing decay set to work vigorously upon fresh straw, and they increase rapidly in numbers. Now, these bacteria are plants, and we must remember that like the crop plants they also require nitrogen, phosphoric acid, and potash for their growth. Within the soil they compete with the young crop for these things, and the crop suffers from the competition. This injurious effect of the fresh straw is only a passing phase, however, because the activity of the germs slows down as the decay advances, and ultimately the manurial constituents of the straw and of the dead bacteria become available to the crop. The final result is beneficial provided the crop outlives the first feverish activity of decay germs induced by the buried straw.

The **amount** of humus varies in different soils. In swamp land it may form the main bulk of the dry sample, but in ordinary soils it is usually under 5 per cent. As free access of air encourages the decay of humus, *cultivated lands* soon contain less than grazing paddocks alongside. Again, as regards soil types, *sandy soils* usually contain less humus than clays because the former are more pervious to air, and their humus is more rapidly used up. Then, again, *lime* stimulates the bacteria which decompose humus, and soils deficient in lime are often richer in humus just because this deficiency exists. It should be remembered, however, that while cultivated soils, sandy soils, and lime (calcareous) soils contain less humus, they can for the same reasons afford to contain less, because owing to its more rapid decomposition in these soils the benefits are more quickly reaped.[1]

[1] The useful bacteria in soils have apparently certain enemies in the form of larger organisms—*protozoa, etc.*—which tend to destroy them,

Soil Nitrogen.—The chemical changes in the decay of humus are closely bound up with the supply of combined nitrogen required by growing crops. There are three actions to be considered :

Nitrification.
Denitrification.
Fixation of free nitrogen.

Nitrification.—Ordinary crops cannot use the free nitrogen of the air (Chap. I.), but must obtain combined nitrogen from the soil. Humus contains combined nitrogen. Indeed, the stock supply of soil nitrogen at any time is contained in its humus. But humus cannot directly satisfy the demands of a crop for combined nitrogen. The nitrogen is not in a proper form of combination, and, moreover, it is too insoluble. Crops cannot use it. The nitrogen of humus must first be changed into simpler compounds of nitrogen within the soil.

Ammonia and nitrates are such compounds. Of those two simpler compounds of nitrogen, nitrates are the more effective form, and, indeed, the only form with which many of the farm crops can reach their fullest development.[1] The production of nitrates within the soil is thus essential to successful cropping. They are produced from the nitrogen of humus. The work is performed by different kinds of bacteria. It is carried through by stages. One kind of bacteria start on the nitrogen—often called *organic nitrogen*—of the humus and convert it into *ammonia*. Then another kind of bacteria (Fig. 43) start with the ammonia produced and convert it into *nitrites* ; then still another kind

just as the white corpuscles in the blood of an animal are believed to antagonise bacteria causing animal disease. These enemies have been found more easily killed by sterilisation than the useful soil bacteria, and by heating soil so as to *partially* sterilise it, the beneficial bacteria are ultimately benefited because their enemies had been killed. Larger crops follow, and partial sterilisation is therefore sometimes employed (in horticulture) for glass-house soils.

[1] Proteins formed by plants are highly complex organic compounds of nitrogen, and their formation is preceded by the building up of simpler compounds containing the "one-handed" amino group $-NH_2$. Such, for example, is asparagine ($CONH_2.CH_2.CHNH_2.COOH$). Such "amide" substances are derivates of various organic acids, and are also closely related to ammonia (NH_3). It is possible that nitrates give better immediate results as a fertiliser than do ammonium salts because (1) they supply *active* $-NH_2$ during their reduction, (2) the oxygen of the nitrate favours oxidation of carbohydrate to organic acid, viz., $2HNO_3 + H_2O = 7O + 2(-NH_2)$.

(Fig. 44) go on to convert these nitrites into *nitrates*. Under favourable conditions these final changes from ammonia up to nitrates are all completed in a few weeks, but the first change from organic nitrogen to ammonia may be spread over several years. The last nitrogen of old humus is very refractory, and the ammonia-producers find increasing difficulty as time goes

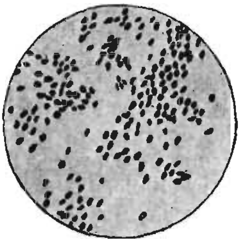


FIG. 43.—*Nitrosomonas europæa* (× 600). (Percival.)

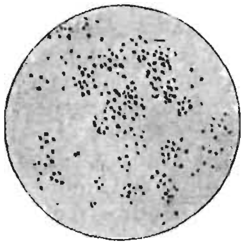


FIG. 44.—*Nitrobacter* Sp. (× 600). (Percival.)

on. The manufacture of nitrates within the soil is known as nitrification.

The following are the conditions for nitrification :—

(1) Soil nitrogen must be present, *e.g.*, as in humus ;
(2) The nitrifying organisms must be present ;
(3) Fresh air—no nitrification in a clay subsoil ;
(4) Darkness—sunlight stops or kills the organisms ;
(5) A suitable temperature—stops in cold weather ;
(6) Sufficient soil moisture—stops in very dry weather ;
(7) Carbonate of lime or other base must be present, and sour lands are unfavourable.

Nitrification by bacteria results in the production of a nitrate, *e.g.*, potassium nitrate (KNO_3), or calcium nitrate $Ca(NO_3)_2$. It will be observed that there is much oxygen in nitrates, and nitrification is a process of *oxidation*.

Denitrification means the destruction of nitrates already present in the soil. Some kinds of bacteria require free oxygen to enable them to live, and such are *aerobic* organisms. The bacteria causing nitrification are aerobic, and other aerobic forms are chiefly responsible for the decay of humus in well-aerated soils. *Anaerobic* bacteria do not require free oxygen, but they can use the combined oxygen of nitrates to oxidise the humus. Denitrification is caused by anaerobic bacteria working in this way. When it occurs the nitrate loses oxygen and is broken up; its nitrogen may then escape into the air partly as free nitrogen gas.

Denitrification, and consequent loss of nitrates is most likely when the land is waterlogged, because the water keeps out fresh air; it is also most serious when the soil contains easily oxidisable humus upon which the anaerobic germs can work. Nitrate of soda, often used as a fertiliser, is easily lost by denitrification when applied to crops on wet or swampy land.

Reduction is a chemical term used to signify taking away oxygen from a substance; it is the opposite of oxidation. In denitrification, the nitrates of the soil are reduced.

Fixation of Free Nitrogen.—Ordinary crops require combined nitrogen, as in the nitrates formed from humus. If a soil is deficient in combined nitrogen the crops will be poor, unless easily available nitrogen is supplied in fertilisers. There are, however, certain kinds of bacteria, viz., *Azotobacter* (aerobic) and *Clostridium* (anaerobic), which are able to combine with free atmospheric nitrogen, and leave it in the soil for the use of crops. These nitrogen-gainers can work only when *easily oxidisable humus* is present in the soil. The soil is then enriched in nitrogen, apart from any nitrogen originally present in the humus. The ploughing in of stubble or straw can cause some gain of nitrogen from the air. It appears that the *Azotobacter* is much more active in warm weather.

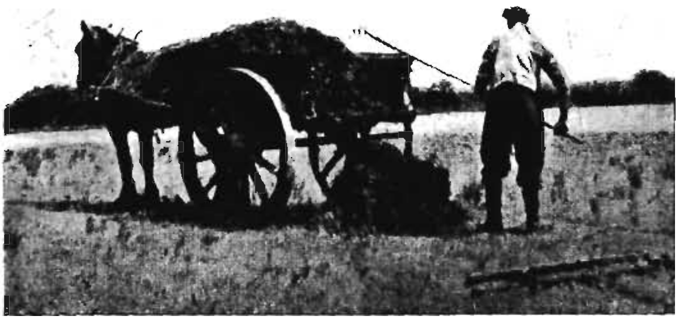
Compared with the very vigorous fixation of free nitrogen effected by certain bacteria working in the roots of leguminous plants (Chap. XXI.), the fixing of nitrogen by those free bacteria of the soil is relatively weak. The two processes are not to be confused.

The **various changes** in the decay of humus, and in the nitrogen of soils connected therewith, are each of them the work of **micro-organisms,** and especially of bacteria. If a soil be artificially sterilised by heat or by antiseptics, none of the changes above mentioned will occur. A good humus supply stimulates the bacterial life of the soil.

CHAPTER XV

MANURIAL REQUIREMENTS OF SOILS

CROPS draw from the soil *seven* necessary constituents. These together form about 5 per cent. of the dry weight of the crop. This small amount is made up of nitric acid, phosphoric acid, potash, lime, magnesia, iron oxide, and sulphuric acid. The substances are absorbed in solution. By the "law of the minimum" (Chap. V.), if any one of the seven necessary constituents be deficient in amount the yield of crop will be deficient in consequence.



[*Photo, by courtesy of A. Voysey.*

FIG. 45.—One Way of Meeting Manurial Requirements.

Whether or not any of the seven soil constituents will be found deficient depends not upon the total amount which the soil contains but upon the amount which it contains in a form sufficiently soluble for the crop to take it up. In practice, experience shows that only three of the seven constituents are liable to be deficient in soluble forms, and therefore the other four essentials cause no worry to the farmer. The three constituents liable to be deficient in soluble forms are *phosphoric acid*, and *potash*, and nitric acid or nitrate *nitrogen*.

Manures, or fertilisers, are employed to supply soil deficiencies in soluble **phosphoric acid,** or **potash,** or **nitrogen.** Some manures supply only one of these three at a time, some supply two, and some supply all three of them. Manures which supply only one or two of the substances are called *special* manures, while those which supply all three are *general* manures. The manurial requirements of a soil are determined by its deficiencies.

The action of manures is direct. They supply what is deficient, and in a form which is generally easily absorbed in solution by the growing crop. If a manure contains its fertilising constituent in a form which cannot be soon absorbed by the crop it has a very low value indeed.

English Soils.—Experience shows, then, that the supply of phosphoric acid, potash, and nitrogen in the soil are of special importance. The value of a soil analysis largely centres round those three constituents. In Table VII. are shown the amounts found in typical soils from Kent and Surrey by Hall and Russell. For convenience the figures are stated in parts per 100,000.

TABLE VII

Certain Food Constituents in Soils (per 100,000)

Soil Group.	Phosphoric Acid.	Potash.	Nitrogen.
Chalk	180	500	250
Clay and loam (average) .	110	540	160
,, ,, (waste lands) .	110	1,000	330
Sandy (average) . . .	130	470	150
,, (waste lands) . .	70	140	430

As in an ordinary soil analysis, the minerals given are the amounts extracted by hot concentrated acid.

Phosphoric Acid.—The results are fairly typical of the different classes of land. Chalky or calcareous soils are usually well furnished with phosphoric acid—the carbonate of lime which they contain being of organic origin. Clays, on the other hand, are often poorly supplied with phosphoric acid, and therefore respond better to phosphatic manures. The effect of basic slag (a phosphatic by-product) in improving second-rate pastures has been particularly noticeable on clay soils. Sandy soils, too, are often deficient in phosphoric acid, and especially the poorer kinds known as waste or "commons." The application of phosphates alone on such soils, however, would often be disappointing, because sandy soils are typically poor in potash at the same time.

Attempts have been made by eminent authorities to lay down **standards of sufficiency** for phosphoric acid in soils. Those showing less than 50 parts per 100,000 have commonly been classed as "poor"; those from 50 to 100 parts as "medium"; and those over 100 as "normal to good." In the table all the soils except the sandy waste would come into the "normal" class—the soil mentioned being definitely below it.

The total amount of phosphoric acid in a soil is not, however, everything, because by far the greater portion in all soils exists in an insoluble form which the crops are unable to utilise. The ease with which it can be dissolved is important. Phosphoric acid is more easily dissolved from some of its combinations than from others. Generally speaking, a good percentage of lime in a soil indicates that its phosphoric acid will become more quickly available, because phosphate of lime is more readily dissolved than phosphate of iron, which is often the chief phosphate where lime is deficient. In order to cast light upon the rate at which the phosphoric acid of a soil is likely to become available for the use of crops, a method of analysis suggested by Dyer is now widely used to supplement the older methods. Here the soil is extracted not by hot concentrated mineral acid but by a cold 1-per cent. solution of citric acid—it being claimed that this weak acid approached the average acidity developed at the roots of crop plants. Phosphoric acid extracted in this way is termed "**available.**"

Table VIII. shows the amount of total, and also of available phosphoric acid in the five soils from Kent and Surrey already mentioned. The percentage of the "total" which is also "available" has been calculated in the last column.

As crops take their phosphoric acid in solution, one would expect that the amount dissolved in very weak acid would indicate —better than does the amount dissolved by strong acid—in how far manures are needed. And this is true. Thus in Yorkshire, Ingle analysed two pasture soils, which may be designated A and B. The A soil contained 150 parts "total" phosphoric acid, and B only 120. When "available" was determined, however, A showed only 4·9 parts while B had 20·5. In a subsequent manuring trial with basic slag a great improvement was observed on A, but soil B failed to respond—the fact being that although B soil actually contained less phosphoric acid yet it held it in a more available form. Dyer regarded a soil showing less than 10 parts " available " as being in immediate need of phosphatic manures.

TABLE VIII

Total and Available Phosphoric Acid (per 100,000)

Soil Group.	Total Phosphoric Acid.	Available Phosphoric Acid.	Percentage of Total which is Available.
Chalk	180	12	6·7
Clay and loam (average) .	110	14	12·7
„ „ (waste lands) .	110	7	6·4
Sandy (average) . . .	130	30	23·1
„ (waste lands) . .	70	10	14·3

The availability test is clearly more informative than the ordinary soil analysis. It is not, however, an infallible guide to manurial requirement. Actually the best method of finding this is by a manurial experiment (Chap. XXIV.).

Potash.—Sandy soils, also calcareous soils, are frequently lower in potash than indicated in Table VII. ; clay soils are typically rich in potash. Although potash is not easily leached downward by rain in ordinary soils, yet it is so to some extent, and subsoils therefore tend to be richer in potash than are the surface soils.

As with phosphoric acid, certain **standards of sufficiency** have been suggested for potash. American authorities claim that less than 250 parts will, if not on virgin soil yet on older lands, call for potash manuring at an early date. European chemists reckon that from 50 to 150 parts is " poor to medium," and 150 to 250 " normal." With potash, as with phosphoric acid, a lower percentage is adequate where the soil is well supplied with lime.

The **" availability "** test is applied to potash in the same way as that described for phosphoric acid. It discriminates between the " total " and the more " available " portion of the potash. The test has moderate success, and has been much used.

Potash required for plant growth is most likely to be deficient in the lighter (sandy) soils, and often also in black swamps. On such lands potash manure will often be effective, and particularly with fruit and root crops and with legumes. Cereals in general more seldom respond to potash—partly on account of their more limited needs.

Nitrogen.—The nitrogen of soils is mostly contained in the humus, the changes in which have already been discussed (Chap. XIV.). As a **standard of sufficiency,** the amount representing adequacy is often placed at 100 parts per 100,000 of soil, but where nitrification is impeded by unfavourable conditions a much larger amount may *still be insufficient.* Pasture lands are often well supplied with nitrogen which easily undergoes nitrification, while on arable fields, unless fresh humus has been added, nitrification becomes each year more difficult. With growing age the humus becomes "tougher" for the bacteria which decompose it. Nitrogen is obtained from humus, and on old land the phrases "*run down*" or "*in good heart*" turn, more than upon anything else, upon the inadequacy or otherwise of the humus supply.

Dyer's method is not applicable to the "available" nitrogen of soils. Rankness of growth, and a deep green colour in the crop indicate a sufficient supply of available nitrogen; poor growth and colour indicate the reverse.

Farm Practice.—In order to replace soil deficiencies in available phosphoric acid, or potash, or combined nitrogen, large quantities of purchased manures are employed by the British farmer.

Chapter XVI

PHOSPHATIC MANURES

Phosphatic manures comprise two-thirds of the manure tonnage used by British farmers. They are valuable because they contain phosphate of lime.

Phosphorus is a non-metal (Chap. X.). It burns in air, yielding a white powder called phosphorus pentoxide, or phosphoric anhydride (P_2O_5).[1] This dissolves readily in water

[1] "Anhydride" means the acid *minus* water.

forming phosphoric acid $\left.\begin{matrix} H_2O \\ H_2O \\ H_2O \end{matrix}\right\} P_2O_5$. This is the *real* phosphoric acid (Chap. X.). For analytical and trade purposes, however, " phosphoric acid " simply means the phosphoric anhydride, or P_2O_5.

Phosphoric acid never occurs free in nature, but is always combined with some base—thus forming a phosphate. The most important natural phosphate is the lime phosphate with a formula of $\left.\begin{matrix} CaO \\ CaO \\ CaO \end{matrix}\right\} P_2O_5$. This is called tri-calcic phosphate because it has three equivalents of lime united to each P_2O_5. The composition of tri-calcic phosphate may be compared with that of the real phósphoric acid given above.

Mineral Phosphates.—Tri-calcic phosphate when pure is a non-crystalline white powder. It forms the chief ingredient of

[*Photo, de L'Ofalac-Algiers.*

FIG. 46.—Mining Rock Phosphate in Algeria.

phosphatic rock, and of the various phosphatic guanos sometimes indistinguishable from phosphatic rock. Minerals of this description are mined in every continent, the annual output amounting to several million tons. British supplies in recent times have been imported mostly from the mines of Northern Africa. Rock phosphates vary in colour owing to impurities always present with the tri-calcic phosphate. Commercial samples may contain from 55 to 85 per cent. of this phosphate of lime.

Tri-calcic phosphate is practically **insoluble in water,** and only slowly in dilute acids. Rock phosphate is thus a slow-acting manure, and where it is used as such, *fineness of grinding* is of essential importance. In some cases even 90 per cent. will pass a sieve with 14,400 meshes per sq. in. Ground rock phosphate is found to act best on soils rich in humus and in a moist locality, in order that the soil acidity may help in its solution. It is least suited to dry calcareous soils. Finely ground rock phosphate is increasingly used in this country, chiefly for pasture improvement.

Superphosphate.—Ground rock phosphate is slow in action because its phosphoric acid exists in the insoluble tri-calcic form. In order to render it more soluble, rock phosphate is first ground, and then treated with nearly its own weight of dilute sulphuric acid containing about 65 per cent. of the pure acid. The operation is conducted at the manure works. The action of the acid is to take away part of the lime from the phosphate, which then forms a *mono-calcic* phosphate :

$$\underset{\text{Tri-calcic phosphate.}}{\left.\begin{matrix} CaO \\ CaO \\ CaO \end{matrix}\right\} P_2O_5} + \underset{\text{Sulphuric acid.}}{\begin{matrix} H_2O,\ SO_3 \\ H_2O,\ SO_3 \end{matrix}} = \underset{\text{Mono-calcic phosphate.}}{\left.\begin{matrix} CaO \\ H_2O \\ H_2O \end{matrix}\right\} P_2O_5} + \underset{\text{Sulphate of lime.}}{\begin{matrix} CaO,\ SO_3 \\ CaO,\ SO_3 \end{matrix}}$$

This equation is often shown in a shorter form, viz. :

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

Two-thirds of the lime is taken to form sulphate of lime, and mono-calcic phosphate is formed instead. On standing, the sulphate of lime in the mixture absorbs water and the material dries up. The " superphosphate," as it is called, is then disintegrated and bagged ready for use.

Mono-calcic phosphate is the important constituent in a superphosphate. It is soluble in water, and hence immediately available to crops. In making superphosphate, a little of the original rock always escapes the action of the acid and remains unaltered. Besides soluble mono-calcic phosphate, therefore, a sample always contains a little of the insoluble or tricalcic phosphate.

During storage there is generally some little decline in the amount of water-soluble phosphate owing to the production of **di-calcic** from the dissolved and undissolved phosphate in the manure :

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

Tri-calcic phosphate. Mono-calcic phosphate. Di-calcic phosphate.

This di-calcic phosphate is sometimes called " reverted " phosphate. It is not soluble in water, but dissolves easily in dilute acids or in ammonium citrate solution, and is readily available to growing crops.

Water-soluble or mono-calcic phosphate forms from 90 to 95 per cent. of the total phosphate in a superphosphate. In Great Britain only this is regarded and paid for, but in some countries the small percentages of di-calcic and tri-calcic phosphates are also estimated and paid for, although at lower rates.

The sale of superphosphate and all other manures is regulated under the **Fertilisers and Feeding Stuffs Act, 1926.** This provides that the actual percentages of *Nitrogen* (N), *Soluble Phosphoric Acid* (P_2O_5), *Insoluble Phosphoric Acid* (P_2O_5), and *Potash* (K_2O) in any manure must be stated in those terms by the seller. The references here to nitrogen and potash will be considered in later chapters ; at this place we are specially concerned with the form of guarantee required for phosphatic manures.

The different phosphates being compounds of phosphoric acid naturally contain that substance. The greater contains the less. The Act requires that any kind of phosphate must be declared as **" phosphoric acid "** and not as " phosphate " only. When phosphoric acid is stated as " phosphate " this always means tri-calcic phosphate (*whether it is soluble or not*), and the effect of such statement is to make the percentage seem larger than when stated as " phosphoric acid." It will be seen that :

Phosphate and *Phosphoric Acid*

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

each contain one P_2O_5, and consequently the same amount of "phosphoric acid." The atomic weights of the elements (Table V.) are used in this calculation:

Phosphate.	*Phosphoric Acid.*
$3Ca = 3 \times 40 = 120$	$2P = 2 \times 31 = 62$
$2P = 2 \times 31 = 62$	$5O = 5 \times 16 = 80$
$8O = 8 \times 16 = 128$	
Molecular weight = 310	Molecular weight = 142

It seems, then, that 310 lbs. (or tons) of "phosphate" contain no more "phosphoric acid" than do 142 lbs. (or tons) of phosphoric acid. A superphosphate, therefore, guaranteed to contain, say, 16 per cent. of "soluble phosphoric acid" could be claimed to contain $16 \times \frac{310}{142}$, or 35 per cent. (nearly) of "soluble phosphate," or phosphate of lime.

Statement of the percentage of tri-calcic phosphate by sellers is voluntary, but for *phosphoric acid* it is compulsory.

Common grades of superphosphate employed in this country supply—

	Soluble Phosphoric Acid	*= Tri-calcic Phosphate.*
Lower grade . . .	13·75	30
Better ,, . . .	16·0	35

There are also higher grades on sale.

As it is richer, the better grade naturally costs more money. In order to compare the costs of soluble phosphoric acid supplied by different grades and brands of superphosphate a system of **unit values** is employed. The unit is each 1 per cent. in 1 ton. At London in March 1938 the better grade just mentioned was selling at £3. 2s. per ton. It is clear that the price per ton divided by the percentage will give the *cost per unit* of soluble phosphoric acid in this manure. It works out at £3. 2s. ÷ 16, or 3s. 11d. The cost per unit could also be worked out for the lower grade when the price is known. After getting quotations from several merchants showing the analysis and price per ton of their superphosphates, it is easy to calculate which brand will supply soluble phosphoric acid at the lowest cost per unit.

The unit system of valuation is of course applicable to other kinds of manures as well as to phosphates. In the *Journal of the*

Ministry of Agriculture there is published each month a statement showing the composition and the average prices per ton of the common fertilisers at the principal centres of distribution. From those data the cost per unit of nitrogen, phosphoric acid, and potash in the different manures can be easily calculated, as was done for the better grade superphosphate cited above.

As 1 per cent. of 1 ton equals 22·4 lbs., the cost per unit ÷ 22·4 would equal the cost per lb. For the better grade of superphosphate here it works out at 3s. 11d. ÷ 22·4 = just over 2d. per lb. of soluble phosphoric acid.

Besides soluble phosphoric acid and the lime which is united to it, the chief constituent of superphosphate is sulphate of lime, or **gypsum.** About half the weight consists of gypsum. This has a certain value especially on clay soils, but it is obtained incidentally and is not paid for.

Superphosphate is the most generally suited of all phosphatic manures to varying conditions of soil and climate. It gives its best results, and continues efficient longest, on soils which are well supplied with lime.

Chapter XVII

PHOSPHATIC MANURES—*continued*

The percentage of soluble phosphoric acid in a superphosphate is not everything. The material must be in a dry and finely granular condition in order that it may be evenly distributed over the land. Faulty condition may be due to unskilful making, or to excess of iron in the original rock.

When **superphosphate** is **applied to land** the next rain washes it down in solution so that it becomes thoroughly incorporated with the soil. Insoluble ground rock or other phosphates do not become so thoroughly mixed through the soil, and its solubility to start with thus gives superphosphate a mechanical advantage.

There is *no danger* of soluble phosphate being washed out of ordinary soils into the drains; the trouble is that it tends to become more insoluble within the soil the longer it lies there. Passing down in solution after rain, the soluble phosphate comes in contact with lime particles (carbonate) on which it is promptly "precipitated" or rendered insoluble as di-calcic phosphate :

$$\underset{\text{Mono-calcic phosphate.}}{\left.\begin{matrix} CaO \\ H_2O \\ H_2O \end{matrix}\right\} P_2O_5} + \underset{\text{Lime.}}{CaO} = \underset{\text{Di-calcic phosphate.}}{\left.\begin{matrix} CaO \\ CaO \\ H_2O \end{matrix}\right\} P_2O_5} + \underset{\text{Water.}}{H_2O}$$

This di-calcic phosphate, while insoluble in water, is quite easily attacked by the roots of crops. For the first crop—the one to which it was directly applied—superphosphate may be said to exist largely as di-calcic phosphate within the soil.

In course of time, however, it gradually unites with more lime within the soil, and gives tri-calcic phosphate—the form in which it had existed in the original rock, but now in a much finer state of division :

$$\underset{\text{Di-calcic phosphate.}}{\left.\begin{matrix} CaO \\ CaO \\ H_2O \end{matrix}\right\} P_2O_5} + \underset{\text{Lime.}}{CaO} = \underset{\text{Tri-calcic phosphate.}}{\left.\begin{matrix} CaO \\ CaO \\ CaO \end{matrix}\right\} P_2O_5} + \underset{\text{Water.}}{H_2O}$$

Tri-calcic phosphate is absorbed with much more difficulty by crops, and by the second year the greater part of the superphosphate will have gone right back. On this account a fresh application of superphosphate is very noticeably more effective than the unused residues from a preceding year.

In soils which are deficient in lime, superphosphate becomes insoluble in a worse form, and to a still greater degree. Instead of tri-calcic phosphate it forms a highly insoluble **iron phosphate,** or an **aluminium phosphate,** which crops can attack only with great difficulty. By liming such land the conversion to iron or aluminium phosphate can be delayed, and the effective service of the superphosphate is thereby lengthened.

For ordinary purposes superphosphate should not be mixed with lime before application, because by so doing its water-soluble phosphate is caused to revert to the di-calcic form, which is insoluble in water. Superphosphate so treated loses its special advantages of extreme solubility, and will not afterwards mix so perfectly over the soil grains. On iron-stone country and soils deficient in lime, however, mixing of superphosphate with lime has been tried with success, because the more insoluble di-calcic phosphate formed will pass less rapidly to the insoluble iron phosphate than will the original mono-calcic phosphate. To meet such cases a **basic superphosphate** was patented—formed by mixing about 15 parts of slaked lime with 85 of superphosphate. It contains di-calcic phosphate chiefly. Basic superphosphate is alkaline because it contains free lime ; ordinary superphosphate is definitely acid.

Bones are very rich in phosphates, but they also supply about 3 to 4 per cent. of nitrogen. Fresh or green bones contain a considerable quantity of fat which retards their decomposition ; in boiled bones a large part of the fat has been removed. Bones contain :

(*a*) A mineral portion.
(*b*) An organic portion.

The latter consists of cartilaginous matter or *ossein*, which forms about 30 per cent. by weight in clean dry bones. The nitrogen of bones is contained in the ossein. The ossein permeates the mineral portion of the bones; and when a bone is burnt or decays, the ossein is destroyed, leaving the mineral portion in a highly porous condition. The mineral portion left after burning consists chiefly of tri-calcic phosphate along with a little carbonate of lime.

The rate at which bones act depends very largely upon the fineness of grinding. As decomposition takes place from the outside of the bone particles, the reason for this will be apparent. "*Crushed bones*," "*bone meal*" and "*bone dust*" represent different finenesses of grinding. Sometimes bones are steamed under pressure to obtain glue and gelatine from the ossein part, and such steamed bones are capable of finer grinding than ordinary boiled bones. *Steamed bone flour* thus prepared is a very finely divided kind of bone ; on reflection one would expect it to contain more phosphoric acid than ordinary bone meal, but very little nitrogen—as a fact it has only about 1 per cent.

Genuine bone meal should contain at least 44 per cent. of tri-calcic phosphate. This is equal to $44 \times \frac{142}{310}$ or 20·15 per cent. of phosphoric acid. Bone meal, as already mentioned, supplies also about 4 per cent. of nitrogen.

Bones have sometimes been adulterated with sand or gypsum, which reduces the percentage of phosphoric acid, and sometimes with powdered rock phosphate, which does not. These have a lower value than genuine bone meal.

Action of Bones.—Partly owing to its porosity the tri-calcic phosphate of bones is more active than rock phosphate ; it is less active than the mono-calcic phosphate of superphosphate. Being less soluble than the latter it acts more slowly upon crops at the time of its application, especially on calcareous soils, but on *soils deficient in lime* it acts more efficiently in later years—being less quickly converted into iron phosphate. It is well suited for long-lived crops as in orchards, and also on account of the nitrogen which it supplies.

Dissolved Bones.—The tri-calcic phosphate in bones can be changed into water-soluble mono-calcic phosphate by treatment with sulphuric acid, as in the manufacture of mineral superphosphate. It is not possible, however, to dissolve much more than half of the phosphate, as otherwise the product is too damp and sticky. The subject is historically interesting. In 1840, Liebig first treated bones with oil of vitriol (sulphuric acid) in order to render their phosphate soluble, and in this country Lawes of Rothamsted extended the method to mineral superphosphate and patented (1842) his process. In modern times it is questioned whether dissolved bones are worth the trouble. For one thing, the tri-calcic phosphate in bones is, for many kinds of soil, fairly active already ; for another, the soluble phosphate in dissolved bones is quite the same thing as that present in mineral superphosphate and the latter can be produced at much less cost. Bone superphosphate is good but relatively too expensive.

Basic Slag is a by-product in the manufacture of steel. Most iron ores contain phosphorus, and steel made from them is brittle unless the phosphorus is removed. Basic slag results from a basic process of making steel. There are two of these. In the older Bessemer process a blast of air is forced through the molten metal, whereby any phosphorus it contains is oxidised to yield phosphoric acid (P_2O_5). This acid then unites with lime, which is added on purpose, and a phosphate of lime is produced. Being lighter, this rises to the surface of the metal as a fused slag ; it is poured off (Fig. 47) cooled, and finally ground to a very fine powder in roller mills. The first slags were made in this way. Another basic process, known as the " open hearth," employs a different manipulation of the molten metal, but also burns out the phosphorus to yield P_2O_5 which, as before, unites with lime added for the purpose. Slags by the second method are often poorer in quality, and less easily absorbed by crops owing to use of fluorspar in the process of manufacture.

Basic slag contains its phosphoric acid in a more **complex combination** than do other phosphatic manures ; it contains a

[*Photo, Brit. Steelwork Assoc.*

FIG. 47.—Tapping the Metal, showing Slag Overflow.

compound of phosphate with silicate of lime, and also some iron. This silico-phosphate is *not* soluble in water. It is less active than the mono-calcic phosphate of superphosphate, but is more active than the insoluble tri-calcic phosphate of ordinary rock phosphate. Unlike superphosphate, it has an alkaline reaction which is in part due to the fact that it contains 2 to 5 per cent. of free lime.

As would be expected in a by-product, basic slag varies widely in quality. In any particular sample there are **three points** to be **considered** :

First.—The *percentage* of phosphoric acid (P_2O_5). This may range from 8 per cent. in low-grade slags up to 18·5 per cent. in the high grades. These figures are equivalent to 17·5 and 40·4 per cent. respectively of tri-calcic phosphate. Before purchasing, different grades may be compared on the basis of unit costs as described under superphosphate.

Second.—The *fineness* of grinding. Availability to crops depends greatly on this, and coarsely ground material is relatively worthless. A common guarantee for fineness claims that 80 per cent. of the material will pass a standard sieve with 10,000 meshes to the square inch. Actually, some samples run to greater fineness than this.

Third.—The *solubility* of the phosphoric acid in dilute acid. A 2 per cent. solution of citric acid (Wagner's test) is used to determine solubility. In some slags most of the phosphoric acid is soluble in dilute acid and in other samples it is not. High-soluble slags have 80 per cent., or over, of their total phosphoric acid soluble in this dilute acid, and low-soluble slags less than 40 per cent. As would be expected, the high-soluble slags are more available to crops. Citric solubility is not to be confused with grade, because low-grade slags with only 8 or 9 per cent. of phosphoric acid may show as great or greater citric solubility than others containing twice as much total phosphoric acid. A statement of citric solubility is not compulsory under the Act, but it helps the material to sell.

As a **fertiliser,** basic slag is well suited to damp situations and to peaty soils and heavy clays. On dry gravels and sands it is less useful. Extraordinary success has followed its use on second-class pastures on clay lands—largely through stimulating the clovers. Superphosphate will usually produce heavier turnip yields, but on " finger-and-toe " infected land, basic slag is to be preferred—a result which has been connected with the alkaline character of the manure.

Chapter XVIII

NITROGENOUS MANURES

In the older countries of Europe and the wetter temperate zones very important manures are those which supply nitrogen. Nitrogen in those countries generally represents what is called the "**dominant constituent**" of manures—it is the constituent which is generally the most deficient in the soils, and the one consequently which must be applied in any case if larger crops are to be produced. In England a case will hardly arise where phosphates are called for on cereals unless care is taken at the same time to provide nitrogen.

The reason why nitrogenous manures are so important in England is largely climatic. Crops prefer their nitrogen in the form of nitrates. Nitrates are plentifully produced from the humus of the soil (Chap. XIV.) during the mild weather of summer, but with the advent of winter, nitrification slows down and may altogether cease. The nitrates formed during the previous mild weather do not, however, remain in the soil. They are too readily leached out by the winter rains. As a result each spring finds the soil very poor in nitrates, however well supplied it may become later in the summer. Thus it is that active nitrogenous manures have a special value to cereals and grass ready for rapid growth in the early part of the year.

Crops which are sown in June and July, such as turnips or rape, do not generally show the same response to active nitrogenous manures as do those which are sown in March.

The supply of available nitrogen in soils is far more **seasonal** in character than is the supply of phosphates and potash. It requires more skill in management. Lack of available nitrogen is one of the outstanding results of poor farming.

A proper understanding of nitrogenous manures is connected with the process of nitrification. In Chapter XIV., when considering soils, we saw that there were certain stages of nitrification and the general conditions were stated.

Nitrogen may be present in **manures** in three forms:

1. Organic nitrogen.
2. Ammonia nitrogen.
3. Nitrate nitrogen.

Organic nitrogen is the nitrogen as existing in blood, bones, straw, soil humus, and similar combustible matters. Ammonia (NH_3) nitrogen is present in sulphate of ammonia, carbonate of ammonia (smelling salts), and other ammoniacal substances, some of which can be recognised by smell. Nitrate nitrogen is present as salts of nitric acid (HNO_3), as in nitrate of soda, nitrate of potash (saltpetre), and other nitrates.

In nitrification, organic nitrogen is converted into nitrate nitrogen by **stages.** It is first converted into ammonia nitrogen, and then the ammonia nitrogen is converted into nitrate. Nitrate nitrogen is the kind of nitrogen which crops particularly want, therefore nitrate of soda, for example, is immediately available. Ammonia nitrogen under favourable conditions can be changed into the nitrate form in a few weeks, but this delay causes sulphate of ammonia to be somewhat slower as a fertiliser than nitrate, although it also is quick to act. Organic nitrogen manures have apparently first to be converted into ammonia before yielding nitrates, and therefore they are the slowest kind of nitrogenous manures. They start at a stage still farther back. With some organic manures it may take years to convert all their nitrogen into nitrates, in others a few months may suffice. The direct absorption of organic nitrogen and ammonia by plants need not be considered here.

Nitrates are **lost to the soil** through crops, and also readily through the drainage water, and sometimes also by denitrification (Chap. XIV.). Ammonia is *not* lost directly through drainage, but it so readily undergoes nitrification that the soil cannot hold it long. Organic nitrogen is the form in which soils hold their main store of nitrogen, and generally they hold it firmly until it has been changed first into ammonia and finally into nitrates, which last may be washed away. Whether or not the crop on any soil will find sufficient nitrogen depends upon how easily the organic nitrogen of its decaying vegetable matter can undergo nitrification, and upon the season of the year.

The **Fertilisers Act** (Chap. XVI.) requires the seller of any nitrogenous manure to state its percentage of *nitrogen* (N). Sometimes nitrogen is quoted as ammonia (NH_3) instead, and this makes the percentage seem greater. Using atomic weights (Table V.), it will be seen that N ($=14$) and NH_3 ($=17$) each contain 14 parts by weight of nitrogen ; therefore a manure claimed to supply, say, 5 per cent. of ammonia actually supplies only $5 \times \frac{14}{17} = 4 \cdot 1$ per cent. of nitrogen. Mistakes of this kind are sometimes expensive.

Nitrate Nitrogen Manures.—The best known of these is *Nitrate of Soda* ($NaNO_3$), which is obtained near the surface in certain rainless districts of Chile. The commercial article is of high purity, and ordinary grades supply 15·5 or 16 per cent. of nitrate nitrogen. The 16 per cent. grade corresponds to 97·14 per cent. of nitrate of soda ; thus calculation should be verified from the atomic weights (Table V.). In 1938 the 15·5 grade was selling at £8 per ton, which works out at 10s. 4d. per unit of nitrogen. The soda in nitrate of soda is not valued, not being an essential plant food.

Nitrate of potash, or saltpetre (KNO_3), is an equally good source of nitrate nitrogen per unit of nitrogen, but it is not used as a manure on account of its high price. It also supplies potash which would be paid for in addition to its nitrogen.

Nitrate of lime $Ca(NO_3)_2$ is made artificially from free atmospheric nitrogen in Norway and elsewhere, and is as good per unit of nitrogen as the other nitrates. It also supplies just a little lime, but not enough to charge for. It gives trouble in storage by drawing moisture from the air.

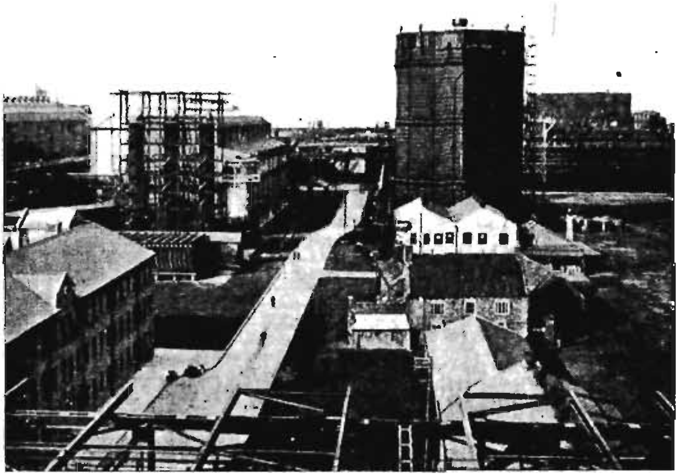
Nitro-chalk is a new British fertiliser, and is a mixture of ammonium nitrate (NH_4NO_3) and chalk. It supplies 15·5 per cent. of nitrogen—half of which is in the nitrate, and half in the ammonia form. In 1938 this cost 9s. 9d. per unit of nitrogen.

All of the nitrates are immediately available to crops and thus well suited for top-dressing purposes. In wet districts they are readily lost through drainage unless a crop occupies the ground.

As an exercise, and using the molecular formulæ given above, the student could calculate whether pure nitrate of soda or pure saltpetre contains the higher percentage of nitrogen. Atomic weights are given in Chapter X.

Ammonia Nitrogen Manures.—The chief of these is *sulphate of ammonia.* For many years this has been obtained as a by-product at gas and iron works ; it is now (Fig. 48) also made in about equal quantity from atmospheric nitrogen in reaction with hydrogen gas. It is not volatile like smelling salts, and has therefore no smell. The commercial article contains about 20·6 per cent. of ammonia nitrogen, and is thus of higher content than nitrate of soda. In 1938 it was selling at 7s. 6d. per unit of nitrogen, being cheaper than nitrate nitrogen, but in pre-war years the latter was often cheaper per unit. The two manures are sufficiently alike in action for farmers sometimes to choose between them simply after comparing their unit costs. Sulphate of ammonia, however, is somewhat slower in action, but on the whole it is better suited for ploughing-in as with a potato crop than is the nitrate. This applies particularly in wet districts, and where farmyard manure given at the same time may cause denitrification losses with a nitrate.

Sulphate of ammonia $\{(NH_4)_2SO_4\}$ when quite pure contains



[*Imp. Chem. Ind.*

FIG. 48.—Part of Synthetic Ammonia Works at Billingham.

21·21 per cent. of nitrogen. This may be verified by calculation from the atomic weights.

Carbonate of ammonia (smelling salts) is a volatile substance and is often lost from farmyard manure during storage. It is too volatile for sale as a manure. It was present along with other salts of ammonia in the famous old ammoniacal *guanos*, which, however, are now practically exhausted. Present-day guanos have been washed by rain so that their ammonia has disappeared, and insoluble phosphates only are left behind. These phosphatic guanos do not compare in value with the early importations.

Ammonium phosphates are now made at the synthetic fertiliser works, and include both a mono- $(NH_4H_2PO_4)$ and a di-ammonium phosphate $\{(NH_4)_2HPO_4\}$. There is no need to follow here the chemistry of those substances, as their use is not yet widespread. The mono-compound has over 12, and the di-compound over 21 per cent. of ammonia nitrogen, while both supply over 50 per cent. of soluble phosphoric acid. Both are highly concentrated manures and save transport charges, but are relatively expensive per units supplied.

Calcium cyanamide and synthetic *Urea* are somewhat closely related to ammonia manures. Like some of those just mentioned, both are artificial products, their nitrogen being " fixed " from the air. Both are rapidly changed to ammonia in damp soil. The cyanamide is *toxic* to plants when first applied, and should be applied a week before seeding and harrowed in. It contains 20·6 per cent. nitrogen, and urea has 46.

Organic Nitrogen Manures.—These are either of plant or animal origin, and are still slower than the ammonia manures. The rate at which they act depends upon the facility with which their nitrogen can be converted into ammonia—the final change into nitrate being a much easier matter.

Dried blood is obtained from slaughter-houses, sometimes the whole blood and sometimes the clot only being dried for manure. A good sample contains about 12 per cent. of organic nitrogen ; there is little phosphoric acid in blood. It is perhaps the most active of the organic nitrogen manures, and being less sudden in action than nitrates, and also less subject to drainage losses, it is better adapted for autumn application and slow-growing crops. *Meat meal* from waste flesh of various kinds is somewhat similar in composition and action ; it usually contains some phosphate from the presence of bone, and consequently a rather smaller percentage of nitrogen.

Bones contain from 3 to 4 per cent. nitrogen ; steamed bones, or bones long exposed to weather, contain less. Bone nitrogen is more valuable the finer it is ground, as it is then more quickly converted into ammonia and nitrates. In 1937 bone nitrogen was valued at 14s. 9d. per unit in bone meal. In the same meal its phosphoric acid was valued at 3s. 9d. per unit. It was selling at £6. 12s. per ton. Where a manure contains two manurial constituents like this, then the allocation of the cost per unit for each is no longer a simple arithmetical problem but becomes a matter of technical opinion.

Horn, *hoofs*, *hair*, *feathers*, *shoddy*, etc., are chiefly used in the manufacture of compound fertilisers, often with treatment by sulphuric acid. They are all of lower value than blood and bone. Leather is used as an ingredient in low-class fertilisers, but is very insoluble. It usually contains about 7 per cent. of nitrogen.

Damaged foods and oil-cakes, such as rape cake, are sometimes used as manures. They are valued chiefly on their percentage of organic nitrogen, of which they contain up to 6 per cent. Their action is, as a rule, fairly rapid.

The **number of years** during which the various nitrogenous manures will **continue to act** depends upon the ease with which they can be converted into nitrate. The nitrate which is not used by the crop will be washed away or destroyed. Nitrate of soda and sulphate of ammonia are expended during the first year. Good blood or bone dust will be nearly expended during the first year ; coarser bone may last in a quiet way for several years. Horn and shoddy will become slowly available during a still longer period, while leather will remain in the soil for a very long time indeed.

CHAPTER XIX

POTASSIC AND COMPOUND MANURES

Potassic manures are required where the land does not contain sufficient available potash for the full development of a crop. An additional application of phosphatic or nitrogenous manure will not make up for a deficiency of potash in the soil.

Potash (K_2O) is the oxide of the soft metal potassium. Potash is very soluble in water, and the solution known as potash lye (KOH) is strongly alkaline and destroys the skin. With acids, potash forms salts. With sulphuric acid it forms sulphate of potash (K_2SO_4), and with nitric acid—nitrate of potash (KNO_3). Being the salts of strong acids, the sulphate and nitrate of potash are *neutral* substances, and do not change the colour of litmus. They are harmless to handle. Carbonic acid is a weak acid, and carbonate of potash (K_2CO_3) is alkaline, but not so alkaline or caustic as is potash itself.

Pure potash is too caustic to be used as manure, and potash manures, therefore, are always salts of potash. Sulphate of potash (K_2SO_4) and the muriate—sometimes called *chloride* (KCl)—of potash are the particular salts of potash used as manures. Nitrate of potash is too expensive; carbonate of potash is present in wood ashes, but is not a commercial fertiliser.

Pure sulphate of potash **cannot contain more** than 54 per cent. of potash, because the acid part of the salt represents a certain part of the weight. This may be calculated from the formulæ of the substances :

Sulphate of Potash	contains	*Potash.*
K_2O, SO_3 (or K_2SO_4)	,,	K_2O.

Referring to the atomic weights of the elements (Chap. X.) we reckon :

Sulphate of Potash.	Potash.
$2K = 2 \times 39 = 78$	$2K = 2 \times 39 = 78$
$1S = 1 \times 32 = 32$	$1O = 1 \times 16 = 16$
$4O = 4 \times 16 = 64$	
Molecular weight = 174	Molecular weight = 94

It appears that 174 lbs. or parts of sulphate of potash contain 94 lbs. or parts of potash. The amount contained in 100 parts sulphate of potash will therefore be :

$$100 \times \frac{94}{174} = 54,$$

and 54, therefore, is the percentage of potash in pure sulphate of potash. Other examples of chemical calculation have already been given.

The **Fertilisers Act** requires the seller of manures to state the potash content in terms of *potash* (K_2O). At times percentage of " sulphate of potash " has been quoted instead, and the effect is nearly to double the apparent richness of the material. This will be understood from the calculation just given.

The following are the **kinds of potash manure** principally used in this country :—

Name.	Percentage of Potash.	Unit Cost (1938). *s.*	*d.*
Sulphate of potash . .	48	4	2
Muriate of potash . .	50	3	4
Potash salts . . .	30	3	5
,, ,, ...	20	3	7
Kainit	14	3	11

The prices per ton in each case can be calculated by multiplying the percentage of K_2O given by the cost per unit.

Potash manures are obtained almost wholly from Europe, where large deposits of crude potash salts occur in conjunction with rock salt. The deposits were formed in times past by the evaporation of sea water from an inland basin. *Sulphate of potash* and *muriate of potash* are manufactured from the crude salts by solution and finally crystallising out. The process for

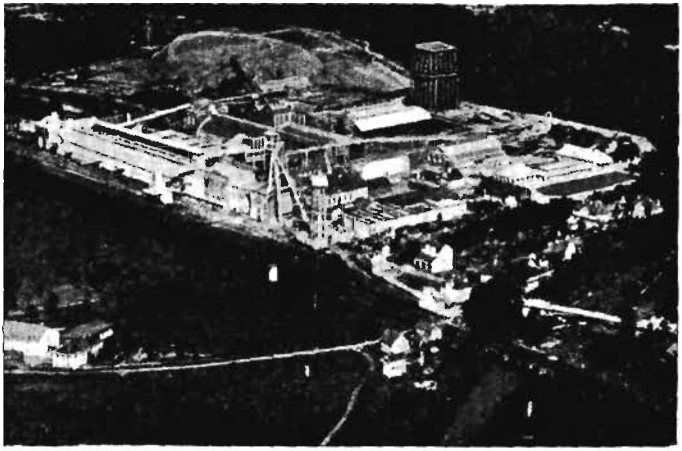


FIG. 49.—" Marie Louise " Potash Mine, Mulhouse, France.

sulphate is more expensive. Some of the crude salts such as *kainit* contain enough potash to be used as manure simply after grinding. Besides its potash, kainit contains much common salt (not charged for), making it specially suited for mangolds and sugar beet. The "*potash salts*" are sometimes crude salts, sometimes manufactured salts, but often a mixture of both.

Prior to 1914 the European production of potash was confined to Stassfurt and other districts in Germany, which was thus able to control output; after 1918 France (Fig. 49) obtained control of certain mines in Alsace. More recently still, production of potash has commenced in Poland, and at the Dead Sea in Palestine.

Wood ashes are chiefly valuable for their potash, which, however, in rainy weather, will soon be leached out. The potash here is present as carbonate, and according to circumstances usually varies from 6 to 10 per cent. of the ashes. The improvement of crop often found around the site of an old bonfire is sometimes due to the potash (K_2O) supplied by the ashes; sometimes it is due to the fact that the potash was a carbonate, which, like carbonate of lime (Chap. XXII.), can correct sourness in land.

The potash manures are all **soluble in water** to begin with, and hence act immediately where the soil is sufficiently moist. Although potash manures are soluble they are **not** at all easily **washed out** of soil, unless on very thin sandy land. In this respect they somewhat resemble soluble phosphates—the potash being more firmly held, and therefore less active in the second year than it was in the year of its application.

Clay **soils,** being usually rich in potash minerals, more rarely require potash manures than do light or sandy soils. Chalky and moorland soils are often markedly deficient also. Besides soil, the **kind of crop** affects the need for potash manuring. Root and fruit crops remove much more potash than do the cereals. In a rotation of crops, therefore, it is common to apply the potash directly to the root crop—leaving to a cereal following the benefit of unused residues only. Leguminous crops generally respond to direct potash manuring.

Compound manures are compounded by the manufacturers from a variety of materials, and usually supply nitrogen, phosphoric acid, and potash in the proportions which seem to be required for the particular crop. Thus we meet "grass manure," "potato manure," "orchard manure" and many others. The basis of such compounds is usually superphosphate supplying a certain amount of soluble phosphoric acid. The nitrogen is often partly drawn from sulphate of ammonia, and in the case of high-class compounds—blood and bone. In other cases, horn, hoof, shoddy, leather and similar materials are used as sources of nitrogen. Potash is often introduced as sulphate or muriate. The *proper price* for compound manures can be estimated by applying the published unit values for any year to the different ingredients as guaranteed in the analysis. About 20s. per ton should then be added to cover cost of mixing and bagging. The mechanical condition can be judged by the eye. The doubtful point regarding many crop compounds is the source from which they derive their nitrogen.

While the manufacturer of a crop compound may have acted upon the best information in regard to the particular needs of the crop he is catering for, it is obvious he *could not know* the character of the land it is to be used on, its cropping record, nor its recent agricultural treatment.

Mixing Manures.—There are some possible errors in mixing manures which should be referred to. Sulphate of ammonia should not be mixed with basic slag or other materials containing lime. Where this is done, sulphate of lime is formed and ammonia as gas (NH_3) escapes and is lost :

$$(NH_4)_2SO_4 + CaO = CaSO_4 + 2NH_3 + H_2O.$$

Other mistakes are of less account, and may often be neglected if mixing is done in small quantities and shortly before use. Nitrate of soda should not be mixed with *damp* superphosphate ; if the latter is dry and powdery, temporary admixture is permissible. Nitrate of soda can be mixed with basic slag, but after a time the mixture will become damp. Sulphate of ammonia mixes well with superphosphate. Basic slag and superphosphate can be mixed, but the latter becomes somewhat less soluble by combining with lime in the slag. Organic manures, such as bones, can be mixed without loss, and indeed are useful to prevent subsequent caking where a mixture is long kept. Muriate of potash or kainit can be safely mixed with anything for short storage, but for long storage their mixtures are liable to become damp and set ; the sulphate has not this defect.

In mixing manures the operation must be **thorough.** The advantage of purchased mixtures is that the mixing was probably well performed at the works. The advantage of home mixing is that the farmer can select the materials to suit his particular soil, and that he can often obtain better value for his money.

Mixed or compound manures supplying all the three manurial constituents are generally **used on crops** like roots, potatoes, and the produce of market gardens. For leguminous crops (see Chap. XXI.), unless the land is very poor, the nitrogen of a mixed manure may be altogether left out. For cereals a general manure is not required except on poor land, but a limited application of ammonia or nitrate in spring will usually be profitable. Grass hay is benefited in the same way. From most manures the greatest gain is reaped in a bad season.

Chapter XX

FARMYARD AND GREEN MANURES

A MANURE which contains only one fertilising constituent, say, phosphoric acid, may miss its mark. The soil may be chiefly deficient in something else, perhaps nitrogen, and then no profitable return is to be expected from the application of phosphoric acid. Farmyard manure is a **general manure,** and contains all the three fertilising ingredients—phosphoric acid, potash, and nitrogen. Such a manure can never miss its mark, because it will supply the deficient ingredient whatever that happens to be. It is like a shot-gun instead of a pea-rifle. Such a manure may be expensive but it is very reliable, and this is one reason why farmyard manure is held in such high esteem.

A general manure, it is true, may be compounded by the farmer from simple ingredients like sulphate of ammonia, superphosphate, and potash salts, and such manures are very reliable under highly diverse conditions even although they may not be economical. But farmyard manure has advantages over the best of artificial compounds. In addition to furnishing supplies of the three fertilising ingredients, it provides a large amount of decaying *vegetable matter*, the presence of which is indispensable in the long run to the continued fertility of the soil.[1]

Farmyard manure is made up of the solid and liquid excrements of farm animals, along with the straw or litter. As animals cannot manufacture phosphoric acid, potash and nitrogen, the value of the manure must depend in large measure upon the character of the food eaten. Indeed the character of the food is the most important factor in determining the value of the fresh manure.

In the digestion and assimilation of food by the animal, the manurial constituents which are present in the food become separated. In herbivorous animals the phosphoric acid and the undigested nitrogen of the food appear in the solid excrements, while the digested nitrogen and most of the potash are excreted

[1] Like animals, plants also secrete certain chemical substances termed "*auxins*" or plant hormones, which direct their growth into certain channels, but the presence ready-formed in farmyard manure of growth-stimulating substances (acting like vitamins on animals) cannot yet be regarded as definitely proven.

in the urine. Farmyard manure takes most of its value from the nitrogen which it contains. If the food be difficult of digestion, the chief value will be in the solid excrement ; if easily digested, the urine will have the greater value. With cows at pasture or fed on concentrated foods, the urine will contain about three times the value of the solid manure in fertilising constituents. The use of litter to absorb the liquid portion is necessary in order to avoid losing the more valuable part of the manure.

The **value of the manure** obtained from the consumption of 1 ton of food can easily be calculated, because with work horses (if not increasing in weight) 100 per cent. of the nitrogen, phosphoric acid and potash present in the food are recovered in the manure. With fattening cattle or sheep the percentage is about 95 ; with fattening pigs, 85 ; and with milch cows 75 per cent. Much attention has been bestowed in this country upon the value to the manure heap of the consumption of 1 ton of different kinds of food. In Scotland the following values have been arrived at (1938) as a working basis for purposes of compensation to an outgoing tenant : Linseed cake, 25s. 6d. ; beans, 19s. 11d. ; oats, 9s. 11d. ; bran, 21s. ; clover hay, 14s. 1d. ; wheat straw, 4s. 11d. The figures are quoted for illustration, and indicate the value of the manure resulting from the consumption of 1 ton of the food. The values have to be recalculated each year from the current unit prices in compound manures. The most expensive constituent in such manures is nitrogen, and generally speaking, those foods supplying the most nitrogen, as in proteins (Chap. XLII.), leave the highest manurial residue.

Farmyard manure is subject to rapid **decomposition** by which it loses weight, and also valuable fertilising materials. In some experiments, 5 tons of fresh manure were reduced to 4 tons when half rotted, and to 3 tons when it could be cut with a spade. The rotted material is in general more active than fresh manure ton for ton, and if properly protected contains a higher percentage of fertilising ingredients, but there is considerably less of it altogether.

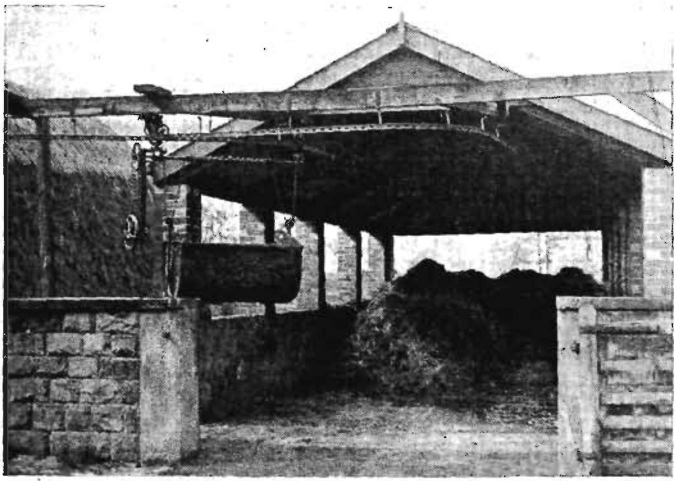
Loss of fertilising ingredients **during storage** may occur either by—

(*a*) Drainage from the heap.
(*b*) Volatilisation into the air.

The dark brown liquid which *drains away* from a manure heap is rich in fertilising substances, and particularly in potash.

Drainage losses are prevented (Fig. 50). when the manure is protected from weather.

Losses by volatilisation are the result of changes brought about by various kinds of bacteria. Here, losses in manurial constituents are practically confined to the nitrogen which passes off largely as ammonia. The nitrogen lost in this way may soon exceed one-half of that in the original material. Escape of ammonia is greatest when the heap is loose and allowed to become



[*Farmer and Stockbreeder.*

FIG. 50.—Farmyard Manure-Storage Shed.

too dry. Compacting the heap and moistening it reduce the loss. Sometimes gypsum or superphosphate have been added to prevent loss of ammonia, but with only moderate success. *Lime should never be added.* The best ammonia-fixer in practice is a few inches of moist loamy soil thrown over the heap—the ammonia being absorbed by a covering of earth.

As a **source of plant food** good farmyard manure is particularly rich in available nitrogen, as is shown by the strong *dark green foliage* in a crop to which it has been applied. It is also rich in potash unless leached by rain. As a balanced manure for general purposes it is somewhat deficient in phosphates, and almost always a better return will be got from each ton of dung by applying only a half-dressing over a larger area, and supplementing this with a half-dressing of superphosphate. Samples of farmyard manure will usually contain from 4 to 9 lbs. of phosphoric acid, 10 to 15 lbs. of nitrogen, and 9 to 18 lbs. of potash per ton. The water will usually range from 60 to 80 per cent.

As already stated, the value of farmyard manure is not to be gauged simply from its content of plant food alone, because owing to its humus content it gives body to a **soil,** and improves its **physical condition.** It is of particular advantage in opening up stiff clay soils, and in binding together light sands.[1] The full advantages of farmyard manure are not to be expected on peaty or swamp lands ; if good results from it are obtained on such lands it may usually be taken as an indication that the peat lands require draining or lime, and most probably both together. Peaty lands have sufficient humus. They may require artificial manures, but to apply farmyard manure to them is not making the best use of the material if the farmer has another class of land on which it can be used.

A dressing of good farmyard manure shows its best results in the first year of its application owing to its high content of *quick-acting nitrogen*—causing crop foliage to be dark green and rank. But the **residue** of the manure **left** in the soil will continue to benefit future crops for a long time. Many examples from experiments could be quoted. In the barley plots at Rothamsted one plot, which had received 14 tons of dung annually for twenty years, not only gave much larger yields than the undunged plot during those years ; it was still giving double the yield of crop at thirty years after the application of dung had been discontinued altogether.

" Synthetic " farmyard manure.—Normally the straw or litter in fresh farmyard manure decays rapidly *because* the bacteria causing decomposition are well supplied with combined nitrogen, phosphates, etc., drawn from the animal excreta with which it is mixed. To ensure rapid decay, the bacteria must be well nourished.[2] To meet those cases where straw or garden refuse is available but no animals are kept to make farmyard manure, a process was worked out at Rothamsted to cover the difficulty.

[1] Humus tends to bind soil particles into larger aggregates of particles, and the results above mentioned are anomalous only at first sight.

[2] See also under " *decay of humus* " (p. 68).

The straw is mixed with about 6 per cent. of its weight of what may be called a manure for bacteria, and is termed " *Adco*." The heap is kept moist for some months while it decays rapidly and takes on the character of good manure. The fertilising elements of the " Adco," after promoting decay, remain in the manure to enrich it for crop production. The process is particularly useful for home gardeners, since the decline in horse traffic has made the purchase of stable manure difficult.

[*By courtesy of the Director.*

FIG. 61.—Ploughing-in Green Manure at East Malling Research Station, Kent.

Green Manures.—Where the supply of farmyard manure is inadequate, sometimes crops are grown just in order to be ploughed-in. These are known as green manures, and the practice is a very old one.

Green manures enrich the soil in humus. Crops draw only about 5 per cent. of their dry matter out of the soil, the balance of 95 per cent. being obtained (Chap. V.) from the atmosphere. This 95 per cent. is the combustible part—the part which forms humus—so that although the crop is simply ploughed into the soil on which it grew, it adds a vast amount of material to the soil which it did not take from it.

For green-manuring purposes a vigorous, rapidly growing crop is preferred, the object being to add as much humus as can be done at one operation. A variety of crops are suitable, such as clover, vetches, mustard, rape, etc., the crop where necessary receiving fertilisers in order to obtain a larger yield. In most cases leguminous crops like clover or vetches have an advantage over mustard or rape in that they provide not only humus-forming material but also nitrogen from the atmosphere. But this subject must be deferred to the next chapter.

When discussing nitrates (p. 87) we saw that the summer supply is readily washed out by the following winter's rain. The only known means to *avoid this loss* is to sow a catch crop in autumn to absorb at least part of the nitrate, and then plough this crop in during spring before sowing the next crop.

In this country farmers usually prefer to fatten stock on a green crop rather than to plough it all in. In such cases practically the whole of the nitrogen, phosphoric acid, and potash in the green crop will be returned to the land just the same, but the addition of humus will be diminished by at least one-half.

CHAPTER XXI

NITROGEN FIXATION IN LEGUMINOUS PLANTS

SOIL nitrogen, as in nitrates, is necessary for the common run of farm crops. There is, however, one important group of plants belonging to the **Leguminosæ** which can dispense with the ordinary supplies of soil nitrogen. This group includes plants like clovers, lucerne, peas, and vetches. Provided these receive from the soil the ordinary phosphates, potash, and other mineral substances required by all plants, they can obtain what nitrogen they require from the *free nitrogen gas* (Chap. I.) of the atmosphere.

It is on the *poorer* soils that the leguminous crops are of special advantage. In good, rich soils there is sufficient combined nitrogen present for any kind of crop, and the special power of a leguminous crop to use free atmospheric nitrogen is then of no use to it. On poor soils, on the other hand, there are no other crops which can be grown successfully without an application of expensive nitrogenous fertilisers. Fig. 52 shows the result from trying to grow various crops on a soil poor in combined nitrogen. It will be observed that the peas alone made satisfactory growth.

The discovery of the **fixation of free nitrogen** by leguminous plants was announced by two German scientists in 1886. The plants, however, have not this power in themselves, because a certain bacterium named *Bacillus radicicola* must be present in the soil.[1] In its absence the "legume" has not power to use atmospheric nitrogen, and just behaves like any other crop.

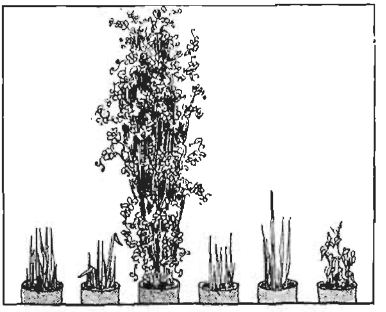


FIG. 52.—Growth of Crops on Soil poor in Nitrogen. (After P. Wagner.)

1, rye; 2, oats; 3, peas; 4, wheat; 5, flax; 6, buckwheat.

Sometimes the necessary bacterium is lacking from the soil, and it is important, therefore, to know whether it is or not. When present it causes little wart-like **nodules** or **tubercles** (Fig. 53) to form on the roots of the crop, and these can be seen by the naked eye. The nodules vary in size and shape on different plants, but their presence can hardly be mistaken. Pea or bean plants in the garden, or clover by the wayside, may be examined for root nodules.

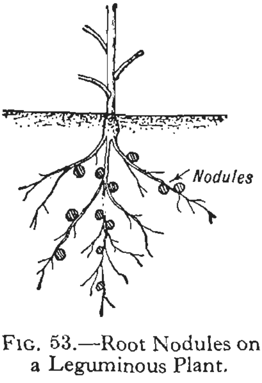


FIG. 53.—Root Nodules on a Leguminous Plant.

When the necessary bacterium is not present in the soil, it can be put there, and the soil is then said to be **inoculated.** Fig. 54 shows with pot cultures the results of some inoculation experiments once conducted at Rothamsted by Lawes and Gilbert. The first three pots contained a poor soil to which all the necessary mineral constituents had been added, but no nitrates. The soils were first sterilised by heat to kill any possible nitrogen-fixing bacteria which might be present; Pot 4 contained good

[1] Sometimes named *Rhizobium radicicola.*

garden soil which was not sterilised. To Pots 1 and 4 no further addition was made, but to Pots 2 and 3 a little water, which had been shaken with garden soil and allowed to settle, was added —in order to convey in this way the necessary bacterium which was known to be present in the garden soil. During growth the peas were watered with distilled water. In the results it will be seen that Pot 1, which had not received the bacteria by the addition of soil extract, was a failure; Pots 2 and 3, grown under exactly similar conditions except that they had been inoculated, showed vigorous growth; Pot 4, of course, was good. When the roots were examined, no nodules were present in Pot 1, but Pots 2 and 3 showed abundant nodules. In Pot 4,

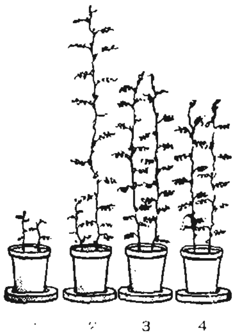


FIG. 54.—Results of Inoculation with Pea Crop.

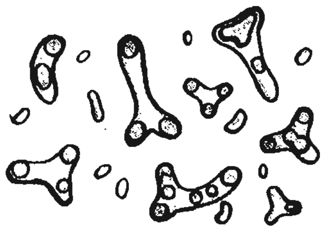


FIG. 55.—Bacteria, and Large Bacteroids from Pea Nodules. (Mag.)

although the crop was good, the nodules were much less—the fact being that nodules are only vigorously produced in those cases where free nitrogen fixation is necessary for the welfare of the crop.

The bacteria which fix free nitrogen are present within the nodules on the roots, and they live with the plant for their mutual advantage. Such a living together is known as **symbiosis.** The bacteria receive sugary matters which had been formed in the green plant, and with this sugar, together with free nitrogen which they take from the air, they get to work. Protein or nitrogenous substances like albumin are built up. The bacteria are well fed, and most of them grow large and lazy. Such overgrown bacteria are termed **bacteroids** (Fig. 55)—they are soft and degenerate, and the crop plant can easily digest them, using their substance for its own needs. Those bacteria within the nodules which do not so degenerate, remain small and hardy —the plant cannot digest them, and when the nodules later decay within the soil those undegenerate bacteria are liberated to inoculate a future crop. Even without a crop they can remain viable in the soil for several years.

If a good leguminous crop has recently been grown on land, the next crop of the same kind is sure to obtain the germ. To meet cases where the necessary germ is absent, *inoculation* is sometimes practised. One method is to obtain some soil from another field which recently grew the same crop, and broadcast this at the rate of 3 or 4 cwt. per acre ; as sunlight soon kills the germs this should be harrowed in. Another method is to obtain a "*pure culture*" of the organism prepared in a laboratory, and with this inoculate some soil to be broadcast, or as is often done, inoculate the seed prior to sowing.

The need for inoculation, however, does not arise only when the *Bacillus radicicola* is absent. It may, indeed, be desirable simply to introduce a more vigorous type of the same thing, but there is another reason than that. There are, as a fact, different "**physiological strains**" of this organism, and each strain has some particular group of leguminous plants upon which alone it is effective. Thus the strain associated with common beans will also at once inoculate peas, but will be unsatisfactory with lupins. The various clovers among themselves employ the same strain, but this is not effective upon lucerne. About eight or nine strains have been isolated. There is some reason to believe that one strain of the germ may gradually adapt itself to a different group of "legumes," but that this will require time, perhaps years. It is because of this difference in strains that inoculation has been particularly successful with new types of leguminous crops introduced for the first time, *e.g.*, lucerne in England, or soy beans.

Like other soil bacteria, the nitrogen-fixing germs are greatly benefited by the presence of **lime.** Root nodules do not form well on sour land even although the bacteria be present. Lime is specially advantageous to leguminous crops, because it stimulates nitrogen-fixation. For this reason an application of lime on pastures is often followed by a vigorous growth of clovers which had previously been too insignificant to catch the eye.

By growing a leguminous crop the **land is enriched** in combined nitrogen by the amount of free nitrogen which the crop had taken from the air. Leguminous crops have thus an advantage over crops like mustard or barley for growing as green manure, as they add not only to the humus supply, but also to the store of nitrogen. It is difficult to estimate exactly the amount of new nitrogen, but experiments in Illinois showed that inoculated lucerne contained 252 lbs. more nitrogen per acre during a single season than did uninoculated lucerne growing alongside. Experiments elsewhere, and with other "legumes," have often indicated heavier gains than this. Such nitrogen easily undergoes nitrification when ploughed-in, and thus benefits the following crops.

Where a leguminous crop has been carted off, say, as hay, the roots and stubble remaining still add greatly to the store of nitrogen in the soil. For centuries, clover has been regarded in Europe as an excellent preparation for a cereal crop. Rothamsted soil analyses indicated a substantial gain in combined nitrogen from the root residues of a clover crop, and a much increased yield from barley resulted in the following year. By adopting a rotation of crops in which "legumes" find a place, the need for expensive nitrogenous fertilisers can in large measure be reduced.

Chapter XXII

ACTION OF LIME IN SOILS

A manure is a substance employed to supply a necessary plant food to the soil. Thus we have phosphatic manures, also potassic and nitrogenous manures. Lime is also a necessary constituent of plant food. But few soils contain so little lime that a farm crop cannot find enough lime for its needs. When lime is applied it is usually for a different reason than that for which ordinary manures are applied. Lime has a certain effect in rendering the other plant foods soluble, and also in many cases improving the physical condition of the land.

Lime (CaO) is the oxide of the white metal calcium, which is a little harder than lead. Some metals such as gold and silver do not oxidise at all easily, not even when hot (noble metals); other metals such as iron and copper oxidise fairly easily (base metals), but not so easily but what they can be used and handled. Calcium is a metal which oxidises so very easily that it cannot be used for any purpose as a metal. Unlike gold, consequently, calcium never occurs as free metal in nature, and must be prepared by the chemist from one of its compounds. When the metal so prepared is burned, it forms the oxide—lime.

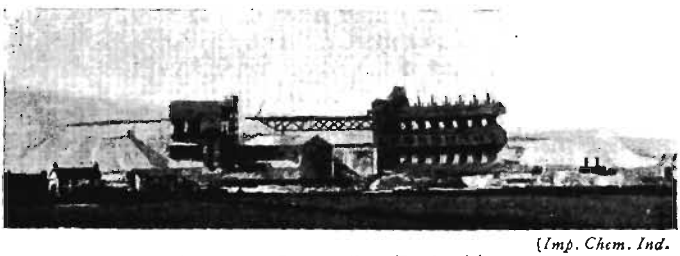
Being the oxide of a metal, lime is a **base,** and unites with acids to form salts. Phosphate of lime, sulphate of lime, and some other salts of lime have already been referred to. An important salt is the carbonate of lime. This occurs widely in nature, and lime is obtained by decomposing the carbonate. To burn the metal calcium in order to get lime would be an impossibly expensive and roundabout way of getting the same result.

Carbonate of lime, or calcium carbonate (CaO, CO_2)—or, as it is often written ($CaCO_3$)—is the essential ingredient of every limestone. Chalk is a loose, crumbly form of carbonate of lime. When limestone is strongly heated it is decomposed—carbon dioxide gas being given off, while lime remains :

(Limestone) gives (lime) and (carbon dioxide).

$$\underset{(100)}{CaO, CO_2} = \underset{(56)}{CaO} + \underset{(44)}{CO_2}$$

The operation is conducted in a kiln, the limestone having first been mixed with fuel which is set alight (Fig. 56) ; the



[*Imp. Chem. Ind.*

FIG. 56.—Lime-kilns, Derbyshire.

object is only to *heat* the limestone which itself cannot burn. Calculating from the atomic weights (Table V.) it will be found that 100 parts of pure limestone yield 56 parts of lime, so that there is considerable loss of weight. Limestones in nature are never quite pure, and those used for lime-burning usually contain from 70 to 90 per cent. only of carbonate of lime. Impure limestone naturally yields a more impure lime. Much magnesium carbonate in a limestone is objectionable.

Lime as it comes from the kiln is variously known as " burnt lime," " quick lime," " cob lime," " lump lime," etc. When water is added to burnt lime, it *unites* with the lime forming calcium hydrate (hydroxide) or slaked lime :

(Lime) and (water) give (slaked lime).

$$\underset{(56)}{CaO} + \underset{(18)}{H_2O} = \underset{(74)}{CaO,\ H_2O}$$

In slaking, the lime falls into a very fine powder of *slaked lime*. Owing to chemical change the mass becomes very hot. Fifty-six parts of pure lime require 18 parts of water to slake it, and yield 74 parts of slaked lime. If too much water is used the excess may be dried off, and if too little, the lime will not all be slaked.

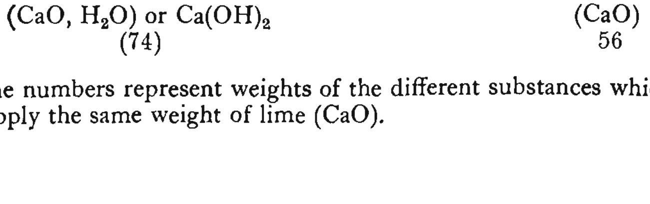
When **slaked lime** is exposed, the carbon dioxide of the air gradually displaces the combined water in slaked lime, and carbonate of lime is formed :

(Slaked lime) and (carbon dioxide) give (carbonate of lime) and (water).

$$\underset{(74)}{CaO,\ H_2O} + \underset{(44)}{CO_2} = \underset{(100)}{CaO,\ CO_2} + \underset{(18)}{H_2O}$$

This happens when slaked lime is applied to land, and also in the hardening of ordinary mortar. The carbonate of lime thus formed is the same kind of substance that was put into the kiln.

It will be seen from above chemical equations that the changes in **lime** move in a **cycle** :



The numbers represent weights of the different substances which supply the same weight of lime (CaO).

In agriculture the name " lime " is used loosely to denote any of the three forms of lime just mentioned. Lime proper (CaO) and slaked lime being more active are sometimes known as " hot lime," while carbonate of lime is " mild lime."

Any of these different **forms** of " lime " may be directly **applied to land.** Carbonate of lime is applied as *chalk* or as *ground limestone* ; *slaked lime*, being a fine powder, is applied as such ; burnt lime itself may be applied after grinding, in the form of *ground lime*, or ground burnt lime.

When ground burnt lime is applied to land it rapidly slakes, even in dry weather, by absorbing moisture from the air. On the land, slaked lime—whether applied as such or as ground burnt lime—is, before long, converted into carbonate of lime by the carbon dioxide of air and soil. When ground limestone or chalk is applied, it furnishes carbonate of lime ready made. The same substance, therefore—viz., carbonate of lime—is eventually obtained in the soil, no matter in what form of combination the " lime " was applied.

In these circumstances the best form in which to apply " lime " becomes largely a question of costs per unit. A sample of ground limestone supplying 90 per cent. of calcium carbonate ($CaCO_3$) is equivalent to only $90 \times \frac{56}{100} = 50{\cdot}4$ per cent. of actual lime (CaO). The figures for this calculation were given under the lime cycle. Under the **Fertilisers Act** the seller of any form of " lime " or chalk must also specify the percentage of *lime* (CaO) it is *equivalent* to; he will also quote prices per ton. Purchases can thus be based upon cost per unit of lime supplied. It will be observed that as ground limestone and chalk will supply a smaller percentage of lime (CaO), they will cost more for transport. In general it requires about $1\frac{3}{4}$ tons of ground limestone to supply as much "lime" as does 1 ton of burnt lime.

Slaked lime is fairly soluble in water (lime water) ; the carbonate form dissolves more slowly. Hot or slaked lime is thus sooner mixed with the soil when rain comes than is ground limestone. From a small application therefore the hot lime will act rather faster at first, but it will be sooner exhausted.

Lime or limestone **acts** upon the soil **in several ways :**

1. Hastens the decomposition of humus.
2. Promotes nitrification.
3. Helps nitrogen-fixation in the Leguminosæ.
4. Removes sourness in land.

5. Makes insoluble iron phosphates more available.
6. Helps to make potash available.
7. Opens up stiff clay soils.
8. Has a binding effect on sandy soils.

The first three of these have already been discussed. As the actions referred to are caused by bacteria, lime has thus a **physiological** effect on soils. Number 4 is closely connected with this effect because the bacteria dislike to work in an acid medium.

Numbers 4, 5, and 6 are **chemical** actions of lime. Carbonate of lime can remove sourness because carbonic acid is a weak acid and is driven out by the soil acids, which then unite with its lime to form neutral salts. Their acidity is thus destroyed, while the CO_2 from the carbonate escapes into the air. Sulphate of lime (gypsum) and phosphate of lime are sometimes spoken of as supplying lime, but in them the lime is united to strong acids so that they cannot remove sourness in land. They should not therefore be viewed as " lime " at all. The most important action of " lime " is that it can remove sourness.[1]

Numbers 7 and 8 are **physical** actions of lime which must be described in a later chapter (XXVI.).

The old **practice in liming** was to apply from 4 to 5 tons of hot or slaked lime per acre at long intervals of time—twenty or thirty years. Smaller applications are now usual, and, indeed, a modern practice is to apply about 20 cwt. per acre of (hot) ground lime, or the larger equivalent of (mild) ground limestone every two or three years.

Lime is often spread by a shovel from small heaps which have been put down over the field to slake. For distributing the smaller quantities used in the case of ground lime and ground limestone, special machines (Fig. 57) are found convenient.

[1] In speaking of soil acidity it is usual to distinguish between its *quantity* and its *intensity*. The former corresponds to the amount of lime which would be required to neutralise it. The latter depends upon the number of ionized hydrogen atoms present in the soil solution, and this hinges upon several associated factors. This " hydrogen-ion concentration " (*p*H) is best determined by electrometric methods, and is expressed by figures—values downward from 7 indicating progressively acid conditions, and values from 7 to 14 progressively alkaline conditions. Crops vary in their *p*H *optima*, and although they often prefer a slightly acid medium (about 6·5), they are injured by too much; *e.g.*, at Rothamsted, barley at a *p*H of 5·77 was good, but at 4·41 it was a failure. In such a case lime will remedy the defect.

On pasture, lime may be applied at any time. On arable land, autumn or early winter is the best time to give it, but it may also be applied in spring *after* ploughing. As the object in using lime is to mix it with the surface soil it is a mistake to plough it in deeply ; it is better to be harrowed in. When one recollects that a regrettable tendency of lime is to " **sink** " in the land, there is no occasion to aggravate this evil.

Clay and peat **soils** can safely take more lime than can sandy soils, which may be injured by heavy applications of lime. Lime causes a more rapid decay of the organic matter, and on light soils the result may be serious unless measures are taken by

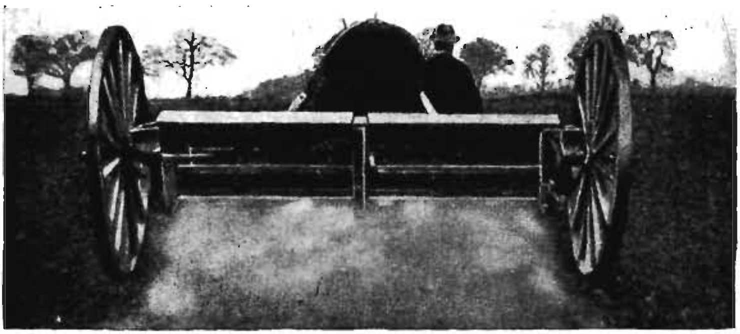


FIG. 57.—A Modern Lime Distributor.
(Harrison M'Gregor & Co.)

farmyard manure, or by folding on stock, to replenish the supply. This is recognised in the ancient rhyme :

" Lime and lime without manure
Will make both farm and farmer poor."

The manure of those days was farmyard manure.

Carbonate of lime is the form of lime which is important in soils. While carbonate of lime is nearly insoluble in pure water, it dissolves rather readily in water containing carbonic acid—then forming a soluble *bicarbonate* of lime. In this form lime tends to be **washed out** of land, thus calling for repeated applications to repair the waste. Temporary hardness in water is due to this soluble bicarbonate of lime which had been leached from the land.

CHAPTER XXIII

EFFECT OF MANURES ON CROPS

WHERE manures are applied to ordinary farm crops the main object is to increase the yield. But other results invariably follow; the quality of the crop, its date of ripening, and the power to resist dry weather or disease are all more or less affected by an application of manure.

The principal object of manures is to **increase the yield.** This can occur only when they supply some constituent in

FIG. 58.—Effect of 60 Lbs. per Acre of Superphosphate on Wheat under a Low Rainfall. On the strip marked by a hat the drill delivered the seed but failed to deliver the manure.

which the soil is deficient. Manures may be applied on good land where there is no need for manuring, or they may supply one constituent when the soil is deficient in another; in either case the result is either no increase at all, or only an indifferent one.

It is surprising what increases of crop can often be obtained from even a small application of manure when it is of the required kind, and is given at the right time and in the proper manner. In this country a top-dressing with 1 cwt. of nitrate of soda or sulphate of ammonia will frequently increase the yield of grass hay or a cereal crop by 60 to 100 per cent., when it is applied in spring. In the drier parts of the Dominions similar surprisingly large returns are obtained from superphosphate on cereals where the manure is drilled (Fig. 58) along with the seed—a dressing of even ½ cwt. per acre frequently doubles the yield.

Crops, however, cannot be increased indefinitely even by the proper manures, and there is a **limit** to the amount which can be employed *with profit*. If a hungry man receive at one meal successive ounces of food, the first ounce will have more value to him than the second, and the second than the third, and if he goes on eating, the last ounces will have no value to him at all. They will probably do him harm. And so it is with a hungry crop on a poor soil. To illustrate the point, the following results (Table IX.) showing the yields of potatoes in Scotland from a larger and a smaller dressing respectively of farmyard manure may be quoted as typical :—

TABLE IX

Yields of Potatoes from Different Quantities of Manure

Quantity of Manure Given.	Yield per Acre.	Increase from Manure.
	Cwt.	Cwt.
No manure	82	...
10 tons farmyard manure .	124	42
20 ,, ,, ,, .	146	64

The results are the average from nine farms. It will be seen that the first 10 tons produced 42 cwt. of increase, while the second 10 tons in the 20-ton dressing produced only 22 cwt. more. Similarly with wheat at Rothamsted on the average of thirteen years. Here a first 43 lbs. of ammonia nitrogen increased the yield by 10 bush. ; a second 43 lbs. added to the first increased the yield by a further 8 bush. ; a third 43 lbs. by only 2 bush. ; and a fourth by just ½ bush. Examples could be multiplied showing that, beyond a certain limit, a crop will always make a smaller return to each additional quantity of manure applied.

This **Law of Diminishing Returns** shows that it will not pay to go on increasing the manure quite up to the point at which it ceases to increase the yield. Profitable manuring stops short of that. If the first 20s. spent on manure yields 30s. worth of crop increase, and a second 20s. spent on manure yields an additional 25s. of increase, then if a third 20s. spent only increases the crop value by another 10s., it would have been better not to spend it. If market prices for crop were good at the time it might have paid to spend the third 20s.; similarly if they were very low it might not have paid to spend even the second. Low market prices do not encourage high farming.

A crop will always yield more increase from a certain quantity of manure when it is applied **at the right time,** and in the **most accessible way.** In this respect drilling the manure with the seed (Fig. 59) has often advantages over broadcasting the manure unless excessive amounts of the material are used. This mode of application has received too little attention in England, but investigations are now proceeding. Hungarian experiments with wheat showed that 93 lbs. superphosphate drilled along with

FIG. 59.—Combined Seed and Manure Drill. Lids of seed box standing open. (Massey-Harris.)

the seed increased the yield by 497 lbs., but double the quantity (186 lbs.) when applied broadcast gave a *total* increase of only 465 lbs. under similar conditions. Corresponding results were obtained on a variety of soils.

Manures also affect the **character of the crop** as well as its amount. Nitrogenous manures have a tendency to delay **ripening,** especially when phosphates are deficient; in a season with heavy rains they also increase the liability of cereals to "lodging," *i.e.*, getting laid flat. Phosphates, on the other hand, accelerate ripening by, it may be, seven to ten days.

At the period of **early life** phosphates have a specially stimulating effect upon the crop. On the average poor soil an application of soluble phosphates gives plants a good start almost independently of what constituents they may find to be deficient later. In the case of cereals the extra vigour imparted assists in the development of adventitious buds giving good tillering, while with deficiency of phosphates the crops tend to be thin.

Root development is found to be strongly encouraged by an application of phosphates, and this is of particular value on clay soils because it is there that root growth finds greatest difficulty. This effect was noticed by Lawes at Rothamsted in the early days of his work. In turnips and swedes phosphates are of special advantage in encouraging the roots to swell, and in increasing the ratio of roots to tops.

The **ratio of straw to grain** in cereals is influenced by the kind of manure. An excess of nitrogen unduly increases the proportion of straw, while phosphate added to nitrogen tends to increase the grain. The following results from the Rothamsted wheat plots will illustrate this point :—

TABLE X

Effect of Manures on Proportion of Straw in Crop

Manures Applied.	Grain.	Straw.	Straw for 1 Bush. Grain.
	Bush.	Cwt.	Lbs.
Phosphates and potash only .	18·3	16·6	102
Phosphates and potash only plus 43 lbs. nitrogen . .	28·6	27·1	106
Phosphates and potash only plus 129 lbs. nitrogen . .	39·0	42·7	123

Although in practice nitrogen gives less grain in proportion to the straw of the crop, still a large crop of straw is necessary to produce a large yield of grain, so that application of nitrogen is frequently necessary to produce the required straw. It is only when the amount of nitrogen in the manure is excessive that the ratio of straw to grain is seriously altered. Excess of nitrogen also gives a greater proportion of tops in root crops and in potatoes.

The **quality,** or chemical composition, of a crop is also influenced by the kind of manure. There is least difference in vital parts like seeds or grain, which are more difficult to alter. Root and forage crops may vary considerably. Potatoes grown with nitrogenous manures alone tend to be watery, while mineral manures, and especially potash, give tubers of a drier or more "mealy" character because containing more starch. Farmyard manure is very nitrogenous in the year of its application and by itself gives rather watery potatoes; for quantity and quality together a half-dressing of farmyard manure along with phosphates and potash is better than the manure alone. Root and forage crops grown with basic slag have been found superior in feeding value to superphosphate produce when consumed by sheep, ton for ton.

Potash deficiency is most felt by crops where starch or sugar is largely present in the produce, *e.g.*, in potatoes and root crops. Potash specially helps the plant in the production of starch and sugar. The importance to potatoes of using potash has already been mentioned. Potash also helps nitrogen-fixation in legumes, possibly because the bacterium must receive sugary matter from the legume before it can fix free nitrogen. Legumes thus also benefit specially from potash manures. Cereal grains also contain much starch, and lack of potash appears to give smaller grains rather than a smaller number of grains. Deficiency of nitrogen or phosphate, on the other hand, influences the number of grains rather than their size. On many soils, however, cereals can obtain all the potash that they require. A deficiency of potash in the soil gives weak-standing straw.

Fungus diseases like rust in cereals, and the notorious "potato disease" find an easier prey in crops heavily manured with nitrogenous fertilisers. The softer, ranker foliage produced seems to favour the spread of such diseases. Potash applications, on the other hand, render the crops more resistant.

Manures are selected primarily with the object of securing the maximum yield per acre, but it is well to keep in mind their secondary effects, particularly in regard to the quality of the produce, and its susceptibility to disease.

CHAPTER XXIV

MANURIAL EXPERIMENTS

A CHEMICAL analysis (Chap. XIII.) cannot give definite information as to what manures should be applied to a soil; it can only give indications. The strong acid used in soil analysis extracts food material much of which could not be rendered soluble enough to aid plant growth for many years. The dilute citric acid method (Chap. XV.) for determining the more available phosphate and potash in a soil comes somewhat nearer the object in view, but even this method is unsatisfactory as a final guide to what manures the soil requires. The last appeal is to the plant. A manure will not give a return unless the constituents which it supplies could not otherwise be found by the growing crop.[1]

The **current deficiencies** of a soil are ascertained by a manurial experiment. The method consists in taking a measured area or " plot " of land which is manured in one way, and comparing this with a similar plot of land which is not manured at all. The effect of the manures is judged from the yields of crop which they are able to produce. The following results of an experiment, conducted at one time by the writer, will serve to illustrate how the manurial requirements of a particular soil may be determined. The system of manuring indicated (Table XI) is that known as the **eight-plot test.** Oats was the crop grown.

Nitrogen, phosphoric acid, and potash are the essential constituents liable to be deficient in soils, and the eight-plot test employs each of them singly, and also in each possible combination to different plots. Different quantities are used for the different manures, but for any one manure it is used in the same quantity whether by itself or along with others. Examination of the crop-yields from such a test furnishes a good method of " analysing the soil in the field."

[1] At one time it was thought that *analysis* of the *crop ash* would be a guide both to the kind and the quantity (except for nitrogen) of manurial constituents which should be supplied. For several reasons this does not hold. For one thing the crop may absorb more of certain necessary food materials than it really wants, and also other mineral substances (Chap. V.) which it does not want at all. Then, again, in applying manures, credit must be allowed to the soil for what it can furnish apart from any application of manures. And there is another matter. Even on washed sand used as soil and which can furnish nothing from itself—it would be necessary to supply considerably more of the necessary manurial ingredients than were found in an analysis of crop ash for the reason that a crop can never " clean up " the manurial substances given *to it.* It is almost like taking broth with a fork! From the manures given, a larger proportion of the constituents offered will always be absorbed from a small dressing than from a large, but in ordinary field practice the necessarily unabsorbed residues will often represent well over one-half of the quantity in the manures applied.

Plot 1 receives no manure, and is the "control" plot by which the effect of the various applications is judged. Of the single manurial constituents—Plots 2, 3, and 4—superphosphate alone gave an increase, indicating, therefore, that the scarcest constituent of available plant food in this soil was phosphoric acid. Comparison of Plot 3 with Plot 5, and then with Plot 7, shows that scarcity was next felt—after removing the phosphoric acid deficiency—in a scarcity of nitrogen. Plot 5 was indeed a considerable improvement on Plot 3. Comparison of Plots 5

TABLE XI

Experiment with Oats, using Eight-plot Test

Number of Plot.	Manures Given.	Crop Yield.
1	No manure	76
2	Nitrogen (as sulphate of ammonia) . .	65
3	Phosphoric acid (as superphosphate) . .	84
4	Potash (as muriate of potash) . . .	73
5	Nitrogen plus phosphoric acid . . .	105
6	Nitrogen plus potash	71
7	Phosphoric acid plus potash . . .	84
8	Nitrogen plus phosphoric acid plus potash .	98

and 8 shows finally that there was no scarcity of available potash in this soil at all.

In **conducting** any **manurial experiment** it is essential that the conditions should be the *same* for all the plots, save only in the matter of the manures whose action it is desired to test. A common manurial experiment is one designed to test whether the phosphoric acid, which is often deficient in a soil, can be more effectively supplied by superphosphate or by bone flour. If such an experiment, however, used superphosphate with, say, the Arran Chief variety of potatoes on one plot, to contrast it with bone flour and Kerr's Pink variety of potatoes on another, it would have no value at all. It would be impossible to say in how far the manure and in how far the variety of potatoes were responsible for the results. The following are the more **important conditions** to be looked to in conducting a manurial experiment :—

1. Same kind of crop.
2. ,, variety of that crop.
3. ,, ploughing and preparatory cultivation.
4. ,, wetness of soil during any such cultivation.
5. ,, date of seeding.
6. ,, thickness of seeding.
7. ,, method of applying manures.
8. ,, treatment of crop during growth.
9. ,, stage of maturity when each harvested.
10. ,, method of harvesting.
11. ,, exposure of plots to weather, and no tree shelter.
12. ,, year's results, and not one year one manure against another year another manure.
13. ,, previous cropping of the land.
14. ,, quality of land.

In practice, there is little difficulty in complying with these conditions except the last. Care, however, must be taken, and farmers often draw wrong conclusions as to the value of some manure by overlooking the importance of bad season, faulty cultivation, wrong kind of seed, or other factor for which the manure was in no way to blame.

Absolute uniformity of soil is the condition in manuring trials which it is impossible to obtain, even where the site of the experiments has been carefully selected. The disturbing element of **soil variation** should always be allowed for in drawing conclusions, and from a single set of experiments conducted in one place in one year it is unsafe to draw conclusions where the differences in yield do not exceed 10 per cent. This " experimental error," as it is called, is much greater on very small plots than on large ; it can be greatly reduced when the whole experiment is replicated four or five times in different parts of the field, and an average struck from all those plots which received the same manurial treatment.

The size of plots employed in **field tests** usually varies from one-fortieth of an acre to one acre. The smaller plots are usually laid down in rectangles or squares, and can be so arranged that each kind of manurial treatment (here designated by A to D) occurs once both down and across.

C	D	A	B
A	B	C	D
D	A	B	C
B	C	D	A

The order of the plots in each replication (reading down) is as far as possible decided by chance—*randomised* plots. This method of arranging plots has been called the " Latin Square."

Where large plots are employed it is found that long rather narrow plots, adjacent and parallel to each other, as in the following plan, are likely to give greater uniformity of soil than do square plots scattered about the experimental area :—

Plot 1.
Plot 2.
Plot 3.
Plot 4.
Etc.

In **laying off,** the area of the plots must be carefully measured, and pegs driven in at the corners to mark their outline. A

[*By courtesy of the Director.*

FIG. 60.—Broadbalk Wheat Plots, Rothamsted—all but six harvested.

placard or tally bearing the number of the plot is also set up (Fig. 60). A path, about 4 ft. wide, should be allowed for lengthways between each plot ; these paths may be kept weeded, or preferably they may be sown with the same crop as the plots, in order to avoid undue stimulation of the plot plants which border on the paths. Such " buffer " crops would be harvested separately, and before the crops on the plots themselves. Whatever the size of the plots—manures applied and crops obtained are always calculated to amounts per acre.

The following **schemes of experiment,** using barley and potatoes are given for illustration, and could be conducted on plots laid off on the foregoing plan :—

Plot.	Barley Experiments.	Plot.	Potato Experiments.
1	No manure.	1	No manure.
2	1 cwt. sulphate ammonia.	2	15 tons farmyard manure.
3	3 ,, superphosphate. 1½ ,, sulphate potash.	3	7½ ,, ,, ,,
4	1 ,, ,, ammonia. 1½ ,, ,, potash.	4	7½ ,, ,, ,, 4 cwt. superphosphate.
5	1 ,, ,, ammonia. 3 ,, superphosphate.	5	4 ,, ,, 1 ,, sulphate ammonia. 1 ,, ,, potash.
6	1 ,, sulphate ammonia. 3 ,, superphosphate. 1½ ,, sulphate potash.	6	4 ,, superphosphate. 1 ,, sulphate ammonia.
		7	4 ,, superphosphate. 1 ,, sulphate potash.
		8	4 ,, superphosphate.
		9	No manure.

In the scheme for *potatoes* the " controls " are two unmanured plots at each end of the experiments ; the average yield of these two would be used to calculate the increase from the manures on the intervening plots. In the *barley* experiments the " no manure " or " control " plot could usefully be repeated between each manured plot—the return due to any dressing being then estimated by comparison with the average yield of the two controls running alongside. It will be seen that Plot 6 receives a " complete " manure—supplying nitrogen, phosphoric acid, and potash ; the results from Plots 3, 4, and 5 are designed to show the effect of omitting any one of these three in turn. Plot 2 is calculated to show whether nitrogen alone is a sufficient application for barley under the local soil conditions and the system of management.

Experiments are sometimes conducted in **pots** instead of on measured field plots. For ordinary purposes 10-in. flower pots, or any like-sized clean containers providing drainage, may be used. Over-watering should be avoided. For demonstrating **in school** the action of manures, the eight-plot test (Table XI.) could usefully be performed. If the soil is too rich the manures cannot be expected to give results, and especially so because the work of sifting and mixing improves its fertility. For use, therefore, good garden soil should be mixed with two to three times its weight of fresh-water sand. Quite *small quantities* of the manures should be well incorporated with this diluted soil, say in a small bath, before transferring to the pots in turn. Suitable quantities of the manures are—superphosphate equal to 0·1 per cent. of the weight of soil as used ; for sulphate of ammonia and the potash manure respectively, use one-half of that amount. The quantities are the same whether to be used alone or in the mixtures. For 10 lb. of soil the superphosphate works out at about one-sixth of an ounce. If desired to extend the demonstration for quantitative results, then one-quarter, and also four times the superphosphate mentioned, can be used in other pots without damage. It is more easy to do damage with excess of ammonia or of potash. Wheat, oats, or mustard, are suitable crops—sowing 12 or 16 seeds in each pot and thinning out to half this number when the plants are fairly established.

A knowledge of experimental methods is useful to **the farmer** by enabling him to appreciate at its true value the work of public institutions, and in helping him to understand their published results. There are many **simple experiments** of a more rough and ready nature which the farmer can carry out without deviating from the routine of his ordinary duties. In applying manures which may cost him several hundred pounds per annum, he should leave small spots untreated in order to judge whether his expenditure was well justified. He should also, in small strips of crop, use double the usual quantity of fertiliser in order to get a rough idea of whether his usual quantity was sufficient. He should also, at times, try the effect of a small quantity of some phosphatic manure *as an addition* to the cereal dressing of ammonia ; on light soils he could occasionally try potash on the same principle. Such variations in practice add to the interest of farming, and may be well repaid. With such simple tests it will often be enough to judge of results by the skilled eye.

CHAPTER XXV

WATER REQUIREMENTS OF CROPS

OF the various requirements for the growth of a crop the most obvious is a sufficient supply of **water.** Ordinary experience shows that the quantity required must be large. Greenhouse plants require frequent watering, or they shrivel and dry up. A crop of clover cut in the morning is soon withered because it ceases to receive water from the roots. Year after year the yields from farming depend very greatly upon the extent of rainfall, and in dry seasons lack of moisture becomes the *limiting factor* in crop growth.

The water required by crops is chiefly **absorbed** through the **root-hairs** (Fig. 8) which are present on the root at some distance behind its tip. These root-hairs vary in number and length on different plants. They are thin-walled, and each forms a single cell or compartment. They contain a layer of *protoplasm* lining the *cell-wall* on its inner side, and inside that is a solution of sugar and acid substances—this solution forming the *cell-sap*. Imagine a long finger of a glove, smeared inside with white-of-egg and then filled up with a weak solution of sugar, and you have some idea of the component parts of a root-hair.

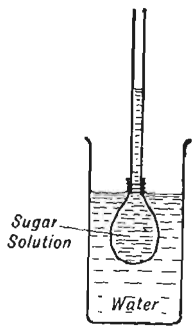


FIG. 61.—Osmosis.

If we take a bladder skin and pour into it a solution of sugar or other crystalline substance (Fig. 61) we may tie the neck of the bladder and hang it up. It will retain the solution of sugar. If, however, the bladder be now immersed in a vessel of water, a little of the sugar will pass outwards through the skin, and a good deal of water will pass inwards through the skin into the bladder. There will thus be passage from both sides, but the denser particles of the sugar solution will move more slowly than the particles of pure water. This phenomenon is known as **osmosis**. The bladder will swell out with the increased contents, and starting with even a moderately dilute solution of sugar the pressure may be enough to burst it. If we start with pure water inside the bladder and place the sugar solution in the vessel outside, then the contents of the bladder will shrink.

By plants, water is absorbed from the surface of the soil particles by osmosis. The walls of the root-hair represent the skin of the bladder, and the cell-sap inside represents the sugar solution. The cell-sap being denser than the soil water outside,

FIG. 62.—Diagram (Enlarged) showing Root (*r*) and Root-hairs (*h*), the latter absorbing water which covers the dark soil particles as a film (light shading). Air spaces as at (*a*). (After Sachs.)

the latter passes through the walls of the root-hair, which then becomes distended by the added water. Osmosis in plants is, however, different from the bladder experiment in one respect. While the living protoplasm lining the walls of the root-hair allows water to pass freely inwards, it does not allow the sugar, etc., of the cell-sap to pass outwards. Fig. 62 shows how the root-hairs (highly magnified) receive water by osmosis from the water surrounding the particles of a soil.[1]

[1] Osmotic pressure increases with the number of dissolved particles in the solution, and is analogous in effect to gaseous pressure at equivalent concentrations and temperatures. Where the soil water is a stronger solution than is the cell sap inside the root-hairs, then water cannot enter

After absorption by the roots, the water **passes upwards** within the plant. When a root-hair becomes swollen with water it is *turgid*, and the living protoplasm, as if resenting this, contracts. Water is then forced inwards through the root, which is composed of small round *cells* (Fig. 63), each of which has its own cell-wall, protoplasm, and cell-sap as had the root-hair. Each of them is alive. With the water received from the root-hairs they in turn become turgid and contract, sending the water

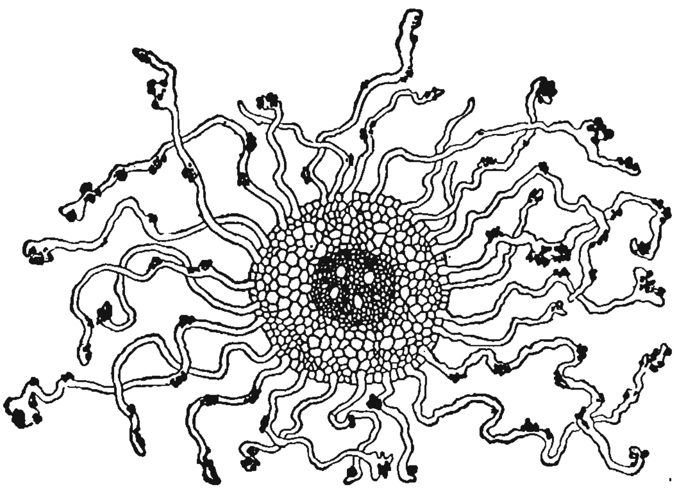


FIG. 63.—Transverse Section of Root (Enlarged), showing (1) Root-hairs, (2) the Cellular Structure of the Root, and (3) Fibrovascular Bundles in Centre.

onward from cell to cell, until finally it reaches the *fibrovascular bundles*, or conducting vessels, in the centre of the root. When

the root-hairs but tends to leave them, and they are *plasmolysed*. This often occurs in the so-called "alkali soils" (Chap. XXXI.) of dry countries, and the plants then suffer from "physiological drought." Compare shrinkage result in above bladder experiment. With many plants a solution developing an osmotic pressure of 4·5 atmos. will induce plasmolysis; weaker solutions, however, only render water absorption more difficult than usual. In England this last effect may show itself in dry summers where excessive amounts of kainit have been applied in spring. Common salt is sometimes put on garden paths to kill weeds.

the living protoplasm contracts, sending on water in this way, it is doing "work." Energy is required to do work, and to obtain this energy the cells of the root must breathe. Water-logged soils do not admit air well, and on such soils, while the roots are able to absorb water by osmosis, they are unable to send it on with vigour; as a result *root pressure* is low, and the upper parts of the plant may not receive sufficient moisture for their support. Besides requiring air, the protoplasm of the roots can work much better in a warm soil (Chap. XXIX.) than in a cold one; this is a physiological result, just as flies are more lively in warm weather.

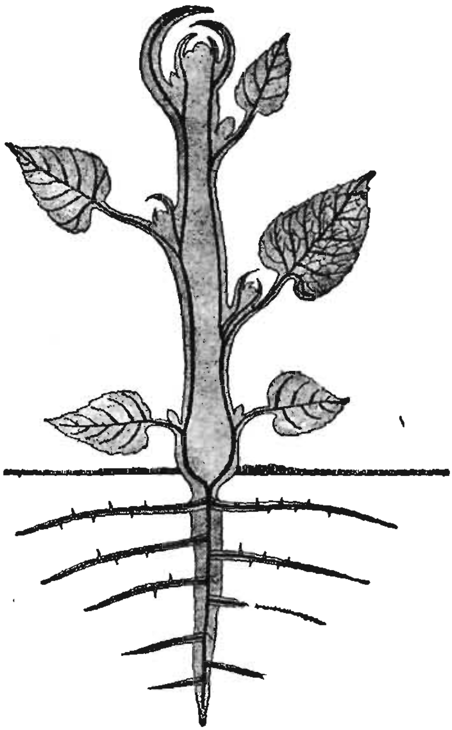


FIG. 64.—Diagram of Fibrovascular System of a Plant.

From the roots the water, then, reaches the base of the stem by root pressure; it passes upwards in the stem through the fibrovascular system (Fig. 64) of the plant. Finally it is distributed in the leaves through the fibrovascular bundles which compose the vein-work of the leaves.

From the leaves, the water (except a small amount used up in making starch) is **evaporated through the stomata** (Fig. 13). In Fig. 65 an enlarged section of one *stoma*, and surface views of four *stomata* are shown. Each stoma is formed by a pair of crescent-shaped *guard-cells* which contain chlorophyll; although small they are very numerous—often over 100,000 per sq. in. of leaf surface. The stomatal openings close very much when the water supply to the plant is deficient and open wide when the leaf is well supplied. They thus act to some extent as automatic regulators of the water lost by the plant, but cannot prevent it entirely. Besides good water-supply, light tends to open and darkness to close the stomata, and for this reason a plant may appear fresh in the morning but withered in the afternoon.[1] Evaporation from the leaves is also, as one would expect, much greater in a dry atmosphere. Loss of water by the plant is known as **transpiration.**

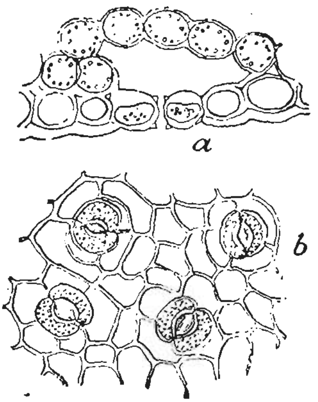


FIG. 65.—Stomata (Enlarged). *a*, in section; *b*, on leaf surface.

The *amount of water transpired* by a crop depends upon the amount which it receives, and the rapidity with which it is lost. The following conditions determine the amount transpired :—

1. The water-content of the soil.
2. A sufficiency of fresh air within the soil.
3. The soil temperature.
4. The relative humidity of the atmosphere.
5. Winds.
6. Amount of light.

Many **experiments** have been conducted in different countries to ascertain the actual amount of water transpired by crops during the entire period of growth. The method generally adopted is to grow the crops in pots containing equal weights of damp soil. The pots lose weight according to the amount of water transpired, and by weighing the pots each day and noting the loss of weight, the amount of water lost can be calculated. Water is then added to bring the pots up to the original weight, and the process is repeated day by day. A record is kept through-

[1] This is apparently connected with the presence of chlorophyll in the guard-cells. These become turgid owing to osmotic pressure set up by fresh products of photosynthesis under exposure to light.

out the season. The pots must be protected from water added by rain, and are usually placed on trolleys (Fig. 66) which can be quickly run under cover when necessary. As a certain amount of evaporation takes place with each pot from the surface of the soil and not through the leaves, it is usual to include in such experiments a pot which does not grow a crop. The water lost by this fallow pot is deducted from the water lost by each of the cropped pots, and the difference shows the amounts of water actually transpired by the various crops.

A large crop grown in a large pot would naturally transpire more water than a small crop in a small pot. To get results

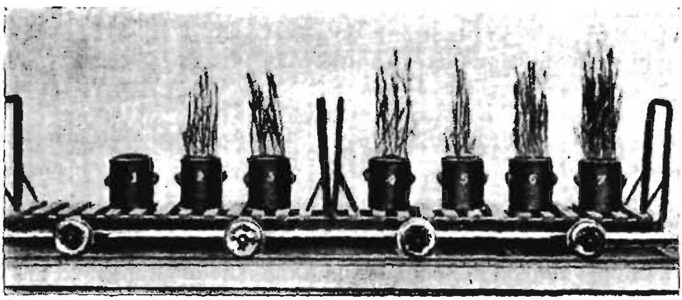


FIG. 66.—Pot Cultures in India, to ascertain transpiration with barley. (After Leather.)

No. 1, fallow pot.

which can be compared with each other, the crops when mature are cut off close to the ground (roots being neglected) and the material is dried. The amount of water transpired can then be divided by the weight of crop produced. This gives the **transpiration ratio** of the crop. If a crop required 700 lbs. (or tons) of water to produce it, and its dry matter amounted to 2 lbs. (or tons), then the transpiration ratio of that crop would be 350.

Table XII. shows the transpiration ratio of some crops as determined in different countries.

The amount of water required to produce 1 lb. (or 1 ton) of dry matter in various crops depends less upon the kind of crop among ordinary crops than upon the climatic conditions of the country where it was grown. The transpiration ratio is much higher in warm, dry climates. This, indeed, might be expected.

We have seen that the leaf is the place where dry matter is built up (Chap. VI.), and much water must be present to help this building up, apart from the small amount of water actually consumed. In warm, dry countries the water passes more rapidly out of the leaf ; it passes so rapidly that it is lost before it can accomplish so much.

In England a 30-bushel crop of wheat will contain in grain and straw about 4,462 lbs. of dry matter (Chap. V.). Taking

TABLE XII

Transpiration Ratios of Crops

	Lawes and Gilbert (England).	Hellriegel (Germany).	Widtsoe (U.S.A.).	Leather (India).
Wheat . . .	247	338	546	850
Barley . . .	257	...	...	680
Oats . . .	...	376	...	870
Peas . . .	259	273	843	830
Clover . .	269	310	...	...

the England figure for wheat (Table XII.), this dry matter involved the transpiration of about $4,462 \times 247 = 1,102,114$ lbs. of water, or 492 tons. This would be the amount of water transpired by 1 acre of average wheat during its growth. There is no wonder that a dry summer limits crop yields. This result follows, however, not only from the direct lack of rain ; it is accentuated by the drier atmosphere and stronger sunshine which accompany the dry summer. Thus in Samara (Russia), while the transpiration ratio of a particular wheat was 444 in an average year, in a very dry year and with the same wheat it went up to 628. The crop then not only received less moisture, but it made a poorer use of what it had.

A very large amount of water is required to produce 1 ton of dry crop. Dr Leather has shown, however, that the water " goes farther " and **less is required** for each ton of crop where the land is suitably **manured**. Table XIII. brings these results out.

By suitable manuring, a crop can make a somewhat better use of the water present in the soil. There is a limit, however, to such improvement, and in all cases a very large amount of water is required.

TABLE XIII

Effect of Manures upon Transpiration Ratios

	Without Manure.	With Manure.
Wheat	850	530
Barley	680	480
Peas	830	530

The water absorbed from the soil by osmosis is **not quite pure** water. It contains in solution a very small quantity of phosphates, potash, nitrates, and the other necessary constituents (Chap. V.) which a crop must obtain from the soil.

CHAPTER XXVI

PHYSICAL CHARACTER OF SOILS

THE **physical condition** of a soil is connected with its texture. It is the physical condition which determines the ease with which land can be dug or ploughed ; the passage of air, water, and the roots of crops into the soil depend upon the same thing. It is sometimes said that the physical condition of a soil is more important than its chemical composition and the supply of plant food, but this is not the case. Both are important, but a good physical condition may be the more difficult to obtain.

The physical condition of a soil is decided by three factors :

1. The size of its particles.
2. The amount and nature of its binding materials.
3. Its management.

The Size of the Particles.—The extremes are found in coarse, loose sands, and in dense, plastic clays. In clay soils the particles are much finer than in sand. In any particular case the sizes of the particles composing a soil are ascertained by a **mechanical analysis.** In such an analysis the soil is separated into different grades of fineness—the coarser grades by means of different sieves, and the finer grades by sedimentation in water.

The results given in Table XIV. for three different soils (Robinson) are intended to illustrate the kind of information furnished by a mechanical analysis as now employed in this country. Coarse material over 2 mm. is termed " gravel," and is weighed but not included in the results. Carbonate of lime, and " organic matter, etc.," removed by preliminary treatment, are included.

TABLE XIV

Mechanical Analyses of Three Soils (Dry)

	Diameter of Particles.	Sandy Loam (Shropshire).	Heavy Loam (Anglesey).	Clay (E. Africa).
	mm.[1]	Per cent.	Per cent.	Per cent.
Coarse sand . .	2·0 to 0·2	66·6	13·6	1·0
Fine sand . .	0·2 ,, 0·02	17·8	17·4	4·1
Silt . . .	0·02 ,, 0·002	5·6	24·7	7·9
Clay . . .	Below 0·002	8·5	35·1	82·8
Carbonate of lime .	...	Nil.	Nil.	Nil.
Organic matter, etc.	...	1·5	9·2	4·2
Totals .	...	100·0	100·0	100·0

It is only necessary to consider the figures generally. Great differences may occur in the fineness of the particles making up different soils. When the coarser fractions predominate and but little of the finer silt and clay are present, the soils lack coherence, and are *light* to work. That is typical of sandy soils. On the other hand, clay soils contain too little of the coarser and too much of the finer fractions; these tend to set hard when dry, and become sticky when wet. Clay soils consequently are *heavy* to work, and farmers usually designate them accordingly.

The Binding Materials.—The physical character of a soil, however, does not rest solely upon the fineness of its particles.

[1] One inch equals 25·4 mm.

Various *cementing materials*, always present in varying amount, can bind the individual particles loosely into groups or "crumbs," and thus modify the structure of the whole mass. The chief binding materials are :—

1. Colloid clay.
2. Humic acids.
3. Carbonate of lime.
4. Iron rust.

The effect of any of these is much greater in soils which are composed chiefly of finer particles ; clay soils easily form crumbs but coarse sands do not.

Colloid Clay.—Colloids are substances in an extremely fine state of division. An ordinary microscope can reveal objects down to about $\frac{1}{125000}$ in. in length, but in colloid material the diameter of the particles may be much smaller than that. (The new electron microscope—using very short invisible rays—will be useful here.) Such finely divided material is present in all soils more or less, and it occurs in large amount in heavy clays.

When a clay soil is shaken up with pure water and the liquid left standing, the coarser particles soon settle to the bottom, but part of the clay remains permanently in suspension in the water making it turbid or muddy. This turbidity is due to the presence of a large number of exceedingly small clay particles. Each carries a low charge of negative electricity. Now, bodies charged *with similar* electricities repel one another, and for this reason the little particles remain dispersed through the liquid and are unable to approach each other and fall to the bottom. The clay is now in colloidal solution. When certain substances are added to this clayey water, however, changes immediately begin. The electricity in the tiny particles is discharged, and these then draw together so as to form larger *aggregates* of themselves—often called floccules. When this happens the clay is said to be *flocculated* ; the floccules subside to the bottom of the container, and the water becomes clear.

Various substances can bring about the *flocculation* of clay. Mineral acids are very effective, as are also many salts. Lime acts well, and so do soluble salts of lime. By adding one of these to turbid clayey water, therefore (Fig. 67), the colloid clay is flocculated, and settles down, leaving a clear liquid. The photograph was taken after standing the jars for nineteen hours. It will be seen that No. 1, to which no addition was made, remained turbid. Lime (2) and gypsum (4) cleared up the water; carbonate of lime (3), being insoluble, did not do this at once, but would in time, when it had changed (5) to soluble bicarbonate.

In practice, muddy ponds may be cleared by adding hot lime at the rate of about 1 lb. per 200 gals. of water. Gypsum is also

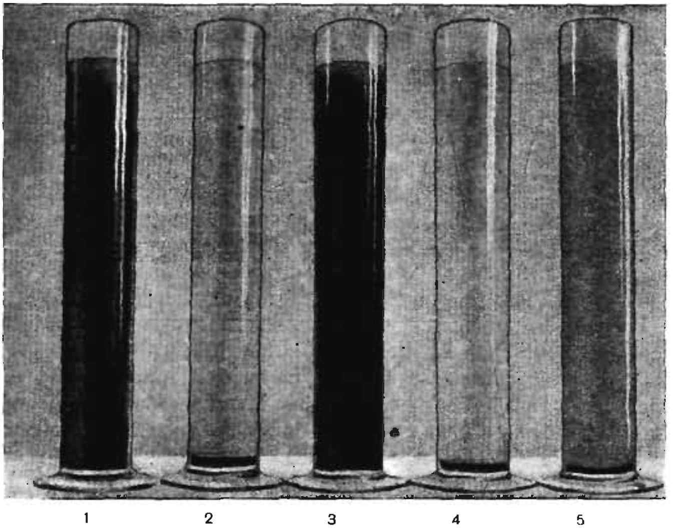


Photo: West of Scotland Agricultural College.

FIG. 67.—*Flocculating Effect of Various Forms of Lime on Muddy Water.*

1, Nothing added; 2, with lime; 3, with carbonate of lime; 4, with gypsum; 5, with bicarbonate of lime.

effective. Alum, at the rate of 1 lb. to 500 gals. is serviceable. Ordinary sea water is not muddy because the common salt is in sufficient quantity to flocculate the colloid clay; in this way are deltas formed at the mouths of great rivers.

In clay **soils in the field,** the colloid clay present may be already flocculated, or it may not. If not, then its very fine particles form a dense homogeneous mass (Fig. 68 (1)) through which water and air cannot pass. Such clay is very sticky. By liming the soil its colloid clay is caused to flocculate. When this occurs the finer silt and clay particles come together so as to form little groups of compound granules or crumbs (Fig. 68 (2)) between which water and air can now circulate. The soil loses its sticky character, and becomes more open and porous. When clay soil is worked up with water the compound granules formed may be broken down; the clay, now *deflocculated*, then becomes tough and sticky. This happens when clay is puddled. Water containing lime will not do to puddle clay, nor can clay be puddled if it contains soluble lime compounds. Lime or gypsum works a great improvement on sticky clays because it causes the formation of compound granules from the altogether too fine particles of those soils.

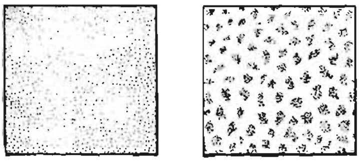


FIG. 68.—Clay Soil.

1, Puddled; 2, flocculated by lime.

Humic acids, like clay, are colloidal substances, and like clay are coagulated by lime. The use of farmyard or green manure thus provides a cementing material which in presence of lime unites the finer particles into larger compound groups. Humus has thus a *binding effect* upon loose sands. By binding the all too fine particles in clay into compound groups it makes these soils more porous. Farmyard manure improves the physical character of clay soils, therefore, and also of loose incoherent sands.

Carbonate of lime has a binding effect on loose soils resembling that in mortar. This occurs in soils containing dissolved bicarbonate when the land dries out, or when slaked lime has been applied—insoluble carbonate of lime being formed and holding loose grains weakly together.

Iron rust is formed by oxidation in soils which are well aerated, and the high value of many red or chocolate soils is due in part to the cementing power of iron rust in holding the oversupply of finest particles in larger porous groups. Without such cement, the finer grained soils would pack too closely when wet, and be hard to work. An application of lime favours the formation of the iron cement.

Hard Pans.—In soils the various cementing materials may tend to wash downward before "setting," if the conditions for setting are unfavourable in the surface soil. A hard layer or "pan," from 4 to 20 in. thick, may then be formed in the subsoil through which neither water nor air can pass. In this way are formed "clay pans," "iron pans," and "lime pans." Such pans must be broken up by subsoiling or other means before successful farming is possible. The formation of pans (except lime pans) is most common in wet situations, and is often due to defective natural drainage whereby an excess of the cementing material was unable to get away before it was caused to set hard.

The Management.—The physical condition of a soil is also dependent upon its management. The effect of *farmyard manure* and *lime* have already been referred to—the former benefits powerfully either light or heavy soils ; lime is particularly useful on the heavy soils. *Drainage* will generally remove the cause of hard pans ; where already formed, subsoiling to break the pans, in addition to drainage, is called for. *Rest*, as under pasture, is beneficial to clay soils by encouraging its colloidal material to flocculate, and stiff clays when first ploughed up from pasture are less liable to "run together" than are clay soils constantly under cultivation.

The time and method of *cultivation* also affects the texture of a soil and the condition of its particles, and this is particularly true of clay soils which are ill supplied with lime. By working when wet they puddle, and on drying, form hard lumps. Harrows and rollers may break those down to a kind of tilth, but the best and cheapest means of reducing such lumps to a crumbly condition are time and weather. These can act in two different ways. On the one hand, winter frosts by expansion of water (Chap. XII.) have a potent action in pulverising clay soils ploughed in the previous autumn, and bringing them to a fine tilth. On the other hand, clay has the property of expanding and contracting very much (up to 18 per cent.) as the result of wetting and drying, and even without frost this helps to break clay down when it lies long. Clay land should never be worked while wet unless it is to lie exposed to the weather for a long time before use. It is better left alone. Sandy soils require much less skill ; there are fewer compound particles and soil crumbs to be broken down ; they do not tend to form clods ; they can be worked wet without serious injury ; and with them rest has little effect upon the physical condition of the soil.

Clays and sands are extreme physical types of soil. A **loam** is a mixture of the two, and the major area of farm lands come under this designation. When clay predominates we have a clay loam ; when sand, a sandy loam. There are many types. Loams usually give the best soils because they contain a greater variety in the size of their soil particles. Good loams contain neither too much of the coarser materials, nor too much of the finer silt and clay, but a fair proportion of each.

Chapter XXVII

RETENTION OF WATER BY SOILS

Crops require much water for their growth. If rain fell every day the retention of water by a soil would be of little importance. Rain, however, does not fall every day, and in dry seasons and districts the power of a soil to hold water may be of supreme importance in determining the size of the crop.

It will be useful to consider this matter first with regard to the naked mineral particles of measurable size—what may be called the skeleton of the soil—because the lessons to be learned are intelligible, and, as a fact, fit most of the experiences of the practical farmer. If the matter is not actually quite so simple as from our study it may appear, the result is due to the varying amounts of *colloidal material*, present in all soils, which tend to cover the larger particles, and intensify their relations to water. It may be that the relation of these colloidal bodies to water differs from that of the larger particles, not so much in kind as in degree —arising from their vast numbers. This matter is not fully understood. With this explanation we may proceed.

According to the manner in which it is held, the **water** in soils may be **classed** either as—

(*a*) Hydrostatic or gravitational water ;
(*b*) Capillary or film water ;
(*c*) Hygroscopic or condensation water.

A clearer view of the subject will be gained by glancing again briefly at the **physical composition** of soils.

In Fig. 69 (1) we have a box of spherical particles or balls each of the same size. These particles may be considered in three ways :

1. How much of the box volume is occupied by the spaces between the balls ?
2. How large are the individual spaces ?
3. What is the surface area of all the balls in the box ?

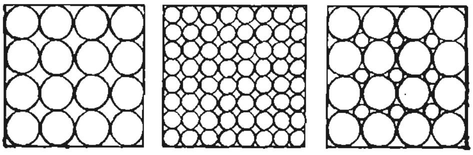


FIG. 69.—Equal Volumes of Different-sized Balls.

Total Water-holding Capacity.—Although the box is full of balls, it could hold some water in the spaces. With the packing shown, 47·64 per cent. of the volume inside the box will be occupied by the spaces, and the remainder by the balls. For this purpose it does not signify whether the balls are small or large provided they are all of the same size. With smaller balls (Fig. 69 (2)) the spaces are smaller, but there are more of them. If the spaces, however, were partially filled by smaller balls (Fig. 69 (3)), then the percentage of pore space would be reduced. This occurs in soils. On the other hand, if the particles were not round and smooth they would pack less closely, and the volume of space would be increased. This also occurs in soils. In a clay soil as much as 52 per cent. of its total volume may be occupied by the spaces between its soil particles, and in a sandy soil as little as 32 per cent. When both are fully saturated, a sandy soil can hold less water than a clay soil in these proportions.[1]

Percolation.—Looking again to Fig. 69, it is seen that while the total pore space will be the same with large or with

[1] While the actual particles in a clay soil and in sand have nearly the same density (each being about 2·6 times heavier than an equal volume of water), still 1 cub. ft. of clay is lighter than 1 cub. ft. of sand, owing to its greater percentage of *pore space*. Thus a cubic foot of clay may weigh 75 lbs. ; of sand 110 lbs. A cubic foot of water weighs 62½ lbs. When the farmer describes clay soils as " heavy " he does not mean heavy in weight, but only heavy or tenacious to work.

small balls (Nos. 1 and 2), still the large balls give larger individual pores. Water flows much more easily through large pores than through small ones. There is less friction. Sandy soils have larger, coarser particles, and the pores, therefore, are larger than in clay. For this reason water will percolate or drain much more rapidly through sand than through clay. The aggregate volume of the spaces decides how much water a soil can hold when fully saturated ; it is the size of the spaces which decides the rate of percolation, and this is important in drainage (Chap. XXX.) operations.

Hydrostatic Water.—Save after heavy rains, the surface soil in normal cases is not fully saturated with water. The water percolates downwards, and in humid localities comes to a level at which it stands unless removed by drainage. Such is hydrostatic water. The level of the hydrostatic water is termed the *water table*, and in wet districts may occur at a few inches below the surface, or at several feet. In dry regions there may be no water table. In a lake or swamp the water table may be said to be above the ground. For agricultural purposes a water table at from 3 to 5 ft. below the surface (Fig. 79) is usually best, depending on the class of land.

Capillary Water.—Water has an attraction for many things which it is then capable of wetting. If a stone be dipped into water and taken out it will be covered with a thin *film* of water. The main supply of water in soils is held as a film round about the soil particles.

Referring again to Fig. 69, it will be seen that each of the balls has got a certain surface. This is the area which would have to be covered if they were painted. If we took 1 cub. ft. of uniformly sized balls and measured the surface of one of them, then by multiplying this area by the total number of balls, we should obtain the aggregate area of all the balls in the cubic foot. If we now took a second cubic foot of uniform balls of just one-half the diameter of the first set, then the surface area of one ball would be only one-quarter as great as before, but there would be eight times more of them—so that by halving the diameter of the particles in a cubic foot the total area of their surface is doubled. Sandy soils, being coarser, have a smaller surface area on their soil particles than have clays, which are finer grained. In Table XV., which is adapted from King, is shown the total *surface area* of the particles in 1 cub. ft. of different soils.

TABLE XV

Surface Area of Particles in 1 Cub. Ft. of Soils

	Effective Diameter of Soil Grains.	Surface of Soil Grains in 1 Cub. Ft.
	mm.	Acres.
Finest clay soil	0·004956	4·0
Heavy red clay soil	0·01111	2·1
Loam	0·02197	1·1
Sandy loam	0·03035	0·8
Sandy soil	0·07555	0·3

It will be seen that the internal surface area of all the particles in 1 cub. ft. of the soils is very great indeed, and that it is much greater in clays than in sands which are coarser grained.

In soils, water tends to spread itself out over the soil particles because it is capable of wetting them. It **forms a film** round the particles. The formation of this film prevents all the water which falls upon a soil from immediately sinking to the water table. Fig. 70 shows how after heavy rain the surface layer of soil (see *a*) is fully saturated, but after a few hours it has percolated downwards (*b*) forming a film round the particles; as percolation proceeds the films draw out and become thinner, the lower layers of soil (*c*) then also receiving a coating of film water.

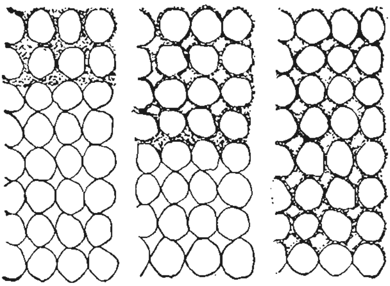


FIG. 70.—Water Percolating Down and Forming Films.

In dry localities the water which is received from rain is retained wholly as film water. The amount of water which can be so retained obviously depends upon the surface area of the soil particles in a particular soil. Referring to Table XV., clay soils should be able to retain considerably more film water than can sandy soils. The latter have less surface upon which the water can spread itself out. With the same thickness of film in each case, the percentages of water held by the different soils are as follows :—

TABLE XVI

Percentage of Water held by Soils under Similar Conditions

	As Percentage of Dry Soil.
Heavy red clay soil	56·96
Loam	28·80
Sandy loam	20·84
Sandy soil	8·36

These amounts are those held *after the soils have drained*, and are dependent upon the greater adherent surface presented to water by the finer grained soils. Clay can hold more film water than sand. The figures, taken generally, coincide with common experience as to the relative water-holding powers of the different soils.

It is the capillary or film water which is absorbed by the roots of crops, and not the hydrostatic water. Fig. 62 should be consulted. As the former only forms a film round the soil particles and does not entirely fill up the pores, therefore air can penetrate the soil—a condition which is essential to enable the roots to breathe.

While **crops** use the **film water** of soils, they can only use it down to a certain *thinness*. After that they wilt. As the same thinness of film represents a larger amount of water in a clay soil than in sand, plants may wilt on clay soils which still retain 10 per cent. of water, and on sandy soils not until only 4 or 5 per cent. remains. Five per cent. of water in a sand will represent as thick or thicker films than does 10 per cent. in a clay, because in clay the water is more extensively spread out.

Owing to their greater internal surface, clay soils can store up more water as film water, but for just the same reason they are unable to give away so much of their last water to a crop during long dry spells. The Mediterranean climate (Chap. IX.) involves long dry summers following rain in winter. As a result in countries with this type of climate, the clay soils do best for summer crops when the previous winter had been really wet, and the sandy soils do best when it had been rather dry. The following figures will illustrate this :—

A.—After a Wet Winter

	Clay.	Sand.
Water stored up in soil (say) .	30 per cent.	20 per cent.
Water remaining when crop wilts .	10 ,,	5 ,,
Water available for crop .	20 per cent.	15 per cent.

In that case the result was due to the clay having greater storage capacity than the sand, which had allowed more of the winter rains to drain away. After a drier winter, however, the greater water-storing capacity of the clay soil is of no use to it because the water had not been received :—

B.—After a Drier Winter

	Clay.	Sand.
Water stored up in soil (say) .	20 per cent.	20 per cent.
Water remaining when crop wilts .	10 ,,	5 ,,
Water available for crop .	10 per cent.	15 per cent.

The results are due to the greater area of surface in the interior of clay soils. In a long dry summer in England, August showers do their greatest good on the lighter classes of land.

Humus greatly increases the amount of water which can be held by soils, because owing to its porous character it presents a very large area of internal surface. Thus on the Rothamsted wheat plots which were sampled some days after the cessation of heavy rain, the plot which had received farmyard manure each year for twenty-six years held 37·6 per cent. of water, while an adjacent plot which had received only " artificials " each year held just 24·7. Like clay, of course, humus is unable to give away so much of its last water to crops as can sandy soils, hence the " burning " effect sometimes ascribed to very heavy dressings of dung in a dry summer.

Hygroscopic Water.—Any body which is exposed to ordinary air always carries a very thin film of water—hygroscopic water—covering its surface, and this film tends to decrease with rising temperature and to increase with the humidity of the atmosphere. This condensation of water-vapour to form hygroscopic water has *nothing to do* with the formation of dew (Chap. VIII.), where drops of liquid water are deposited from a saturated atmosphere upon a cooled surface. Hygroscopic films are slowly lost in quite dry air, or when the substances carrying them are sufficiently warmed. In a laboratory, samples dried at steam heat are usually left to cool in the dry air of a desiccator; without this precaution they would absorb some hygroscopic water and weigh too heavy. As would be expected, and apart from chemical affinities, it is those substances with the greatest internal surface which absorb the most hygroscopic water when exposed to ordinary air. Humus and clay soils absorb very much more than does sand. Within soils the hygroscopic water forms too thin films for crops to utilise it.

CHAPTER XXVIII

WATER IN SOILS—*continued*

THE free or hydrostatic water in soils moves owing to the force of gravity, and the film or "wetting" water moves owing to the surface tension of the liquid. The force of gravity can be measured at any latitude by weighing a body of known mass with a spring balance, and the force exercised by surface tension can be conveniently measured by a capillarity experiment.

Capillarity.—Water can wet some things and not others. It cannot wet some greasy parchment nor a cabbage leaf. When water cannot wet those things the reason is that its own particles have a greater attraction for one another than they have for the thing to be wetted. They stand aloof from it, and form little globules upon its surface. Now in such visible globules of water there are naturally a very large number of the minute water particles, or *molecules*, which compose it; and just as in any crowd a number of individuals are forced to take up an outside position, so also a number of these little molecules are forced to take up an outside position in the water globule. But they hate to do this, so all these "outsiders" with one accord and with equal vehemence strive to gain a place inside the globule. As a result of these uniform efforts the globule takes the form of a perfect sphere. Liquid mercury cannot moisten wood, and this result may be seen by dashing a very little mercury on a wooden table; the perfect sphere is also formed in a drop of falling rain.

Where, however, the water *can* wet the solid in contact—say, clean glass or a soil particle—the behaviour is different. It tends to spread itself out over it. The result will be understood from Fig. 71, where some open glass tubes of different diameters have their ends immersed in water. The attraction of the water for the clean glass is sufficient to raise it for some distance up the tubes, viz., to the point at which the upward pull is just balanced by the downward pull of gravity upon the lifted water. If the diameter of the tube be doubled, then the water will rise only one-half as high, because, while the attracting surface inside the wider tube is just doubled, still the volume of water to be raised is increased four times. This phenomenon was first studied in narrow or hair (L. *capillus* = hair) tubes, and is thus termed capillarity. In a tube of 1 mm. diameter at 32° F., water will rise to a height of 14 mm. and alcohol to a height of 6 mm. These figures are a measure of the reluctance of their particles to occupy the outside positions in free globules of the liquids—in other words—of their *surface tension*. At a higher temperature than the one stated, the liquids will not rise quite so high.

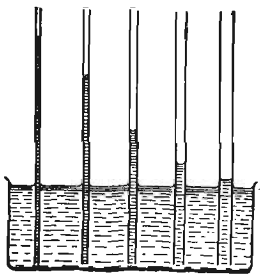


FIG. 71.—Capillary Rise of Water in Narrow Tubes.

The use of tubes, as in Fig. 71, furnishes a convenient means of measuring surface tension. But " capillarity " can manifest itself without regular tubes. The rise of oil in a lamp wick, or the lateral spread of spilt ink on blotting paper, are familiar examples. In soils, water can rise to the surface by " capillarity," and this ascent of water bears many resemblances to the ascent in glass tubes and it has the same cause.

In soils the water is present as a film (Fig. 70) round about the soil particles. When water rises in a soil it slides over the film (Fig. 72) from particle to particle. The particles must be touching, and the film is continuous over the particles while the water is passing. If water from such a system be taken off from A (Fig. 72), whether by evaporation or by the root of a crop, then the film at A will become thinner and more tense and water will slide along over the system from B in an endeavour to make the film equally thick over all the particles. Owing to gravity the bottom particles will have somewhat thicker films than those of similar size at the top after equilibrium has been reached, but this is a detail.

Where a soil of good texture is already thoroughly *moist*, and a water table exists at a depth of a few feet, much water can be raised to the surface by capillarity working over the soil grains. Experimenting with large cylinders of rather fine soils in America, King found that the amount raised was 1 lb. per sq. ft. of soil surface per day from a water table 4 ft. underground. This quantity is equal to a rainfall of $1\frac{1}{3}$ in. per week—a supply fully ample for vigorous crop growth.

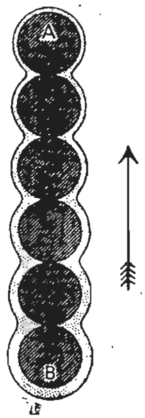


FIG. 72.—Ascent of Film Water over Soil Particles.

In ordinary farm **practice** the capillary rise of water from a water table is not usually so effective as in King's experiments. His soils were of intermediate fineness, and field soils may be either too fine or too coarse. When *too fine* the pores or passages between the soil grains are so small that excessive friction impedes the capillary ascent of water, and the land begins to dry out. Indeed, with much colloid material present, the pores may be blocked to such a degree as to render the passage of water from any cause impossible. Again, where the soils are *too coarse*, the smooth run of capillarity is hampered. Coarse soils present less internal surface upon which the water can draw itself up, and they will often be unable to maintain their larger pores full of water. The result of this is to draw in air which here again tends to dry the soil out. King's soils were very moist to start with, but, as land dries out, its power of lifting water by capillarity is greatly reduced. If conditions for capillarity are not ideal, field crops may wilt although there is a water table only a few feet from the surface. This is especially liable to occur on coarse soils and on the finest silts and clays.

As a fact, crops are dependent in ordinary cases not so much upon a water table as upon recurrent falls of rain. What happens is that after heavy rains, good water films are formed within the upper layers of soil from the rain percolating (Fig. 70) downwards. Crops utilise this water to meet their requirements, and the films become thinner. Evaporation from the surface of the ground also reduces the thickness of the films. While the films are still relatively thick, capillary movement quickly takes moisture to the points where crop roots or atmospheric evaporation has thinned them. If new rain comes, there will be a fresh general thickening of films through the body of the soil. But suppose a dry period supervenes. The films become gradually thinner and thinner, until the upper layers of soil become very dry throughout.

Now when land begins to dry out in this way the upward or capillary movement of water is much slower, because the water slides with increasing difficulty over very thin films. A

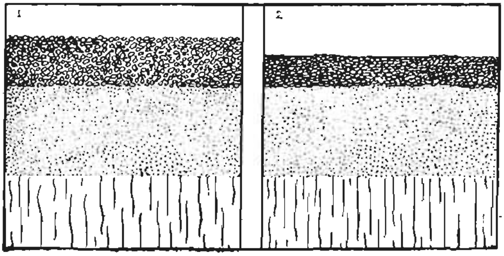


FIG. 73.—Soil Mulch. In (2), partly broken down by rain.

dry sponge does not mop up water so well as does a damp one. When the films become extremely thin by drying out, they are then able to pass on water only very slowly indeed.

This fact is sometimes taken advantage of to **conserve water** in a soil. After heavy rain the consolidated surface is loosened up by cultivation, so that the upper layers of soil become not only loose but, under the influence of weather, also very dry. This dry, loose layer forms what is called a *soil mulch*. It is unable to conduct much water from below, because its particles have become too dry and their points of contact with the unmoved soil below greatly reduced in numbers. Fig. 73 (1) shows in section the formation of a loose, dry, soil mulch. Its action in preventing the ascent of water from a damp under-soil will be understood. In Fig. 73 (2) it has been broken down by rain and requires harrowing to remake it.

The best **thickness of mulch** has been investigated by King. There appears to be no advantage in forming a deeper mulch than 3 in. Sandy soils yield a more effective mulch than clay, and stirring the surface even to ½ in. can greatly reduce evaporation losses. To attain the same object, gardeners sometimes protect damp soil with a covering of straw, fallen leaves, etc.; this is the most effective mulch but is hardly practicable under large field conditions.

In dry countries where the rainfall is insufficient or uncertain, farmers often crop the land one year and the next year leave it lying idle. During the idle year the land is ploughed during the rains of winter, and is then harrowed over in spring, when the surface is dry enough, in order to provide a loose, dry mulch which will reduce evaporation losses under the strong summer sun. The next crop is sown in autumn and grows through the following winter. The object is to obtain the rainfall of two winters for the crop of one season. The idle year increases soil moisture not only through the action of the soil mulch through the idle summer, but also by the fact that the land was carrying no crop, and thus avoiding transpiration losses. Results from Nebraska are striking, but not unusual for this type of farming. Here it was found that land under crop lost from 550 to 700 tons more water per acre than did an adjoining well-mulched fallow in each of three successive years.[1]

In this country a good deal of the winter rain can be saved within the soil for cropping purposes by cultivating the land in spring as *soon* as the surface is dry enough for the harrows. This is particularly important on land in preparation for turnip or other small seeds to be sown later in the season, and is too often neglected. Ploughed land, packed by the winter rain, dries out very rapidly in England during April.

[1] Where a soil is fully saturated with water, the amount of evaporation is somewhat greater than from an equal area of free water surface (Chap. IX.), and is the same for all soils. The reason is that the wet soil exposes a rougher surface with many convexities of film. As the soil becomes drier, evaporation of course is less than from a water surface.

The evaporation from a partially dried soil takes place not only at the surface of the ground, but it also occurs directly into the pores of the soil from the film surfaces deep down—the water vapour then diffusing upward through the pores. The reduction of evaporation by a soil mulch is indeed partly due to the loose, dry mulch being a *bad conductor of heat* so that the lower soil does not become so hot as it would under a firm, baked surface; internal evaporation is thereby reduced.

As the formation of a loose soil mulch limits evaporation losses, so, on the contrary, **rolling** the land tends to **increase** them. The soil particles are brought together by rolling, and in the presence of a little moisture the film connection with the soil below is again created. It is an advantage to roll land when small seeds like turnip are being sown, as this helps to keep the soil damp around the seeds. Rolling helps to draw soil moisture to the surface. But in so doing, it somewhat reduces the water content at lower levels. Land which has been rolled will often appear damp on the surface, while adjacent land—harrowed the previous day—appears dry. The damp appearance of the rolled land indicates that it is continuing to lose water coming up from below ; the dry appearance of the harrowed mulch shows that it cannot bring up water to lose.

Soil **moisture and cropping.** When land is fully saturated with water for any length of time, the roots are unable to breathe and finally die. In ordinary cases crops use the film water (Fig. 62) and best results are obtained when the soil holds from 40 to 60 per cent. of the full saturation capacity. Lack of water leads to reduced yields for many reasons. One of the chief reasons is the fact that it greatly hampers photosynthesis (Chap. VI.). It has been found that this is retarded long before plants show obvious signs of wilting. Again, the seven essential food materials (Chap. V.) drawn from the soil require water before they can be absorbed in solution by the root-hairs ; as, however, the intake of water and of the soil food materials proceed *independently* of each other, it is unlikely that lack of water commonly retards this.[1] Lack of water in the soil may also impede a crop indirectly through retarding the soil processes which bring insoluble food materials into available forms. An example is nitrification, which requires a good deal of soil moisture for it to proceed. But just as a clay soil can give away less of its last water to crops than can sand, so also for nitrification more water must be present in clay than is necessary in sand before it can proceed. Nitrification stops when the water films become too thin.

[1] The salts absorbed from the soil are to a large extent dissociated into *ions* when they are *dissolved in water* (*e.g.*, $\overset{+}{K}$ and $\overset{-}{\overline{NO_3}}$), and it is the particular ions derived from salts which the plant wants or does not want. Wanted ions will move to the points of demand within the plant with great rapidity, provided, of course, the soil is able to supply them and that the soil is not quite too dry for their formation.

The **Soil Atmosphere.** There is no free air in a soil fully saturated with water because there is no room for it. In other cases the quantity of air varies inversely to the amount of water present. This air may be collected through an iron tube forced into the ground and examined. Its principal difference from the ordinary air (Chap. I.) is that it contains rather more carbon dioxide and correspondingly less oxygen. The carbon dioxide often ranges round about 0·2 per cent., and is continually being lost by diffusion into the air. This loss is accelerated by a falling barometer, temperature changes, and winds. The principal sources of the carbon dioxide are exhalation from the roots of crops, and from the organisms causing humus decay. Naturally there is greater production during the summer months. Production of carbon dioxide on uncropped soils has sometimes been taken as a measure of bacterial activity, but it does not cover fully all the facts. There is more carbon dioxide in the subsoil, not because more is produced there but because it cannot escape so readily. Sometimes in water-logged soils the carbon dioxide may rise even to 10 per cent., and free oxygen fall to a very low figure, but such conditions are unfavourable to any useful purpose.

Besides the free air in soils, there is some other air present dissolved in the water films and occluded on the soil particles, but this cannot be easily collected. It is richer in carbon dioxide than is the free air of soils.

Chapter XXIX

SOIL TEMPERATURES

For each crop there is a range of temperature inside which alone it can grow. The *minimum* temperature is the temperature below which it cannot grow because it is too cold. The *maximum* is the temperature above which it cannot grow because it is too hot. The *optimum* is the temperature at which it grows best. This lies somewhere between the minimum and the maximum, but always nearer to the latter than to the former.

The **effect** of **soil temperature** upon plant growth is well seen in **germination.** The following will illustrate for a few crops :—

TABLE XVII

Temperatures for Germination (Fahr.)

Crop.	Minimum.	Optimum.	Maximum.
Mustard . .	32°	81°	Above 99°
Barley . . .	41°	84°	Below 100°
Wheat . . .	41°	84°	,, 108°
Maize . . .	49°	92°	,, 115°
Pumpkin . .	65°	91°	Above 111°

The figures explain why some crops will start growth in early spring, while others will only germinate later, or under glass.

The soil temperature continues to affect the **growth** of a crop **through life.** This is indicated in Table XVIII., showing the growth of maize roots during twenty-four hours when the soil was kept at different fixed temperatures.

TABLE XVIII

Effect of Soil Temperature on Root Growth (Fahr.)

Temperature of Soil.	Root Growth.	Temperature of Soil.	Root Growth.
	mm.		mm.
63°	1·3	101·0°	25·2
79°	24·5	108·5°	5·9
92°	39·0		

Growth falls away as the temperature is further removed from the optimum. Another way in which unfavourable soil temperature affects growth is by diminishing the upward movement of water from the roots. Thus Sachs found that tobacco and pumpkins wilted at night when the temperature fell to 55° F., even when the soil was well provided with water.

Unsuitable soil temperature also affects the crop indirectly, by giving a slower **preparation** of available **food materials.** This applies particularly to soil processes brought about by bacteria, because with them the optimum temperature usually lies between 86° and 95° F. There is little and often no nitrification in cold soils.

The **soil receives heat** in different ways :—

1. By the decay of organic matter within the soil.
2. By conduction from the interior of the earth.
3. By condensation of water vapour from the air.
4. By radiation from the Sun.

Decay of organic matter is used to heat the soil by gardeners, who make (Fig. 5) hotbeds with a liberal supply of horse manure. But in ordinary farm operations the heat obtained from the decay of organic matter may be neglected. At Tokyo, 20 tons of farmyard manure per acre mixed with the surface foot of soil raised the temperature by only 1·7° F. during the first twenty days, and its effect at later dates was scarcely noticeable.

Conduction from the interior of the earth must tend to heat the surface soil to some extent which it is impossible to determine. The effect is probably small.

Condensation of water vapour from the air to form hygroscopic moisture, also as dew, will heat the soil in some degree. When water evaporates, heat becomes latent in the vapour (Chap. VII.), and when the reverse process occurs the latent heat is set free again, and goes to raise the temperature of the soil. The result is not of great importance.

The **radiant heat of the Sun** is by far the most important source of heat to the soil. As the rays travel in straight lines, lands *near the Equator* must receive more heat per acre than do lands nearer the Poles, where the rays strike the soil at a more oblique angle. Fig. 74 shows that the same amount of heat is received on a smaller area of land when the Sun is high in the heavens.

Again, a *southern slope* (in the Northern Hemisphere) receives more heat rays on a given area than does land with a northern exposure. This will be gathered from Fig. 75, where the south side of a hill receives more than its due share of the Sun's rays, while the north side receives less. Early fruit and vegetables come more quickly forward on a southern slope.

As the Sun's rays must pass through the atmosphere, a part of their heat is absorbed by the water-vapour always (Footnote, p. 34) present there. It will be seen from Fig. 76 that after sunrise and towards sunset the rays have to traverse a thicker stratum of air than towards midday, and therefore lose more heat during their passage. The Sun is hottest round about *noon*.

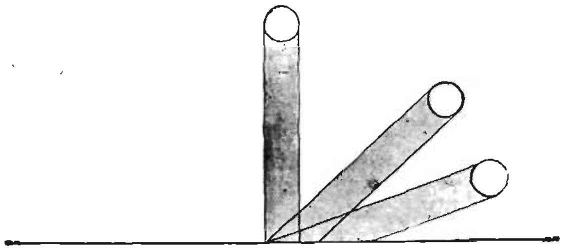


FIG. 74.—Showing how the Heat is Received on a Smaller Area at the Equator.

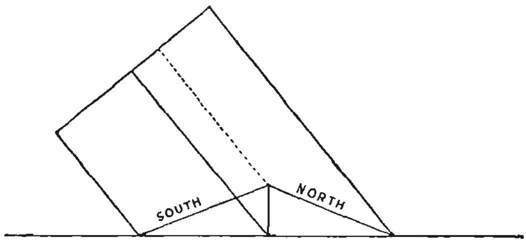


FIG. 75.—Showing Advantage of a Southern Exposure.

When the Sun's rays reach the land surface a large part of their heat is **absorbed,** and the temperature of the soil is raised. In bright summer weather in England the surface may reach 100° F.; in South Africa 160° F. has been recorded. In such bright weather the soil becomes much warmer than the air above it. *Dark-coloured soils* absorb more of the Sun's rays than do light-coloured ones, and with natural soils in Europe a difference of 8° F. has been observed simply owing to colour. In the Canary Islands a difference of 25° F. has been observed between black and white sands. The dark soils become warmer. There is no difference on cloudy days.

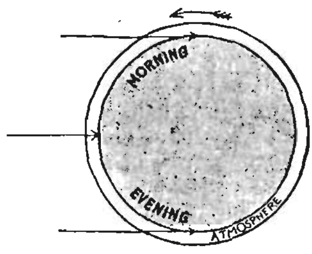


FIG. 76.—Effect of Atmosphere in Modifying Surface Temperature.

The extent to which **heat** absorbed at the surface will **raise** in **temperature** the body of the soil depends upon :—

1. The conductivity of the soil.
2. Its specific heat.
3. The evaporation of water.

The **conductivity** is least in fine-grained soils, and is therefore less in clay than in sand. Stones help. Compacting as by rolling, of course, improves the conducting power, while on the contrary a soil mulch, made by loosening the surface, keeps the lower layers of soil from becoming quite so hot. Water is not a good conductor of heat, but it is better than air, so that the difference in temperature between the surface and the undersoil is always less where the land is moist.

Specific Heat.—Heat is a form of energy. Water may be measured by units, and thus one speaks of "so many" pints or gallons of water. So also may heat be measured by units. The British Thermal Unit (B.Th.U.) is the amount of heat required to raise 1 lb. of cold water through 1° F.

Temperature is not to be confused with heat ; it is only heat-level. If one pint of water is poured into a tall narrow jar, and one pint poured into another tall jar which is wider than the first, then both jars will contain the same amount of water ; in the wide jar, however, the water will stand at a lower level. The wider jar requires more pints of water to raise its level by an equal amount. And so also some substances require more units of heat to raise their heat-level (temperature) than do others. Thus if 10 B.Th.U. will raise 1 lb. of water from, say, 40° to 50° F., the same number of thermal units will raise 9 lbs. of iron, or 11 lbs. of copper through the same range of temperature. In fact, iron behaves like the narrow jar, and it requies nine times less heat, than does an *equal weight* of water, to give an equal rise in its heat-level. Weight for weight, as it happens, water requires more heat to give a desired rise in temperature than anything else does, and the specific heat (S.H.) of water is taken as 1.

All other substances have a S.H. which is less than 1. For iron it is 0·11, and for copper 0·094. Soils have a specific heat which varies from about 0·16 to 0·25, so that about 5 lbs. of dry soil requires no more heat to raise its temperature by a given amount than does 1 lb. of water. The presence of water in a soil will obviously cause much more heat to be required to raise its temperature ; owing to its better retentive power for water it is found that wet clay requires about twice as much heat to warm it as wet sand does—after both have been wetted and allowed to drain. That is one reason why sandy soils are " earlier " in spring than retentive clays ; they are more easily warmed up.

As soils require less heat than water does to raise their temperature, so in exactly the same degree do they give out less heat again when their temperature falls. They lose less heat on cooling.

The **evaporation of water** has a cooling effect on soils, as heat must be drawn from somewhere to become latent in the water vapour formed (Chap. VII.). Soil does not give away very much heat on cooling, and the evaporation of 1 lb. of water requires as much heat as will lower about 500 lbs. of dry soil by 10° F., unless the soil is meanwhile receiving heat from the outside. Wet soils are thus cold soils. As an example, King found that a well-drained loam showed a surface temperature of 66·5° F., and an undrained black marsh 54° F.—the records being made in the same locality on the same day.

Soils not only absorb radiant heat, but they also **lose heat** again by radiation. At night the losses far exceed the gains. Most loss by radiation occurs under a dry atmosphere and a cloudless sky, and at night the surface temperature falls below that of the surrounding air. Soils covered by vegetation lose heat by radiation more slowly, and for this reason winter frosts do not penetrate so deeply in pasture land as they do in bare soil.

As one would expect, wide variations in soil temperatures occur between **summer** and **winter**. The following table shows at two seasons the average readings obtained in the temperate climate, with a moderate rainfall, of Nebraska :—

TABLE XIX

Soil Temperatures at Different Depths (Fahr.)

Average of Twelve Years.	Air Temp.	Soil Temperature at Depth of—			
		1 In.	6 In.	12 In.	36 In.
Winter .	25·9°	28·8°	29·5°	32·2°	39·1°
Summer .	73·8°	83·0°	79·1°	73·8°	66·2°

as the lower levels are reached. At Greenwich Observatory, on gravel soil, the average annual range at 3·2 ft. is 21·4° F., and at 25·6 ft. it is 3·4° F. As would be expected, temperature-changes to this depth travel down slowly, the yearly maximum here not being reached before 30th November, and the minimum not until 1st June of the following year.

In the table the seasonal changes in the surface foot of soil are well marked. At Rothamsted on a cold, cloudy day in June, uncropped soil at the 6-in. depth gave a reading of 60·5° F., and on a cold day in January of only 36·5° F. In spring the land requires warming up before vigorous growth can be expected.

Well-drained, rather coarse soils, which conduct heat best, become heated fastest in spring, and especially when they have a southern aspect. Such are **early** soils. Clay soils are **late** soils, partly because they are fine-grained, and largely because they hold more water, which makes them difficult to heat. Lateness or earliness is chiefly a matter of temperature.

Chapter XXX

DRAINAGE

Drainage is required to remove excess of hydrostatic water, which causes the water table to stand for lengthy periods too near the surface of the ground. With such an excess of water, cultivation is often impossible and it is always unprofitable.

Excessive wetness may arise from several **causes.** Flat lands receiving a heavy rainfall may become too wet when they are underlaid at no great depth by an imperious layer of clay or other material—the water being prevented from soaking downwards. Wet lands, however, are most often found in the low grounds of undulating country. Additional water may collect there either from *surface* drainage down the surrounding slopes, or it may come as *underground* seepage or springs through water-bearing strata from higher lands. Fig. 77 shows land which may be wet for both reasons.

Land is wet because the water cannot get away. The growth

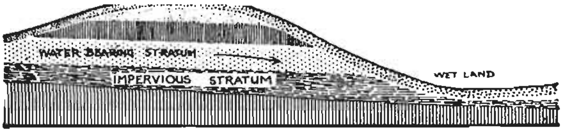


FIG. 77.—Showing how Water Accumulates in Hollows.

area may be shown by digging *test holes* here and there and leaving them open (Fig. 78); they will soon be filled with water up to the height of the water table. Such water table naturally rises

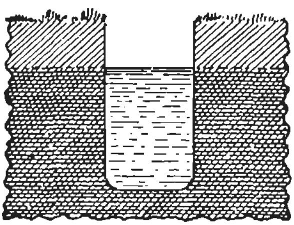


FIG. 78.—Test Hole showing Need for Drainage.

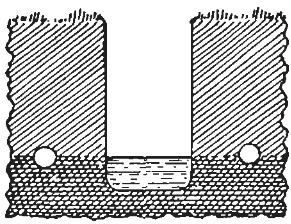


FIG. 79.—Showing Water Table Reduced to Drain Level.

after heavy rain, but if it stands at within 2 to 3 ft. from the surface for several days after the rain has ceased it may safely be concluded that drainage will benefit the land.

Drains may be of two **kinds,** viz., open or closed drains. *Open* drains or ditches are as effective as any, but they interfere with cultivation and traffic. Small open drains, or "sheep drains," are often used on damp hill grazings in Scotland. *Closed* or covered drains are the usual type on agricultural land; they are more costly to establish but less expensive to maintain. They occupy no cropping space and permit of cultivation in any direction.

In **closed drains** various materials have been employed for constructing a *water-way* at the bottom of the drain before it is filled in. Bundles of faggots, or round poles, or rough boards laid on edge—also stones usually broken, but sometimes built flatwise—have all been used to provide a channel for water. The common practice in modern times is to use the ordinary drain *tile* (Fig. 80) made from burnt clay. Such tiles are made of various diameters and measure about 1 ft. in length. The carrying capacity of pipes (not allowing for friction) is proportional to the square of their diameters, so that one tile of 3 in. is rather better than two of 2 in. diameter. For general purposes tiles of 3 in. are often employed, larger sizes of 4, 6, or 8 in. being used in the main drains into which the smaller drains discharge. While placing tiles in the drain they are carefully laid end to end (Fig. 80), and the water enters at the joints.

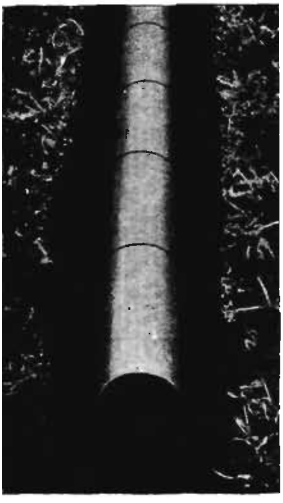


FIG. 80.—Water Enters at the Joints between Tiles. (Lunsford Co. Ltd.)

Water runs downhill, and before draining the first step is to find an **outfall** from the lowest part of the field into some natural or artificial watercourse. Where this cannot be found, the question of drainage must often be abandoned. Sometimes, as in the Fen country, the drainage water is led into open channels, from which it is raised by pumps to a level at which it can flow away. Windmills performing similar work are a familiar feature in Dutch landscape.

Land has been drained with a **fall** of 1 in. in 100 ft., but a greater fall is very desirable; where the fall is doubled, the carrying capacity of the tile is increased by about one-third. In flat country, and with shorter drains, fall may be got by making the drain somewhat deeper at the lower end. Before laying the tile the bottom of the drain should be carefully smoothed and graded to an even slope so as to avoid accumulation of silt in any tiles lying just a little below their proper level. Such irregularities reduce the carrying capacity of the drain, and are worst where the lie of the land provides little fall.

In laying off, and where the whole area is wet, the drains are usually put down parallel to each other (Fig. 81), and in the direction which gives the maximum fall, *i.e.*, straight downhill. The minor drains or *laterals* empty into a larger *main drain*, which discharges the water at the lowest part of the field. The laterals should connect with the main drain tile near its upper side and at an acute angle so as to avoid any sudden changes in the direction of flow. A scale plan of any lay-off may be useful in locating future stoppages.

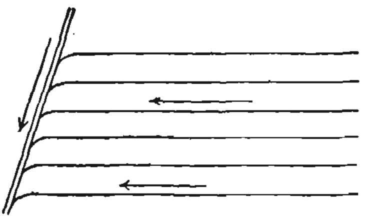


FIG. 81.—System of Parallel Drainage.

Drains are usually made from 2½ to 4 ft. **deep.** Shallow drains are more liable to silt up, and deep drains cost more to put down. When in working order, the water table will never rise above the drains (Fig. 79) save for a few days in flood times. In clay soils the drains in practice are generally shallower and closer together. Drains, however, should never be too deep—a frequent mistake of earlier times—and coarse, sandy soils may be damaged by too deep drains, as they cannot hold capillary water far above a water table. In peaty soils the tile should, if possible, be laid right down on the underlying clay or sand, even if 6 ft. deep, as tile laid in peat is liable to displacement later; this is due to the accelerated, but necessarily uneven, decay of the peat material as the result of laying drains.

The proper **distance between** drains depends upon their depth, and upon the class of land. Drains will " draw " further in sandy soils than in clays which offer more resistance to the percolation (Chap. XXVII.) of water.[1] In drained land the level of standing water is always higher (Fig. 82) between the drains, and is lowest just over the drains themselves. If these are too wide apart, then the water-table may come too near the surface at midway between drains, in which case the drains should have been closer. In sandy soil, owing to better percolation, the water gradient is flatter between drains. Fig. 82 also

[1] In any one class of land, drains draw better in summer than in winter because the *viscosity* of water decreases with a rise of temperature. Boiling water will leak through a small hole which cold water cannot pass. Thus King found that percolation through sand increased 50 per cent. when the temperature rose from 48° to 75° F.

indicates that the drains may be wider apart if they are deep. In practice the distance between drains varies from about 20 to 100 ft.

When drains are refilled after laying the tile the surface soil should be replaced on the top, as the raw subsoil is more

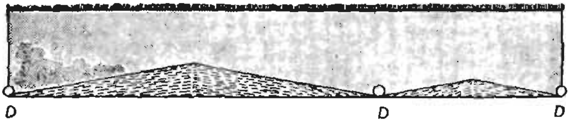


FIG. 82.—Diagram showing Action of Drains (D) upon Water-level.

or less infertile. Where this is neglected, the lines of drain may be marked by poorer crop for several years.

Drains are subject to choking or **stoppage** from various causes, viz. :—

1. By displacement of tiles.
2. By silting up.
3. By obstruction from roots.

Displacement is apt to occur where the tiles are laid within the substance of a peat, or in oozy clay. The only remedy is to open up the drain and relay it. *Silting* up may be due to washing in of fine silt, and may occur at faulty joints and especially in shallow drains. In a long drain the change from a steep gradient at the beginning to a flatter gradient near the end tends to silting up in the lower section. Silting up may also be caused by red deposits of iron rust. The insoluble rust is formed actually within the tile, and results from the oxidation there of a certain less-oxidised compound of iron which had entered the drain in solution (as bicarbonate).[1] This occurs especially in sour, peaty soils. *Obstruction by roots* is only serious where the drain has to carry water from higher ground at periods when the soil itself at the place has dried out ; otherwise there is no special inducement for roots to enter, and orchards can be successfully tile-drained. Where the conditions, however, encourage stoppage by roots, the joints of main drains may be closed with cement.

[1] Ferrous bicarbonate on oxidation yields ferric hydrate (rust) and loses CO_2, because ferric oxide (a weaker base) does not form the carbonate.

Sometimes other drains have their joints, including the underside, packed in cinders or in gravel, and gas-tar poured over them.

A curious **result of draining** is that while it removes water from the soil it may render the crop less subject to drought in a dry summer. This applies more particularly to fruit trees on land which stands wet during winter. Roots cannot live in stagnant water owing to lack of air, and while on drained land a deep-rooted crop can develop, so on wet land only shallow roots (Fig. 83) can be formed. When the land dries out in summer

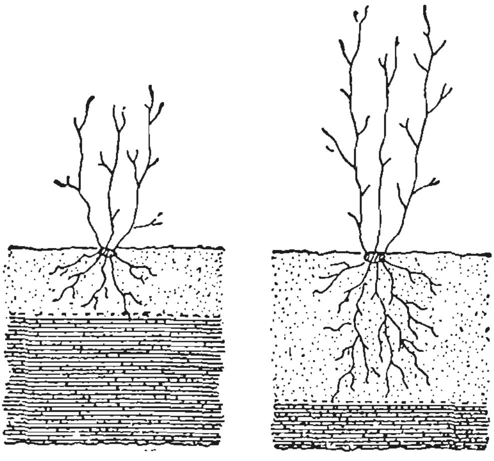


FIG. 83.—Wet Land bears a Crop with Shallow Roots.

the shallow-rooted crop has a more limited area from which it can draw moisture, and this area being near the surface is also particularly dry.

Drainage removes excess water from the soil, and this permits earlier and easier tillage, and also raises the temperature of the soil, which contributes to better growth.

In a previous chapter we considered lime. Lime on wet, peaty soils neutralises the **sourness** which readily accumulates there. Lime thus removes the **effect** of sourness already present. But organic acids will continue to be produced so long as the soil is badly aerated (Chap. XIV.), and this is always the case where it is too wet. By removing excess water, drainage allows air to enter, and the accumulation of organic acids is stopped. Good aeration tends to destroy them. Unlike lime, therefore, drainage removes the **cause** of sourness. To apply lime on wet, peaty soils is like a man continuing to pour water into a holed bucket in order to keep it full. It would be wiser to repair the hole, and then fill up the vessel once for all and be done with it. The farmer does this in effect when he drains his wet swamp first and applies the lime *afterwards*, so as to remove any relics of the sourness which still remain. As in the bucket simile, he is then " done with it."

The following are the chief **advantages of draining** wet lands. It will be noticed that the first six of them are due, not so much to the fact that drainage takes water out, as to the fact that in taking water out it allows fresh air to enter :—

1. Larger roots are developed with a larger feeding surface.
2. The crop develops greater root-pressure, and can send absorbed water to the leaves with greater vigour.
3. A better and quicker decay of humus is encouraged, and the noxious humus acids formed are destroyed.
4. Nitrification is encouraged.
5. Denitrification is impeded or stopped.
6. Nitrogen fixation by Leguminosæ is encouraged.
7. A better soil texture is obtained, by assisting the finest soil particles to form crumbs.
8. The soil temperature is improved.
9. Poisonous iron and other compounds are washed away in the drainage water.
10. Land can be sooner worked after wet weather, with less damage, and with a lighter draught.

Taken together, the above advantages tend to greater certainty in cropping, heavier yields, improved quality, and reduced liability to fungoid disease.

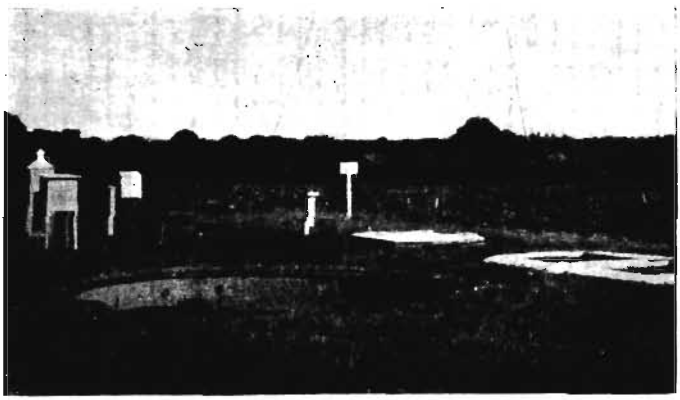
Chapter XXXI

DRAINAGE LOSSES AND FERTILITY

The water which falls as rain is partly evaporated again. This may occur either directly from the surface of the soil, or in transpiration through the leaves of crops. The part which is not evaporated in those ways disappears in the drainage.

What proportion exactly of the rainfall at any place will drain away depends on a number of conditions. There will be more under a heavy rainfall, and on hilly country, and from porous soils ; there will also be more where the land does not carry a crop. The famed **drain-gauges** at Rothamsted (Fig. 84), built in 1870 by Lawes and Gilbert, supply definite information on drainage losses under the conditions ruling at that place.

There are three gauges at Rothamsted, and each has an area



[*By courtesy of the Director.*

Fig. 84.—The Rothamsted Drain-gauges.

of $\frac{1}{1000}$ acre. The soil is a heavy loam and the surface is always kept firm but free from any vegetation. In making the gauges, the soil was left *undisturbed* in its natural field state of consolidation and a cemented wall was built round each of them; perforated iron plates were then introduced below to carry the weight, and a metal funnel was fixed underneath so that all drainage water from the soils could be collected. The soil in the three gauges is of 20, 40, and 60 in. in depth respectively. In Table XX. are given the average annual results, as recorded for the shallow and deep gauges during sixty-six years of observation. From the figures it is seen that almost exactly one-half of the annual rainfall is **lost as drainage** water under the local conditions at the station.

The table deals with the whole year. If we were to go further and quote details for each month, additional interesting facts would emerge. Most of the loss by percolation occurred during the winter months. Thus in the 20-in. gauge 73·5 per cent. of the total drainage for the year was collected from October to March, and for the deepest gauge 73·7 per cent. during the same period. The heavier percolation typical of winter started (October returns) earlier in the shallow gauge, but it continued later (March returns) in the deep gauge. These monthly details are of the order that one would naturally expect.

TABLE XX

Average Annual Drainage of Rain Water through Undisturbed Soils

Depth of Soil.	Annual Rainfall.	Evaporation.	Drainage.	Per Cent of Drainage.
	In.	In.	In.	
20 in. . . .	29·158	14·416	14·742	50·6
60 „ . . .	29·158	14·505	14·653	50·2

The Rothamsted results are from uncropped soils. From **land under crop,** a smaller proportion of the rainfall is lost by drainage. This is due to transpiration requirements. Thus, working near London with a turfed sandy loam, Greaves found that from a rainfall of 25·7 in., only 7·6 in.—or 29·6 per cent. of the rainfall—percolated to a depth of 3 ft. as drainage water. His results are the average of fourteen years. As a matter of general experience it will often be found during the summer months that the whole of the rainfall is eventually evaporated from pasture land, and that percolation losses during this season only follow heavy storms.

The drainage water which percolates from land is never pure water, but it always **contains dissolved substances** taken from the land through which it has passed. This would be expected. The nature and quantity of those leachings from land are important from the manurial point of view, because they indicate how fertility may be lowered through drainage losses. Useful information on this point is again available from Rothamsted—from the wheat plots (Fig. 60). These plots lie side by side, and are all differently manured, and each year the old kind of manuring is repeated on any one plot. Down the centre of each plot runs a tile drain from 2 to 2½ ft. deep, and the water delivered by each drain is measured and samples have been analysed. The composition of the drainage waters from three typical plots is given in Table XXI.—the figures showing parts per million of drainage water collected.

TABLE XXI

Composition of Drainage Waters (Rothamsted). Parts per Million.

	Manures Applied Each Year.		
	No Manure.	Farmyard Manure.	Complete Artificials.
Organic matter, CO_2, etc.	67·7	77·3	84·6
Nitrogen as nitrate	15·0	62·0	32·9
Nitrogen as ammonia	0·14	0·2	0·24
Lime	98·1	147·4	143·9
Magnesia	5·1	4·9	7·9
Potash	1·7	5·4	4·4
Soda	6·0	13·7	10·7
Iron oxide	5·7	2·6	2·7
Chlorine	10·7	20·7	20·7
Sulphuric acid	24·7	106·1	73·3
Phosphoric acid	0·6	...	1·54
Silica	10·9	35·7	24·7
Total solids	246·4	476·0	407·6

The tiles deliver little or no water between March and September, so that the drainage losses are practically confined to the winter months. It will suffice in this place to consider only the main lessons from the analyses.

The important **manurial constituents** in soils (Chap. XV.) are available nitrogen, phosphoric acid, and potash. As regards *nitrogen*, there is very little loss in the form of ammonia, but the loss as nitrate is serious during the winter months. This loss is naturally greater where a fresh application of farmyard manure is made each year than it is from the "no manure" land. The plot receiving artificials gets 200 lbs. of ammonia salts each year (in addition to phosphates and potash), and although ammonia is not itself washed out in any appreciable amount, still during the previous summer it had been changed into nitrate; this nitrate is easily lost in the next winter's drainage—except, of course, in so far as the nitrates had been used by growing crop. In "organic matter, etc.," figures, only about one-third is actually organic matter, and this has quite a small percentage of nitrogen; loss of nitrogen in the organic form is therefore unimportant. *Phosphoric acid* is lost in drainage only to a trivial extent—as was explained in Chap. XVII., the fate of phosphatic manures is not to be washed away, but to take less and less available forms of combination as years go by. Incidentally, this tendency is greatest in sour lands badly supplied with lime. *Potash* is washed out to a somewhat greater extent than phosphoric acid, and, as one would expect, the figures show considerably more loss from the farmyard manure (rich in potash), and from the complete artificial, than they do from the "no manure" plot which receives no potash manure at all. The losses, however, even where manured, are low, and by far the greater part of potash residues will normally remain in the soil, but in less available forms to benefit the succeeding crops.

So much for the three "essentials" of manures lost in drainage. Apart from these we have seen that *lime* (Chap. XXII.) has an important *indirect* action in promoting soil fertility. In the table—and it will be the same on most farms—the largest individual loss through the drainage waters is lime. The loss at Rothamsted was least from the "no manure" plot, but it greatly increased where the farmyard, or the complete artificials, were given. The lime would be washed out as soluble bicarbonate, and sulphate, and chloride, and nitrate. Soils do not hold sulphuric acid, chlorides, or nitric acid well, and when sulphate of potash or sulphate of ammonia is applied to land, the sulphate part is washed out as sulphate of lime formed by double decomposition within the soil, while the potash or ammonia remain there. It has been found at Woburn and elsewhere that continued use of sulphate of ammonia gradually makes land sour because so much lime is washed away as sulphate of lime, and some more later on as nitrate of lime when the ammonia part of the manure has been nitrified. Loss of lime is continuous. Assuming a mean annual drainage equal to 10 in. at the Rothamsted plots, the loss of lime shown by plot receiving " complete artificials " would equal 326 lbs.[1] per acre per annum.

The winter leaching of **soluble salts** from lands is not, however, an unmixed evil, although farmers in Britain may have difficulty in realising it. As Table XXI. shows, the winter rain leaches out considerable quantities of soda, magnesia, and their compounds with chlorine and sulphuric acid. And the loss of these things is all to the good. An excess of soluble salts in a soil can render it either partially or altogether sterile and barren.

Soils everywhere continue to add to their supply of soluble salts from two **sources.** One of these is the soil itself—the natural weathering process resulting in a gradual production of some soluble salts. Soluble salts are also brought down in the rain. Thus at Rothamsted, 24 lbs. of common salt and 31 lbs. of sulphate of soda were obtained annually per acre through rain ; at Canterbury (N.Z.) the corresponding figures were 98 and 26. Rain always supplies soluble salts, and the amount is greatest in coastal districts.

Whether in any particular soil the soluble salts increase depends upon whether or not the annual gains exceed the annual losses. With good drainage and sufficient rainfall, any excess of soluble salts is soon washed away. The salts of the sea have been washed from the soils of districts with a sufficient rainfall. In districts with a small rainfall or bad natural drainage, all the salts produced or received in the soil tend to accumulate. Generally speaking, excess of soluble salts is an evil which is confined to arid and semi-arid countries. Notable examples are found in India, Egypt, and the dry States of America. In the last named, excess of soluble salts is known as **" soil alkali."**

The principal salts accumulating in the alkali soils of dry countries are common salt (sodium chloride), together with magnesium chloride, sodium sulphate, and sodium carbonate. The last is the worst because it corrodes and destroys the tender rootlets of plants. Common salt and the others are harmful, chiefly by hindering the absorption of water by osmosis (Chap. XXV.). In alkali soils the land must be wetter than

[1] One inch of water over 1 acre weighs 101 tons, and as an exercise this figure may be recalculated, using Table XXI.

For *general* purposes it is often useful to remember that 1 cub. ft. of water weighs 1,000 oz. (62½ lbs.) ; and that 1 gal. of water weighs 10 lbs.

usual to prevent the crop withering. In bad cases (Fig. 85) the land would require to be so wet that roots would be unable to breathe.

In this country heavy applications in spring of soluble manures like kainit can produce in mild form the baneful effects of alkali so common in semi-arid countries. The results will be seen in greater tendency to wither in a dry summer. Owing to our winter rains the evil effects will vanish before the second year. Where water is available in countries of low rainfall the best treatment for alkali is under-drainage, followed by liberal irrigation to wash the salts away.

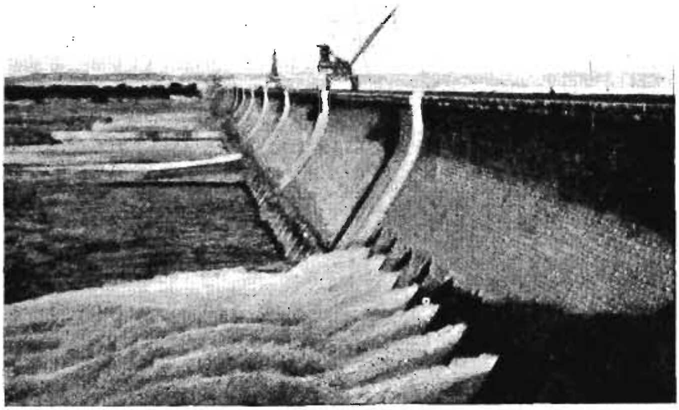
(Imp. Bureau of Soil Science.)

FIG. 85.—Salt Land near Lahore, India. Vegetation destroyed by excess of the salts.

Irrigation consists in applying water to land—either natural, or mixed with manure as on sewage farms.

The **use of natural** water obtained from rivers, streams, wells, and artesian bores is very extensive in the dry, warm regions of the world. Countries bordering on the Mediterranean, Egypt, India, China, Japan, and parts of America all possess elaborate irrigation works. In such hot and dry countries irrigation is more effective in crop production than it could ever be in England, where relatively low temperatures and lack of sunshine act as limiting factors in plant growth. In this country the use of natural waters is practically limited to irrigation of water meadows adjacent to running streams.

Such *water meadows* are quite common both in England and Scotland, but increasing costs of construction have hampered their extension in recent years. The water taken from an adjoining stream (in Scotland a " burn ") is led along a feeding channel which follows the line of contour; from this it is allowed to trickle slowly across the grass towards a draining channel opened along a lower level. The intervening land becomes soaked. In any system of applying irrigation water it is essential that air be allowed to enter the soil, and to secure this, any heavy flooding should be intermittent -continuing perhaps for a few days, after which the land is allowed to partially



(*Egypt Travel Bureau.*)

FIG. 86.—Irrigation Works at Aswan on the Nile.

dry out. Porous soils give the best results from irrigation, and *good under-drainage* is essential. In countries abroad many important failures have occurred in irrigation practice owing to lack of foresight with regard to drainage. Water meadows are usually mown for hay, and are allowed to dry out in advance. The yield is considerably greater than from dry fields, but rather coarse in quality.

Water naturally *warm* is better than cold water for irrigation, as, owing to the high specific heat of water, cold water can appreciably cool down the soil. King has calculated that 4 in. of water at 45° F. applied to a field having a soil temperature of 75° would cool the surface foot of soil down to 65° or 62°. This was in America. During frosty weather in this country the balance of advantage, however, may be on the other side. In such weather running water has a higher temperature than the air, and on this account winter application often stimulates the spring growth on water meadows.

Irrigation offers the best means of **utilising sewage.** Soils readily absorb potash and ammonia (Table XXI.) when it is offered to them, and irrigation is, indeed, the only practicable way of utilising those valuable constituents of sewage. Manchester and many of our large cities now run extensive sewage farms. The old Craigentinny grass meadows near Edinburgh were watered with sewage from the city and yielded about five cuttings each year—the annual crop then ranging from 50 to 70 tons of *green* grass per acre. Such records are, indeed, remarkable.

Chapter XXXII

OBJECTS OF CULTIVATION

Good cultivation is necessary in order to get the best results out of land. In early times the operations of ploughing and

Fig. 87.—Ordinary Wheeled Plough. (Bedford Plough Co.)

harrowing were usually badly performed, partly owing to lack of proper implements, and often through carelessness. In 1733 Jethro Tull, an English farmer, called attention to the large crops which he had obtained simply by thorough cultivation. Tull even claimed that good cultivation was of itself sufficient to maintain the fertility of the soil, and that where it was practised the need for manures would never arise. This, of course, was wrong, but a valuable service was done by his insistence on thorough cultivation, the value of which had not been duly appreciated.

Ploughing is usually the first step in cultivation, and it is the most thoroughgoing. The purpose of ploughing is to loosen the soil and then invert it—thus exposing a fresh surface to sun and air. In the result *water* and *air* can then *enter* freely, and the various processes whereby plant *food material* is rendered *available* are thereby stimulated. Ploughing also affords a means of *burying* weeds, crop residues, and farmyard manure under the surface so that they are converted into humus at the place where they do most good.

An important objective in ploughing is to secure a **good tilth,** and the problem is more difficult on *clay soils.* Here autumn ploughing is desirable in order to obtain the pulverising action (Chap. XII.) of probable winter frosts, and also to assist drying out in spring. Ploughing here, if done up and down a slope, assists drainage, and the surface should be left rough to reduce the likelihood of surface caking. In spring, a shallow cultivation or cross-ploughing on such land, followed by harrowing, will usually provide a crumbly tilth for spring-sown crops. On *light lands* containing less than about 10 per cent. of clay, the tilth problem practically disappears, and on such land ploughing is often deferred until late winter or early spring, or even until the seed-bed is in preparation. The delay here is even an advantage, as by autumn ploughing on such lands the inevitable winter loss of nitrates by drainage would be still further increased.

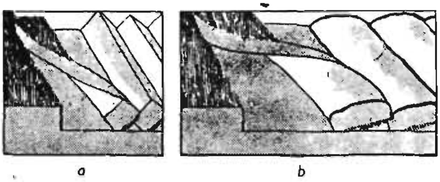


FIG. 88.—Forms of Furrow Slice.
a, unbroken rectangular; *b*, broken.

Ploughs are of different **kinds,** and suited to different purposes. The most significant variation is in the shape of the *mould-board.* Fig. 87 shows the *ordinary wheeled plough* so familiar in England. There the mould-board has a long, easy twist, and is designed to invert a furrow-slice in one piece without breaking it. Fig. 88 (*a*) indicates the class of work performed. The other type of mould-board is seen in the *digging plough* (Fig. 89), which is of American origin. The sharp, hollow curvature will be noted. With this plough the furrow-slice is not pushed over against the previous one, but is forced up the concave of the mould-board, and falls over in a broken (Fig. 88 (*b*)) condition. The digging plough has greater pulverising action,

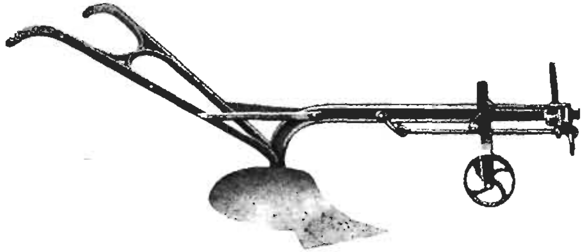


FIG. 89.—Digging Plough. (Bedford Plough Co.)

and is thus somewhat harder to pull.[1] It is very suitable for ploughing light lands (except grass or " lea "), or for cross-ploughing in spring, but is not suitable for heavy clays. The long mould-board type of plough is better there because it has less of a puddling effect, and it leaves the soil better exposed to weathering. Where the next crop is to be broadcast, that type of plough also does better work—especially on grass-land—because it leaves the furrows well set up, so that the seed can be covered on harrowing. The digging plough is better adapted to prepare for sowing by drill.

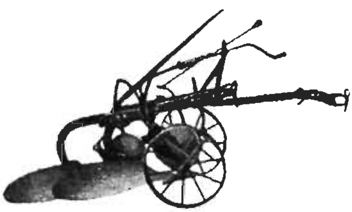


FIG. 90.—Double-furrow Tractor Plough. (John Wallace & Sons.)

In Scotland and the North of England the long mould-board plough is often used but without wheels, and this is the *swing plough*. It requires more skill in handling, and is thus more likely to be kept in proper adjustment. *Double-furrow ploughs* (Fig. 90) are always wheeled, and are sometimes used on the

[1] According to American trials. Where the digging plough (as often) is lighter in draught than the long mould-board type, this may be ascribed to the lesser dead-weight of the American implement and not to the character of its work.

lighter lands ; they reduce labour costs. *Multi-furrow ploughs* are used with tractors, also in the Dominions where six or eight horses in one team often turn five furrows at a time—about 4 in. deep. *Turnwrest*, or one-way ploughs (Fig. 91), can throw the furrow to either side as desired, and are sometimes used for work across a hillside- starting along the bottom.

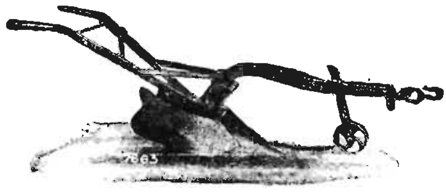


FIG. 91.—Turnwrest Plough. (Ransomes.)

The proper **depth to plough** varies with circumstances, and may range from 4 in. up to 1 ft. Shallow ploughing is carried out in spring in preparation for barley or oats, where " roots " had been grown in the previous year. Deep ploughing here would bury manurial residues too deep, and would also create a too loose seed-bed—retarding the upward passage of water by capillarity. Spring working should generally be shallow. The deepest ploughing is usually undertaken in autumn in preparation for a root crop of the following year. Deeper ploughing on any land, but particularly on clay, must be initiated with caution, as much inferior subsoil may be brought to the surface, thereby reducing fertility. Where clay land is constantly ploughed at the same depth a *plough pan*, *i.e.*, a layer impervious to air and water, may form, because the pressure of horses and ploughs being always on the same stratum had consolidated it. Changes in depth thus become desirable.

The **draught in ploughing** varies with the conditions. It increases more than in proportion to the *depth*, and this particularly with the digging type of plough. Draught is conveniently expressed in lbs. of pull required per square inch of cross-section of the furrow slice (Fig. 88 (*a*)). As regards *soil types*, Pusey in England found the draughts to be : In sandy loam, 5·55 ; in clay loam, 9·72 ; and in blue clay, 12·27 lbs. per sq. in. Clay soils are termed " heavy," *i.e.*, heavy to work. *Wetness* of soil naturally has an effect. In America, and keeping to the same type of plough and of land, Sanborn found a draught of 3·52 lbs. when a soil was in best condition, and 8·61 lbs. when it was rather dry. Such figures are only for illustration. More recently at Rothamsted, on clay loam, it was found that an applica-

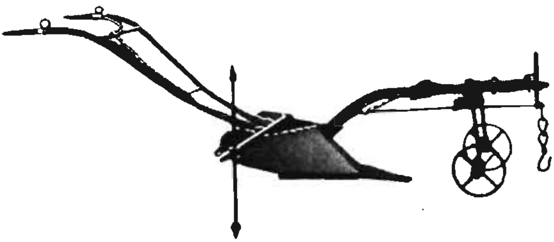


FIG. 92.—Ridging Plough with Marker. (Bedford Plough Co.)

or potatoes. It is double-breasted somewhat after the manner of a snow plough, and leaves the surface furrowed as in Fig. 93. The ridges are often 27 in. apart, but this may be varied. Manures are generally distributed in the furrows, and the same plough is then used to go over the land again and "split" the old ridges, so that the manure is left along and below the centre of each new ridge. Turnips, mangolds, etc., are then drilled along the tops of the new ridges and thus have the ***manures concentrated*** just where wanted. Potatoes are planted on the manure before the old ridges are split (Fig. 41), and have easy access to it. Cropping on ridges assists *soil aeration* and *drainage*,

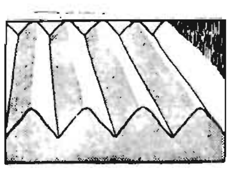


FIG. 93.—Land Prepared by Ridging Plough.

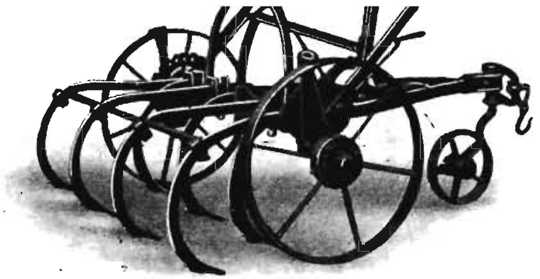


Fig. 94.—Cultivator. (W. N. Nicholson & Sons.)

has lain " in the furrow " during winter, and for this purpose they are preceded by harrowing. The curved sloping tines tend to bring *clods*, also the rhizomes of *couch grass* (Fig. 14), to the surface, where they can be dealt with. Usually several cultivations at different angles across the field, with intervening harrowings, are required during spring in the preparation of fallows for root crops.

The **horse-hoe,** or drill cultivator (Fig. 95), in various forms is employed for working between the rows (intertillage) of growing crops like potatoes, roots, and beans which are planted at such a width as will permit the passage of the implement. The primary object is often to *destroy weeds*, and for this various kinds of broad cutting points have been devised. At the same time the horse-hoe leaves a loose soil mulch which *reduces* *evaporation* losses in dry weather. By breaking a soil crust, which previous rains may have formed, it also *admits air* to crop

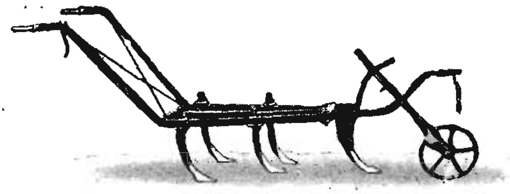


FIG. 95.—Horse-hoe. (John Cooke & Sons.)

roots—a result of value to all crops, and perhaps in particular to potatoes.

Harrows (Fig. 96) have usually straight tines and are forced into the soil by their own weight. They are used for *covering*

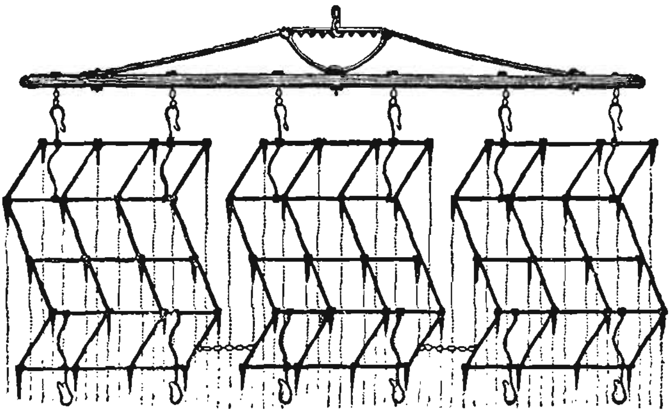


FIG. 96.—Zigzag Harrows.

seed after broadcasting. They are also used to shake out the "*couch*" while working the fallows; also to *break clods* which have come to the surface. For couch they are most effective when the land is dry; for clods when it has a moderate but not excessive moistness. Harrows are most effective when driven fairly fast. Young wheat crops, even when several inches high, are often benefited in spring by harrowing to *kill* young *weeds*, and break a *soil crust*.

Rollers are of different kinds. The smooth cylindrical iron rollers are the commonest (Fig. 97), and these are usually in two or three sections to facilitate turning to come back. Rolling is useful in spring to compact the surface and *hold more moisture* around germinating seeds or young plants. It is also done to *smooth the surface* for harvesting which will come later in the year. The roller is also used to *break clods*, and for this purpose

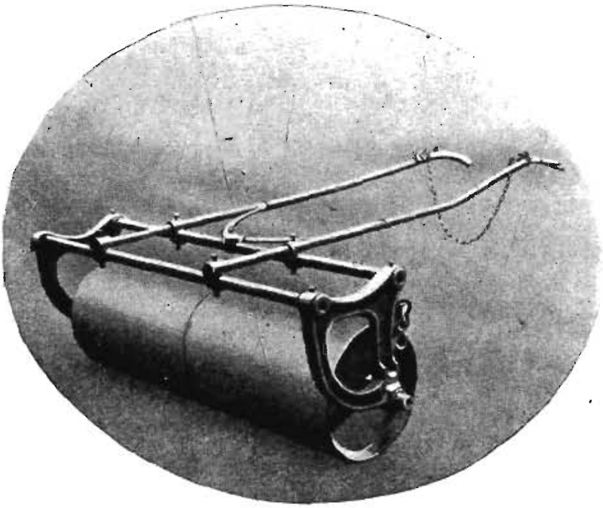


FIG. 97.—Cylindrical Iron Roller. (W. N. Nicholson & Sons.)

the roller of small diameter is more effective for the same weight than the large hollow roller, as it gives more of a dragging action; it is also harder to pull. Some heavy clod-crushers, instead of the usual cylinder, have a number of narrow discs revolving like separate wheels strung on the central axle—as in the Cambridge roller. Where heavy clays had been ploughed in the previous autumn, the extra expense of using such clod-crushers would often be avoided. But this matter was discussed earlier in the chapter.

The **distance travelled** to cover 1 acre with any implement may easily be calculated. As 1 acre equals 6,272,640 sq. in., and 1 mile equals 63,360 in., therefore $\frac{6272640}{63360}$, or 99 miles, must be travelled to plough 1 acre if a plough turned a furrow of only 1 in. wide. Remembering this **99**—if a plough turn a furrow of 11 in. wide it must travel $\frac{99}{11}$, or 9 miles per acre ; if a roller is 72 in. wide it must travel $\frac{99}{72}$, or 1·375 miles, to roll 1 acre. These figures neglect some unavoidable overlapping with the roller, or the movement of the plough turning on the headlands.

CHAPTER XXXIII

CORN CROPS

As a matter of convenience, **farm crops** are usually classed under four groups. These are the (*a*) corn crops, (*b*) root crops, (*c*) fodder crops, and (*d*) fibre crops. The last named are of minor importance in this country.

Corn Crops are of two main kinds, viz., the *cereals* and the *pulses*. Pulse crops produce leguminous seeds like bean and pea, which are both grown in England rather widely. In some foreign countries other pulse crops than those named often form the mainstay of local agriculture.

Cereal Crops include wheat, oats, barley, rye, maize, millets, and rice. They all belong to the natural order of plants known as Gramineæ, or Grasses. Cereals are grasses in which the seeds are large, and contain much food material or endosperm.

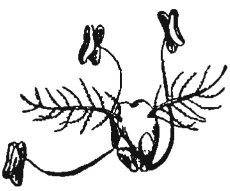


FIG. 98.—Flower of a Grass.

The **flowers of grasses** are not brightly coloured, and indeed the sepals and petals (Chap. IV.) are practically not formed. Three stamens and one carpel, however, are usually present in each flower (Fig. 98), the carpel consisting of the ovary below and a divided feathery stigma. For fertilisation to occur, pollen from the stamens is transferred to the stigma, and a seed subsequently develops inside the ovary. When a seed remains inside the ovary, as it does in grasses, we have a *fruit*. A wheat grain is a fruit, but is popularly called a "seed."

The flowers of grasses occur not singly but on little **spikelets** [1] (Fig. 99), and there are often three or more flowers on each spikelet, but the upper ones may not develop properly. On the axis of each spikelet besides the flowers there are also formed certain small leaves called the *glumes* and *pales*. Each spikelet has one set of glumes, and each flower has, in addition, an outer and an inner pale to itself. These pales cover up the young flower; at a later stage the pales open and the anthers protrude (Fig. 100) because their stalks or "filaments" grow longer. The plant is then at the "flowering" stage.

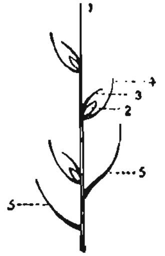


FIG. 99.—Diagram of a Spikelet in Grasses.

1, axis bearing three flowers; 2, one of the flowers, each being furnished with an outer and inner pale; 3, inner pale; 4, outer pale; 5, glumes of the spikelet.

In many of the Grass family **pollination** is by wind, the pollen being thus carried to the flower stigma from another plant of the same species. This cross-pollination is particularly common among perennials like rye-grass; in such cases it is usually an advantage, and often, indeed, an essential to seed formation. Other grasses, again, are normally **self-pollinated**, and here the anthers open to discharge pollen upon the flower stigma *before* they emerge (Fig. 100) from between the pales. This happens with wheat, oats, and barley. The common cereals are thus self-pollinated, and natural crossing with them is rare. Were it otherwise it would be difficult to maintain distinct varieties of wheat or oats.

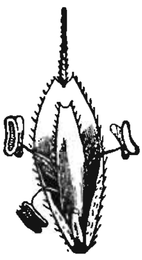


FIG. 100.—Flower enclosed in Pales.

Fertilisation follows soon after pollination, and a fruit is formed. When the crop is ripe, the pales may continue to *enclose the ripe fruit* as in oats and barley; these carry "husks." In other cases the ripe fruit

[1] On the ear of wheat (Fig. 102) about twenty-four well-developed spikelets may be counted.

comes out from between the pales, and this is seen in common wheat and rye, and in "skinless barley," which are *naked* grains.

The single flowers in cereals (and grasses) occur, then, on little spikelets, and after fertilisation they form fruits. When the individual spikelets themselves have long stalks we get a

FIG. 101.—Ear (Panicle) of Common Oats carrying many Spikelets. (*Scottish Society for Research in Plant-Breeding.*)

FIG. 102.—Ear (Compound Spike) of Wheat carrying about Twenty-four Spikelets. (Carters.)

panicle (Fig. 101) as in oats, and when the spikelets have no stalks we get a compound *spike* (Fig. 102) as in wheat.

Wheat.—The word "wheat" is allied to white (A.-S., *hwit*), probably in contrasting its white flour with that of rye. To botanists, common wheat is known as *Triticum vulgare.* Following the plan of Linnæus, every plant has a scientific name consisting of two words in this way. The first word always indicates the **genus** to which it belongs and is the generic name, and the second word indicates the **species,** and is the specific part of the name. Any plant species is made up of individuals so nearly alike that they may be regarded as springing from a common stock. A genus includes a number of different species which, however, have important characters in common—particularly in regard to their floral parts or organs of reproduction. Besides the *T. vulgare*, there are some eight or ten other species of *Triticum*, varying according to the views of different botanists, and several of these other species are in cultivation in different parts of the world, *e.g.*, *T. durum* (hard or macaroni wheat) in South Europe, and in the drier parts of the U.S.A.

T. vulgare is the common wheat (Fig. 102). It exists in thousands of **varieties.** The varieties within a species exhibit certain distinct peculiarities in regard to colour, form, size, and many minor characters ; also physiological differences as regards earliness of ripening, liability to " lodge " or get laid flat before harvest, tendency to lose grain in high winds, power to withstand long spells of dry weather, and resistance to disease. Such physiological differences in particular may be very important to the farmer. In any locality success with wheat or with any crop depends very largely upon using a crop variety which is suited to the local environment and to the system of farming.

Much valuable work has been done by scientific workers in **producing improved varieties** of wheat, oats, and other crops. Two methods are employed, viz. : (*a*) selection ; (*b*) cross-breeding, followed by selection.

The **selection method** is practised in two ways. In *mass* selection (first practised about 1832) a few pounds of grain are collected from the best ears of the best plants ; it is all mixed together, and then sown on a piece of well-prepared land. The produce of the first harvest is used next season to grow a larger supply of seed to be used ultimately on a commercial scale. In *individual* selection (adopted later) each parent plant is tested separately. Here the seeds, often 100, from each selected plant are sown on separate experimental rows (or squares), and the grain yields are weighed at harvest. The worst yielders are rejected. From the best yielding row the seed is again sown separately for two or three years until there is enough seed descended from one plant to meet the requirements of the grower. Selection methods for improving cereals, with gradually improving technique, have continued over the last hundred years. The object of selection is to discover and segregate the best-yielding members of a variety already in use.

In **cross-breeding** it is sought to produce an entirely new variety. For this purpose pollen is taken (Fig. 103) from one variety—then called the male—to fertilise the flowers of another variety—then called the female. The choice of parents is now generally based upon the discoveries of **Mendel** (an Austrian abbot), published in 1865, and for a time forgotten. Mendel insisted on what are called "*unit characters.*" For example, working with peas he found "tallness or dwarfness," and "coloured flowers or white flowers," etc., to be unit characters.

Photo: Gartons Ltd., Warrington.

FIG. 103.—The late Dr John Garton crossing Oats.

Any plant (or animal) has its whole nature determined by a vast combination of its unit characters. These units, however, vary in their power to reproduce themselves in the next generation. Peas normally *pollinate themselves*, but Mendel was able to fertilise one variety with pollen taken from another. When he crossed in this way a tall with a dwarf pea, the first cross generation or first filial (F_1) were all tall. Therefore he called tallness a *dominant*, and dwarfness a *recessive* character. Similarly, coloured flowers were dominant to white, and first crosses all had coloured flowers.

But let us return again to the tall and dwarf peas. Although the first or F_1 cross were all tall, they were no longer all capable of producing only tall peas when left to pollinate themselves. They were not always pure-breeding for this particular unit character. When the F_1 peas were sown next season, the F_2 generation was the crop produced. But these were a mixed lot. Twenty-five per cent. of them were tall, and could be relied upon to produce only tall peas. Fifty per cent. of them were also tall, but these could not be relied upon to produce only tall peas. Finally, 25 per cent. of the F_2 crop were dwarf, and could be relied upon to produce only dwarf peas. The F_2 generation thus comprised 25 per cent. pure dominants, 50 per cent. impure dominants, and 25 per cent. pure recessives. The same ratios have been found in the F_2 generation with other unit characters in peas, and also in experimenting with the various unit characters found in wheat and other crops.

Wheat also is normally self-pollinated. After crossing wheat, the seed from each approved plant of the F_2 generation must be sown next year in separate rows to find out whether all the F_3 plants in the same row are identical in regard to a particular unit character. If they are not, then the character in the new variety has not been " fixed." If they are, then they are either pure dominants or pure recessives, and the breeder retains those rows which show the unit character (dominant or recessive) which he was trying to breed into his new wheat.

In theory the wheat breeder might seem to have a fairly simple task in breeding a new desired character into a wheat which is otherwise good. In practice he has not. A wheat has so many other unit characters besides the one it is desired to replace that there is the old risk of the dog losing the bone while grabbing at its reflection. In other words, while the desired new character is being introduced certain useful old characters may be lost in favour of the corresponding but undesired unit characters in the other parent of the cross. Some of these undesired characters may lower the economic value of the new wheat. The net results of crossing are highly intricate for the reasons stated, and while great benefit has come to farming from the plant-breeder it will be understood why much less than 1 per cent. of new crosses ultimately justify themselves when the new wheats are subjected to careful selection tests in the field.

Wheat varieties in this country include Squareheads Master, Little Joss, Victor, Yeoman, Rivett, Red Marvel, and many others. The names are only quoted as examples. Sometimes, as with other crops, one variety has two different names. Varieties differ in best time to sow, in soil preferences, hardiness during unfavourable weather, standing power of straw, tillering capacity, earliness, resistance to diseases, weight of yield, and quality of the grain.

In producing new wheats, much attention has been given to finding varieties which yield a **strong flour.** The work of Professor Biffen at Cambridge should be mentioned. Strong wheats show a flinty fracture when broken across, while soft or weak wheats appear floury and dull. Strength of flour determines the amount of water absorbed while kneading, and the tenacity of the dough which can be made from it. Weak dough does not inflate so well by expanding gases while in the oven, and does not produce such well-shaped loaves. It behaves like a child's poor-quality balloon. Strength of flour is in some way dependent upon the gluten content of the wheat, but not altogether so. English wheats are rather weak as a rule, although some varieties such as Yeoman produce strong flours. These are often poor yielders. Starch does not contribute to strength in wheat, and as relatively more starch is deposited in the grain during *slow* ripening, it is possible that highest yield and greatest strength cannot normally be expected in the same variety of wheat.

Chapter XXXIV

CORN CROPS—*continued*

The *stem* of **wheat** is usually hollow except at the nodes; there are often six internodes, the sixth bearing the inflorescence. The *leaves* arise from the nodes (Fig. 12) and stem growth takes place at each node. Thus it comes that in early life the leaves seem to arise close together on the young stem, forming a " rosette," but as the stem begins to elongate at each node they become vertically separated. Leaves grow from their bases—this would be surmised from the square-tipped new growth on recently mown lawns. *Branches* or lateral shoots may arise from the stem, but only from nodes which are covered with soil. The formation of such shoots is known as *tillering*, and it increases the number of stalks to each plant. Tillering takes place from the lower nodes only, and usually about 1 in. below the surface of the ground. Numerous *adventitious roots* also are developed from those underground nodes.

Winter wheat is usually cultivated in this country, being often sown in October and November; **spring wheat** in February or March. For spring sowings it is necessary to use a spring variety as the ordinary winter varieties would not mature in time. Winter wheats typically tiller better than the spring varieties, and in that way also lose time.

The seed may either be **drilled** or **broadcast.** The drill (Fig. 104) has the advantages that:

1. It places all the seed at a uniform depth so that it comes more evenly forward to maturity.
2. All the seed is covered, and there is no waste.
3. About 1 bush. extra seed per acre is required in broadcasting.

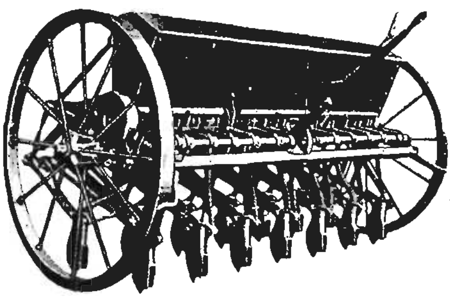


FIG. 104.—Hornsby Seed Drill. (Ransomes.)

Rate of seeding is increased as the season becomes later and colder, because the young plant *tillers better* in the *milder weather.* If 2½ bush. per acre are drilled at the end of September, the amount is increased to 3 bush. for late October, and 3½ bush. for November sowings. For the same reason heavier seeding is employed in the northern and upland districts than in the milder south. In the warm, dry countries of the Dominions, from ¾ up to 1 bush. is a common rate of sowing for wheat.

Thinner seeding is also called for on *good land* because the better-nourished crop tillers better. Under any circumstances, too thin seeding gives less grain, but a higher ratio of grain to straw; it also gives encouragement to weeds. It may also retard ripening by giving greater encouragement to tillering, which delays the development of the crop.

Manuring.—Wheat has a deep root-system and can better collect the phosphates and potash dispersed through the soil than can barley, which is shallow-rooted. Nitrates, on the other hand, are principally in the surface soil where they were formed, and are not better collected by wheat than by barley. Unless following on a good clover crop (Chap. XXI.), an application of, say, 1 cwt. sulphate of ammonia or nitrate of soda in *spring* will usually return a good profit ; this is particularly useful after a wet winter. Why ? On poorer land some superphosphate may be applied at *seeding*. Potash is less often required.

Spring Cultivation.—After a hard winter the crop should be rolled in spring to consolidate the soil loosened by winter frosts. If, however, the season has been mild and open, then harrowing is preferable when the land is dry enough ; the object is to break clods, destroy a surface crust formed by winter rains, and to check young weeds. Being deeper rooted, young wheat can stand more rough handling than the other cereals. Hoeing is sometimes practised. Crops which are too advanced—" winter proud "—for any reason, may be checked by sheep, and so reduce liability to lodge before harvest.

Harvesting is usually done by the reaper and binder (Fig. 105). The straw should then be yellow under the ears, but on pressing the grains they should not yield a milky sap. The material filling the grain was originally formed in the leaves, and if the crop were cut too early this material had not had time to migrate fully from the leaves ; so on drying after harvest the grain becomes small and shrivelled. On the other hand, if allowed to become dead ripe before harvesting, a poorer yield of flour is obtained on milling owing to thickening of the bran (Chap. XLIII.) ; also, when over-ripe, some varieties lose grain by shelling out in boisterous weather. For seed wheat the extra ripeness is desirable.

After cutting, the sheaves are dried in *stooks* or *shocks* for about ten days to lose natural sap, and they thus become lighter. When **stacked** they contain about 15 per cent. of moisture. If too damp they can maintain (Chap. L.) bacterial decomposition inside the stack, which then becomes warm and discoloured. Warmth further accelerates this bacterial decomposition provided sufficient moisture is present. In the stack, the straws of wheat being stouter than those of oats or barley are less flattened by pressure, thus helping ventilation ; wheat can thus be stacked rather damper than oats. Smaller stacks are advisable in humid or late districts, but involve more *thatching* per ton of crop.

The crop is **threshed** from the stack when convenient. In the dry countries, from which much of our wheat is imported, the grain is usually threshed straight from the growing crop in the field by some form of " Combine." The grain is very *dry* (about 9 per cent.) and can be bagged for export straight from the harvester. The method is economical where straw is not wanted. For a number of reasons—including climatic—it is doubtful whether this system of harvesting could ever receive general support from British farmers.

Rye (*Secale cereale*) is extensively grown in Northern Europe on light soils as a bread food, but in Great Britain the area is

FIG. 105.—Reaper and Binder. (Harrison M'Gregor & Co.)

only some 20,000 acres ; the area under wheat is about ninety times as much. Unlike wheat, barley, and oats, the rye plant is normally cross-fertilised, its flowers being often self-sterile ; there are thus few distinct varieties of rye. Rye bread is black or brown with a sweetish acid taste. The straw is not hollow but filled with a pith, and is used by harness-makers. Apart from grain, rye is sometimes sown in autumn for a fodder crop, as its foliage makes early growth in spring.

Barley (*Hordeum sativum*).—The area grown in Britain is about 1 million acres, of which some 10 per cent. is found in Scotland. The ear of barley differs from that of wheat in the arrangement of its spikelets ; here three one-flowered spikelets arise together at each joint of the ear alternately, but the two lateral ones may be infertile, as in two-rowed barley. In six-rowed, all are fertile. Barley is grown in different varieties, and for different purposes. *Bere*, or (so-called) four-rowed barley, is hardy, and is grown chiefly for a feeding grain, or to provide early green fodder for stock. Where barley is suitable for *malting* a much better price is obtained, and to secure the necessary quality the two-rowed barleys are in great demand, including the Archer, Goldthorpe, and Chevalier types.

Malting barley is usually spring-sown, but autumn sowings are increasing in East Anglia and the Midlands. The best-quality grain is produced on light open soils with a limited rain-fall ; heavy clays and peaty soils yield an inferior sample. Barley is shallow rooted but withstands drought better than might be expected. Unless the land is rich a moderate dressing of nitrogenous manure is profitable, and here sulphate of ammonia has been found to give better quality than nitrate. On the other hand, if the land is too rich the crop grows too rank, and quality suffers. Good malting barley must contain much *starch*, and rapid ripening in hot weather lowers starch content and the value of the sample. Any heating while in stack, or bruising while threshing, lowers the percentage of germination, which is important for the malting process. The general management of barley is similar to that described for wheat.

Oats (*Avena*) are the most widely grown cereal in Great Britain, and especially in Scotland and Wales. In the ear, the spikelets resemble those of wheat, each containing several flowers, but the spikelets have stalks (Fig. 101) forming a panicle. On threshing oats the empty glumes (Fig. 99) constitute the " chaff," while the outer and inner pales continue to invest the oat fruit, thus forming the husk of the oat grain. These husks may be white, yellow, brown, or black according to variety, thereby giving the colour to the grain, as in black oats. The husks weigh relatively more than in barley, and may vary from 25 per cent. upwards of the weight of oat grain. The husks have little feeding value. Owing to the presence of husk, oats often weigh 42 lbs. per bush., while malting barley weighs about 56 lbs. and wheat 63 lbs. per bush.

There are two principal species of oats. The commoner (*A. sativa*) has an open bell-shaped ear (Fig. 101), while in *A. orientalis*, including Tartarian oats (Fig. 106), the spikelets are confined to one side of the main axis. Different varieties within those two species differ in regard to soil preferences, hardiness, and other characters, as described under "Wheat Varieties." Cross-breeding and selection also follow along the same lines.

Oats are the hardiest of our cereals. The root system is shallower than in wheat and deeper than in barley. Oats prefer a cool climate and a good rainfall, and the grain from dry, warm localities is thin and husky. Foreign imported oats are often of very poor quality. No other crop succeeds so well as oats do on peaty and moorland soils, and on turf newly broken up. Oaten straw is the best fodder among cereal straws; it is still better if harvested *before* fully ripe, because it then contains part of the food materials which would have passed to the grain, and also had less time to become woody.

In late districts frequent *change of seed* from an earlier district is particularly helpful with oats. The crop is spring-sown, except occasionally in the southern counties. The oat grain differs from wheat and barley in that it contains a useful percentage of oil.

FIG. 106.—Ear of Tartarian Oats. (*Scottish Society for Research in Plant-Breeding.*)

Maize (*Zea Mays*) is a large cereal of warmer countries, and often from 6 to 12 ft. high. The world produces annually about 4,000 million bush. of maize, of which (Fig. 107) 75 per cent. is grown in the U.S.A. It is there known as "corn."[1] In maize the male and female parts are borne on separate flowers arising

[1] While "corn" is properly applied to cereal grains of all kinds, it is often locally restricted in meaning to the kind of grain most widely grown in the district. Thus in many parts of England "corn" means wheat; in Scotland, oats; in Germany, rye; and in U.S.A., maize. From the last is manufactured "corn-flour."

at different places but on the same plant, and pollination is by wind. There is no question of self-pollination as happens with our own cereals. As there are several sub-species of maize and many varieties of each, the production of seed maize requires very special care.

Rice, Millets, and **Sorghums** are also warm-climate cereals which are very widely cultivated in Asia and Africa by the native races.

Pulse Crops.—These are grown for their leguminous seeds, and have the advantage that they are able to fix free nitrogen (Chap. XXI.) out of the air. Beans and peas suit our local climate. Taken together there are roughly 300,000 acres of beans and peas grown annually in this country, the area being about equally divided between the two crops.

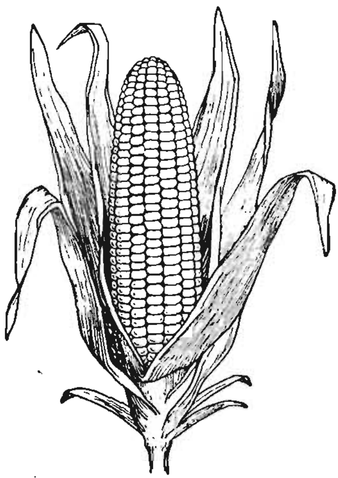


FIG. 107.—Cob of Maize.

Beans.—The name is commonly applied to crops of quite different genera. The common field and garden bean are varieties of *Faba vulgaris*, while French beans and scarlet runners, etc., belong to different species of the genus *Phaseolus*. The latter are more delicate. Beans grown in British agriculture are of the former class.

There are many varieties of *F. vulgaris*. The garden varieties or broad beans have larger seeds than the common field varieties —like the Tick bean—but their form and habit of growth is the same. The flower is of the characteristic " butterfly " type, which is described in Chapter XXXVI. The bean flowers occur in racemes bearing two to six flowers. The stem of the plant is four-sided, angular, and hollow without branches, and usually three stems arise from each seed.

Beans prefer heavy land, and respond well to farmyard manure. Phosphates and potash (if no farmyard manure) are generally useful, but nitrogen should not be required. Beans are usually drilled on the flat with about 2 ft. between rows—in autumn for

" winter beans," and in early spring for " spring beans." The latter look the same but are less hardy. The rows can be hand-hoed and horse-hoed in summer, and the crop harvested later with the (Fig. 105) reaper and binder. As with peas, the food material of the grain is contained in the fleshy (Fig. 7) cotyledons. Beans are highly valued by farmers as a constituent of horse corn during busy periods, and—in the meal form—as part of the ration for dairy cows.

Peas (*Pisum*) are grown in two species, viz.:

Pisum sativum—Garden Pea.
P. arvense—Field Pea.

The former has white flowers and is less hardy. There are many varieties of each—field peas including Common Grey, Partridge, Early Dun, etc., which are named from the colour of the seed-coat in each case.

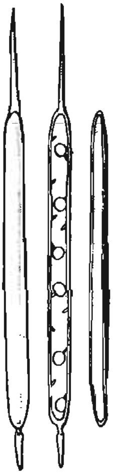
Peas prefer lighter soils than beans and do well on calcareous soils. If the soil is too rich the crops run too much to straw. They respond well to phosphates and potash, but should be able to fix their own nitrogen if the proper strain of *Bacillus radicicola* is present. The crop is either drilled or broadcast in early spring, but broadcasting requires more seed. A good crop helps to kill weeds by depriving them of the light necessary for (Chap. VI.) photosynthesis. Peas are troublesome to harvest, and the crop is often mown by hand and left in rows to dry out. It is time to cut when the lower pods become brown ; if left too long, many peas shell out after drying, when the material is moved. Peas are extensively used in meal form for dairy herds.

Chapter XXXV

ROOT CROPS

The cereal crops are annuals. They spring from seed, and produce stems, leaves, flowers, fruits, and seeds all within one year, and then they die. **Biennials** require two years, or at least two seasons, to complete their life. In the first year they spring from seed and develop their vegetative parts, laying up a store of foodstuffs for future use. Then follows a period of rest, and in the second year the plant proceeds to form its flowers and fruits. In the second year the foodstuffs stored up during the first year are drawn upon for the plant's support. Root crops are biennial plants, and in them the food collected during the first year is stored up in the roots. When root crops are harvested at the end of their first year of life, the foodstuffs which they have stored up are available for the sustenance of animals.

Among root crops which are used in this way may be mentioned turnips, swedes, mangolds, sugar beet, carrots, and parsnips. Potatoes are not, properly speaking, root crops, because their habit of life is quite different; as a fact, the potato tuber is not a root but a thickened underground stem. In popular language, however, they are usually included among "root crops," and will therefore be considered in this chapter.



a b

FIG. 108.—Fruit of Rape.
a, still closed; *b*, opening to discharge its seeds.

Swedes and **turnips** belong to the natural order of plants known as Cruciferæ, which takes its name from the "cross-bearing" form of the corolla in the *flower* (Fig. 18). This has four sepals, four (often yellow) petals, six stamens, and two carpels. Rape, cabbage, mustard, and cress also belong to the order, and have the same kind of flower. After fertilisation the carpels form a *fruit* (Fig. 108), which finally opens and discharges small, roundish, dark coloured seeds. The seeds are rich in oil. Crops of the order often possess a characteristic pungent flavour due to a volatile compound of sulphur, and when fed to cows the flavour may be imparted to the milk.

Swedes are distinguished from turnips by their smoother leaves, which also have a bluish colour like common cabbage, in contrast to the rough green leaves of turnips. In swedes, too, the upper part of the "root" is drawn out into a "neck" carrying the leaves; not so in turnips (Fig. 109). They belong to different but closely allied species. Swedes are somewhat hardier. There are many varieties of each.

Swedes and turnips are *shallow-rooting* crops, and are suited only to fairly humid conditions. They succeed better in Scotland than in southern England, where they are often substituted by mangolds. Especially after seeding is the farmer anxiously looking for rain, as the young plant is easily killed by dry weather. The crops are usually drilled in rows about 27 in. apart, so that they can be afterwards thinned in the rows, leaving from 5 to 8 in. between plants—wider spacing on good soils. In wet districts drilling is performed on ridges, and in drier localities on the flat. About 2 lbs. of seed is enough. Superphosphate or other readily available *phosphate* is particularly useful. At maturity the crops are either eaten on the ground by sheep (good manurial effect), or the roots are carted home for cattle.

The **mangold** (*Beta vulgaris*) is the cultivated descendant of a wild plant whose habitat was the sea-shore. It belongs to the natural order—Chenopodiaceæ. The flowers of this order have no petals and are small and greenish; the "seed" sown is composed of small *clusters of fruits*, each of which contains one seed.

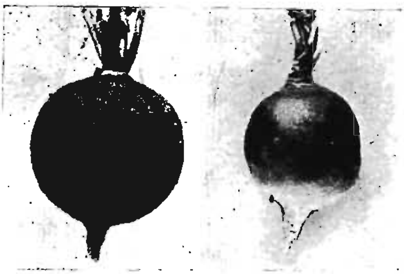

1 2

FIG. 109.—1, Turnip; 2, Swede. (Gartons Ltd.)

Mangolds prefer a warmer climate than turnips, and revel in *sunshine* provided sufficient moisture is available. About one-quarter million acres are grown in Britain, but less than 1 per cent. of this comes from Scotland where turnips do better. Mangolds are *deep-rooted* crops and can resist drought better than turnips, especially on the heavier soils. For the same reason they are less dependent on phosphatic manures than turnips are, but they respond better to manures which supply easily available nitrogen. They are gross feeders. Common salt added to the mixed manure is generally an advantage—a fact, no doubt, related to their maritime ancestry. Drilling, thinning, and subsequent cultivation is very similar to that of turnips. From 8 to 10 lbs. of "seed" is drilled per acre, and the "seed" is sometimes soaked beforehand to hasten germination. This is only safe where the land is sufficiently moist to sustain the germination after it has been started.

There are many varieties of mangolds which differ in regard to the colour and shape (Fig. 110) of their roots. Record crops up to 100 tons per acre have been grown, but the average is about 20 tons. The roots, when first raised in autumn, contain too much nitrate for stock-feeding, but this evil disappears when they are stored for some months before use. The same necessity for preliminary storage does not arise with turnips and swedes.

Taken generally, **root crops** become more **digestible** as they ripen—their food materials being then partly changed into sugar. **Fodder crops,** like clover or rye-grass, on the other hand, become less digestible as they ripen, their food materials then tending to become woody. Hay, therefore, should be cut before ripe,

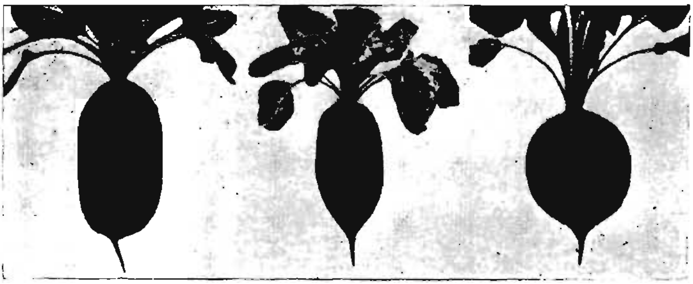


FIG. 110.—Types of Mangold.
1, Tankard ; 2, intermediate ; 3, globe. (Suttons.

but root crops should be allowed to ripen, *i.e.*, attain the end of their first season's growth. This stage is indicated by the failing vigour and colour of their leaves.

Sugar beet is a special kind of *Beta vulgaris* which has been modified by repeated selection so as to obtain roots with a high sugar content for manufacturing purposes. The sugar is cane sugar, as it is in mangolds, but in beets the percentage of sugar is around 16 per cent., while in mangolds it is about 7. A bright, sunny season increases the percentage of sugar, but the yield of beets is less. Potash increases the sugar content. Sugar beet for manufacture is a relatively new industry in Britain, but the area of crop—about 400,000 acres—now considerably exceeds the mangold area. Beet is a smaller plant than mangold, and is drilled in narrower rows—otherwise treatment is similar. When ripe, the roots are delivered to sugar factories, and are paid for on the basis of sugar content. Success with this crop depends even more than usual on obtaining the right seed.

Potatoes (*Solanum tuberosum*) are a regular article of human food, and while substitutes may be found for roots intended for stock-feeding, there is no such substitute for potatoes. The potato is a native of South America.

The potato belongs to the natural order—Solanaceæ. The tomato, deadly nightshade, and tobacco also belong to this order. Most plants of the order are poisonous at some part, and stock have been poisoned by eating largely of potato haulms.

The **flower** of potato has five sepals and five petals, which may be white or lavender according to the variety of potato. There are also five stamens producing pollen, and two carpels. When the carpels are fertilised by pollen a " berry " *fruit* is formed which much resembles the tomato fruit but is smaller and greenish ; in this are the *seeds* of the potato. When the seeds are sown they produce potato plants. A great deal of work has been done in *crossing* potatoes by taking pollen from one variety to fertilise another, and so produce a new variety of potato. The new varieties must be grown for several years before it is known whether they are worth keeping, and as in new cross-bred cereals, the great majority of them are not.

The farmer never sows seed obtained from the potato berry, but he plants a **tuber** instead. The tuber is a thickened underground stem (Chap. IV.), and from the buds of the tuber there are developed roots and shoots—the new crop being simply a continuation of the one before. A variety of any crop propagated in this way is termed a *clone*.[1] Under continued cultivation from the tubers a variety tends to contract virus disease, and in the past the plant-breeder has found it necessary to go on producing new and vigorous varieties for the farmer, direct from the seed.

The **stem** of the potato extends below-ground as well as above, and at the ends of the branches which are below-ground the tubers (Fig. 111) are developed. From these subterranean branches numerous fine roots spring, and through these roots the plant absorbs water and the ordinary food materials from the soil.

[1] In a field of corn or turnips there are millions of separate individuals, but in a field of potatoes of any single variety there is practically only one.

The potato prefers a loose, free-working **soil**, rich in organic matter, and under these circumstances the tubers can develop in good natural shapes. Cool climatic conditions favour tuber formation. The land should be well drained but fairly moist. Heavy clay land is unsuitable. Potash is often a dominant ingredient in a potato manure, but a general dressing supplying phosphates and nitrogen in addition is usually required. The crop responds to heavy manuring. Excess of nitrogen tends to give rather watery potatoes, while phosphates and potash improve the *quality* by increasing the amount of starch. Farmyard manure by itself supplies too much nitrogen to produce best-quality tubers.

FIG. 111.—Formation of Tubers on Potato Plant. (*Reduced.*)

Potatoes are **planted** in rows about 27 in. apart, and with 12 to 15 in. between the plants. In humid districts planting is done in ridges to assist drainage and aeration ; in drier localities on the flat. About 4 in. is the usual depth. **Cultivation** during the growing period is particularly useful to the potato crop in order to kill weeds and admit air to the underground parts.

Varieties of potatoes are very numerous, and sometimes one variety has several names. These are often classed as " First Earlies," " Second Earlies," and " Late " or " Main " crop, according to the rate at which they mature. It is important to employ " seed tubers " suited to the locality, and the purpose for which the crop is grown. The late varieties are typically the heaviest yielders—having had a longer period to carry on photosynthesis, but the early varieties may catch the best market.

Care is necessary in selecting **" seed potatoes."** *Virus diseases* are caused by living germs, which, however, are too small for an ordinary microscope. Now, individual plants in a crop are liable, through carrying insects like green-fly, to contract certain **virus diseases** such as " leaf-roll " and " mosaic " ; these diseases are too mild to kill them, but severe enough to lessen their vigour.[1] The result is smaller yield and

[1] In " leaf-roll " the edges of the leaflets roll upwards and become brittle ; " mosaic " is indicated by a yellow mottling of the foliage.

greater liability to other diseases. If tubers from such debilitated plants are used for " seed," the next crop shows similar loss of vigour. English growers often plant Scottish seed because the colder northern climate is less favourable to the virus-carrying insects, so that potatoes grown in the north better retain the original vigour of the variety. Where virus disease has been present in parts of a crop, the use of the smaller tubers (seconds) from that crop for planting increases the likelihood of giving preference to the weakened plants as " seed "—the disease had led to smaller tubers in the plants attacked. *Certified seed* is grown from virus-free plants, in locations reasonably remote from infection, and under close supervision during its development.

[*Amateur Gardening.*

FIG. 112.—Potatoes Sprouting in Tray.

For planting, healthy, medium-sized tubers (coming between $1\frac{1}{4}$ and $1\frac{3}{4}$ in. riddles) are the most profitable ; large tubers are cut to reduce costs. This is done lengthwise, leaving at least one " eye " or bud in each section, and not making these too small. It has been found that larger crops are obtained where the tubers intended for " seed " are harvested before maturity ; but this practice increases the difficulty of storage because fully ripe tubers keep much better. Potatoes—especially for early crops —are sometimes spread out in shallow boxes under diffused light to " green " them and start (Fig. 112) development of fewer but *stronger* sprouts. This saves time, and also gives larger crops. On the average about 12 cwt. of potatoes are required to plant 1 acre.

Potatoes are **harvested** for new potatoes when they are large enough and for main-crop purposes when the haulms go down, and the skin does not easily rub off. Potatoes do not keep well unless they are stored in a dry place, and they are easily damaged by frost.

CHAPTER XXXVI

FODDER CROPS

Fodder, or forage, crops (unlike corn and root crops) are cultivated exclusively for their leaves and stems to be employed in the feeding of live stock. Sometimes a fodder crop is grown as the *main crop* for that year, as when rape replaces turnips in a rotation, or when vetches replace oats. At other times the fodder is grown as a *catch crop*, *i.e.*, a crop snatched between two principal main crops. Thus "trifolium" is often sown in autumn on cereal stubbles and eaten off in spring, before sowing turnips as a main crop in June. For climatic reasons catch crops are mainly confined to the southern counties.

Fodder crops belong to different natural orders, including especially the Leguminosæ, Cruciferæ, and Gramineæ. Botanical features of the two latter have been considered under root and corn crops respectively, and we shall go on at once to deal in similar fashion with the first-named order.

Leguminosæ.—Fodder crops of this order are very important on the farm. They have the power to utilise free nitrogen (Chap. XXI.) from the air. This power brings two direct advantages. On the one hand it enables them to flourish on soils too poor for other crops without the use of expensive nitrogenous manures. On the other hand it produces fodder of very high protein (Chap. XLII.) content—a hereditary trait no doubt connected with their command of "easy" nitrogen. Crops of this order are often deep-rooted and withstand drought well.

In Fig. 113 is shown the **flower** of a typical leguminous plant. There are five united sepals and five coloured petals, which together form a "butterfly" corolla. Enclosed in the corolla are the stamens, usually ten in number, and one carpel. Some leguminous plants (pea) are self-pollinated. With others, *insects* are attracted to the flowers by (1) their bright colour, (2) smell,

(3) honey which is secreted by the flower. These insects carry pollen from one flower to another, and after fertilisation, seeds are formed inside the carpel which then becomes a **fruit**. The common form of fruit in the Leguminosæ is the pod or legume (Fig. 114), and from this fact the order takes its name. After the legume opens, the seeds are liberated from the interior of the fruit. A few leguminous crops, however, form a different kind of fruit, and some do not open readily to discharge their seed.

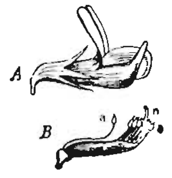


FIG. 113.—Flower of Leguminous Plant.

B, with sepals and petals removed; *a*, anthers; *n*, stigma.

Sometimes the single flowers are large and conspicuous, as in beans and peas (Chap. XXXIV.); at other times the single flowers are quite small, as in clover and lucerne. A head or "flower" of clover contains actually a large number of quite small flowers, forming together a kind of *capitulum* (Fig. 17). These small flowers each contain the several parts of a large pea flower.

FIG. 114.—The Legume or Pod of Pea.

The foliage leaves are usually compound, as in a clover or vetch leaf, and bear stipules at their base. The Leguminosæ are mostly deep-rooted—the tap-root penetrating well into the ground. For the fixation of free nitrogen, nodules (Fig. 53) may be developed on the roots. Some leguminous plants are *annuals*, some are *biennials*, and some of them are *perennials*. Perennials are plants which live more than two years. The agriculturally important members of the order are *herbaceous*; others, like gorse and laburnum, are *woody*, forming shrubs or even large trees.

Clovers (*Trifolium*) take their generic name from the compound leaves of the plant which are typically composed of "three leaflets." There are many distinct species. The flower heads always consist of clumps of the small pea-like flowers, and vary in colour according to the species of clover. Many of the smaller clovers form a valuable constituent of pasture or grazing land (Chap. XXXVII.), while the larger kinds are cultivated as forage crops. It is necessary here to mention only a few of the latter.

then in the following year it grows vigorously and is often cut twice for hay. This happens in the more southern parts. In the north, with its shorter growing season, the first cut only is taken, and the second growth or *aftermath* is usually fed off with sheep. When hay is taken the crop is cut while in flower; even more than in grass hay, does clover become *woody* and lose in nutritive value as it matures. After its second year[1] the common red clover usually dies out. After a good crop of any clover—but particularly of this one—the land is liable to become "*clover sick*," and refuses to grow clover successfully until it is given a rest—up to ten or twelve years is allowed in some cases. This acute necessity for rest does not arise with the ordinary farm crops.

FIG. 115.—Broad Red Clover. (Suttons.)

Crimson or Scarlet Clover (*T. incarnatum*) is often known to farmers as "trifolium," and, unlike the last, it is an *annual*. It carries an elongated head of bright scarlet flowers, and a field in bloom is a beautiful sight. It is generally used in southern England as a catch crop—the seed being simply harrowed into

[1] There are many strains of *T. pratense*, and some of these live longer than two years. But the longer-lived strains are typically sparse seeders, and are not therefore in favour for seed-production. The seed of all strains is the same to look at. By a kind not of natural but of commercial selection, the short-lived heavy-seeding strains thus enjoy an advantage in the struggle for existence. The same thing holds for most species of clover, and for the common grasses.

and is the premier forage crop of the hot dry countries of the world. In America it is known as *alfalfa*. In England it is receiving delayed attention in the drier southern counties. An established crop of lucerne should continue to crop for many years before it is necessary to plough it up.

Vetches or tares (*Vicia sativa*) have nothing to do with the biblical tares, but are a valuable crop of pea-like habit with purple flowers. The compound leaves (Fig. 116) have their terminal leaflets transformed into tendrils which "bind" the plants together—hence the generic name. Tares as a forage crop may be either of the winter or spring variety, the former being sown in autumn in the Midlands and southern counties. Spring tares are less hardy. This crop suits the heavier soils. Tares are often sown in mixture with rye or oats, which helps to hold them up, and the produce may be used for "*soiling*"—which means that it is mown and carted green daily to animals fed elsewhere. Surplus crop may be dried for hay, but for this purpose it should be cut while the pods are quite immature. As with other forage crops, there is loss of feeding value as ripening proceeds.

FIG. 116.—Leaf of Vetch (*Vicia sativa*).

Cruciferæ.—For general characters, see Chapter XXXV.

Rape is a cruciferous biennial, closely allied to turnips or swedes, but it has not the fleshy roots, and it comes sooner to flower. The leaves and stems have a high value in feeding, and are usually eaten on the ground by sheep. As in other crops, rape forms about 95 per cent. of its dry substance by photosynthesis in the leaves (Chap. VI.), and if the crop is always kept closely eaten off by sheep it is obvious that it cannot form much food material by photosynthesis. To do so would be to kill the goose that lays the golden eggs. It is better not to turn the sheep in until the crop is about 1 ft. high. When eaten off early,

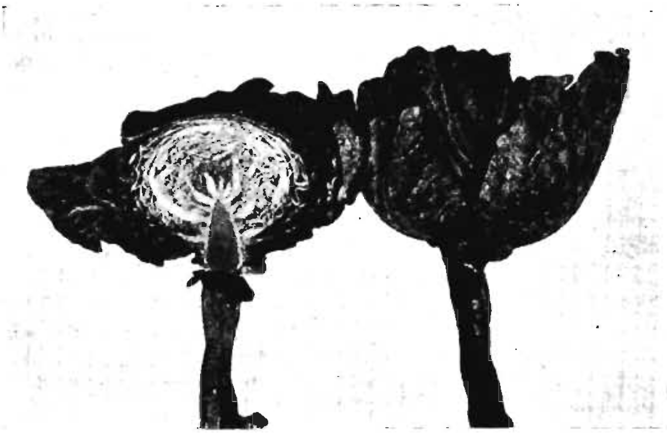

a b

FIG. 117.—Common Cabbage. (*a*) In section.

FIG. 118.—Thousand-headed Kale. (*Scottish Society for Research in Plant-Breeding.*)

the crop will come again if given a rest —fresh leaves being formed with which the crop builds up more plant material out of the atmosphere.

Cabbages are also biennials. In the first year the main stem remains short, so that the leaves are closely packed round the short internodes forming a "head." Owing to absence of light no chlorophyll is formed inside the head. A cabbage cut down the centre into two halves should be examined. The closely packed leaves contain a store of food materials from which the plant in its second year would produce flowers and fruits-- but here the stock-feeder intervenes.

Kale (Fig. 118) is similar to cabbage, except that the main stem elongates so that the leaves become separated and wide-spreading. They become green under the action of light. Cabbage and kale are gross feeders, and produce immense yields under liberal treatment. Kale is very hardy.

Mustard (*Sinapis*) is a cruciferous *annual*. The *white mustard* (*S. alba*) is a popular catch crop in some districts, owing to its very rapid growth, which may enable sheep to be turned in at two months from sowing. The plant has whitish yellow seeds- -hence its name. *Black mustard* (*S. nigra*) has smaller dark brownish seeds, which is grown to provide table mustard, etc. It is not cultivated as a forage crop.

FIG. 119.—Italian Rye-grass. (Suttons.)

Gramineæ.—For general characters, see Chapter XXXIII.

Italian Rye-grass (*Lolium italicum*) resembles perennial rye-grass, but it is a larger plant, shorter lived, somewhat more prolific in seed production, and more tufty in habit. As in other rye-grasses, the leaf-sheaths often show a purplish tinge at the base. The spikelets are placed edgewise to the main axis of the ear (unlike wheat), and each spikelet has only one glume (contrast Fig. 99). In "Italian," the outer pales carry awns (Fig. 119), which are rarely found in perennial rye-grass.

"Italian" is remarkable among grasses for its rapid initial growth, and a heavy yield can be obtained during the year of sowing. It is often used as a catch crop, *e.g.*, after early potatoes. The produce is often used for "soiling." At other times it may be dried for hay, or used for grazing.

Rye (*Secale cereale*) for forage is often sown as a catch crop in autumn—the stubble from a previous cereal being first ploughed. It provides very early feed in spring for ewes and lambs. Winter oats and winter barley are used in the southern counties in the same way.

Mixed Crops.—In growing certain of the forage crops it is often of advantage to use a mixture rather than a single pure crop. This principle has long been acted on, *e.g.*, by making mixed sowings of rye-grass and clover rather than sowing either by itself. In mixed crops the units composing it should be of approximately the same size. Suitable mixtures for forage among crops which we have mentioned would be: rye with vetches; oats with peas; beans with vetches and oats; rape with rye. Such mixtures could be extended and varied considerably, but must contain only such crops as can individually succeed at the season of year when the mixed sowings are made.

The following **advantages** may be secured by **suitable mixtures**:—

1. Shallow and deep rooters tap different zones in the soil.
2. One crop may help to hold another up, *e.g.*, rye and vetches.
3. A legume seems to be of some advantage to a cereal that is growing along with it.
4. A wet season may suit one crop, and a dry season suit the other crop.
5. Insects or disease may attack one crop and leave the other unscathed.
6. Animals usually thrive better on mixed fodder than where their nourishment is derived wholly from a single plant species.

Less seed is required on good land, when using the proper manures, also when the seeding is done at the proper time. The reasons for this will be understood.

Chapter XXXVII

PASTURES

In this country the area under pastures greatly exceeds that devoted to arable farming.

Pastures are divided into "**permanent**" and "**temporary.**"

The former never come under the plough. Temporary pastures, on the other hand, form part of some cropping rotation. Here the land is sown down either with grass or more often with a mixture of grass and clover, and is then left out of cultivation for a period varying from one to about six years. Such are called one-year or six-year *leys* or *leas*. The longer-duration leys often tend to deteriorate rather rapidly in the later years, so that the land has to be again ploughed up, cropped for several years, and then sown down again for another temporary ley.

FIG. 120.—Perennial Rye-grass. (Suttons.)

The tendency of temporary pastures to deteriorate is—in part, at least—a matter of climate and soil. In the bleaker districts of the north the *whole* farm is often constantly under cultivation, but with a long-duration pasture ley as an integral part of the cropping rotation. This practice is sometimes known as "alternate husbandry." In the warmer south, on the other hand, one *part* of the farm is often relegated altogether to permanent pasture, while the balance is devoted to short rotations of continuous cropping.

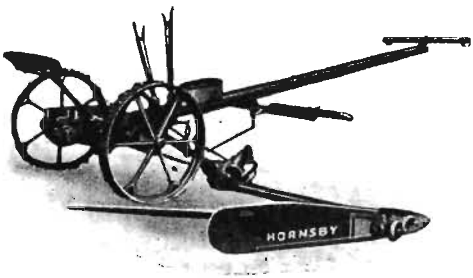


FIG. 121.—Grass Mower. (Ransomes.)

Grass-land may be cut for **hay.** Hay cut from temporary or sown-down grass (or grass and clover) is known as "*seeds hay*," while that from permanent grass-land is called "*meadow hay*." Seeds hay is often taken in the first harvest year, *i.e.*, in the year after the year of sowing under a nurse crop. The yield is typically heavier than that of meadow hay but it is more costly to produce.

Pastures always contain a **mixture** of **plant species.** In good old grazings the number may exceed fifty; under unfavourable conditions there may be only seven or eight. The best pasture plants are those which are (*a*) most productive, (*b*) most palatable, (*c*) most long-lived and hardy. They must produce *palatable bulk*. Apart from this the nutritive value of ordinary pasture is determined much more by soil, manuring, and climate than it is by the species of plants growing. This would be news to many people. But practical farmers seem to know it instinctively; when inspecting a grazing they always pay more attention to the condition of the stock carried than to its botanical composition. The result is actually connected with the better *mineral content* of herbage which has been grown on good land.

The **ideal mixture** in a pasture is composed of:

Top grasses.
Bottom grasses.
Leguminous plants.
Miscellaneous herbage.

The *top grasses* are tufted in their growth, are tall and productive, and are especially useful for cattle and in yielding bulk. *Bottom grasses* are small and fine-leaved, and form a close turf between the top grasses; they are sometimes of creeping habit. *Leguminous plants* such as clovers are valuable in collecting nitrogen, and thus improving fertility. Some of the *miscellaneous herbs* are serviceable in providing variety, and at times in yielding a bite at seasons when better feed is scarce. It will be useful to refer briefly to a few typical members of the above groups.

Top Grasses

Perennial Rye-grass (*Lolium perenne*) is very largely used for temporary leys, the seed being cheap and plentiful (Fig. 120). Plants grown from commercial seed show vigorous *early* growth, but often die out in the third year. For more permanent mixtures rye-grass is often included to cover the ground until other grasses —more slow in development but far more lasting—have established themselves. It is important to remember that (as with other grasses) there are many *strains* of "perennial" rye-grass. Some of these are widely spread and indigenous to many of the best old English pastures, especially on rich loams and clays;

such strains typically produce far less seed, produce more bottom foliage, and are truly perennial. It is difficult to get seed of them. Rye-grass comes early in spring, but is not a very good summer grass. After cutting for "seeds hay" it grows little aftermath.

Cocksfoot (*Dactylis glomerata*) is slower in maturing than rye-grass, but is more lasting. It is not included in mixtures for

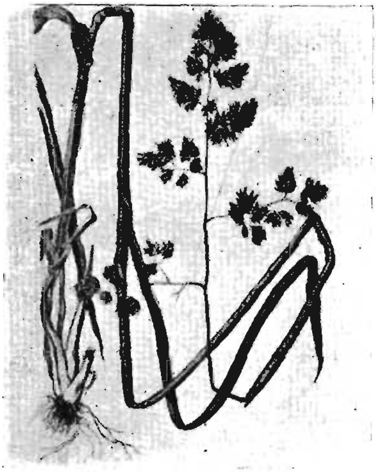


FIG. 122.—Cocksfoot Grass. (Suttons.)

FIG. 123.—Timothy Grass. (Suttons.)

one year, but generally finds a place in sowings for longer leys (Fig. 122). It produces very heavy yields, is deep-rooting, and resists drought better than rye-grass. Even more than most grasses, cocksfoot becomes *woody* with approaching ripeness; to avoid this it is desirable to keep the herbage young by close grazing during the summer. For the same reason cocksfoot in hay should be cut early. It yields a good aftermath.

Timothy (*Phleum pratense*) or Catstail (Fig. 123) is also a deep-rooting perennial. Being slow to establish itself, it is rather sensitive to competition from other species, and is at its best when sown by itself to form permanent hay meadows. It suits cold heavy clays and peaty soils where other grasses would fail.

Sometimes the seed of timothy is "husked"—so that the part sown is the true fruit as found in wheat or naked oats.

Bottom Grasses

Crested Dogstail (*Cynosurus cristatus*) is a small perennial common all over the country, and is often included in mixtures for more than two years, especially on lighter lands. It is unsuitable for mowing, but is readily eaten by sheep which, however, neglect the flower stalks (Fig. 124). From that fact considerable self-seeding can result. It is a poor yielder, but occupies the spaces between larger plants.

FIG. 124.—Crested Dogstail. (Suttons.)

FIG. 125.—Rough-stalked Meadow Grass. (Suttons.)

Rough-stalked Meadow Grass (*Poa trivialis*) is one of the finest bottom grasses, and is usually represented in permanent mixtures where the conditions are sufficiently moist (Fig. 125.) It is specially useful in providing a green bite in winter and early spring when other grasses are resting. A small annual relative (*Poa annua*) is a common weed in gardens.

Leguminous Plants

Broad Red Clover (*Trifolium pratense*).—There are a number of strains varying in size, time of flowering, and in permanence (see also Chap. XXXVI.). The common red clover (Fig. 115) is practically a biennial, while some of the later-flowering strains, commonly known as "*cow-grass*," might rank as perennials. The common strain of red clover is widely used in short-duration leys, especially for providing hay and aftermath, while the late red or "cow-grass" is preferred for long-period sowings, and where continued grazing is kept in view. Its seed is harder to get.

Alsike (*T. hybridum*) has rose and white flowers, and was wrongly supposed to be a hybrid between red and white clovers. It is somewhat more permanent than the common red clover, and can be substituted for the latter on clover-sick land. Unlike the red, it leaves a poor aftermath.

White or Dutch Clover (*T. repens*) has a "creeping" habit, and is smaller than the previous clovers (Fig. 126). Here again some *strains* are longer-lived than are others. It is suited for grazing, and is often included for temporary leys. Closely resembling it in appearance is the **Wild White Clover.** This is a true perennial, is indigenous to many parts of Great Britain, and is perhaps the most generally valuable of all pasture plants. The seed of "Wild White" is expensive, but a small amount is usually included in permanent mixtures.

FIG. 126.—White or Dutch Clover. (Suttons.)

Besides true clovers, the leguminous plants in pasture may include **other genera**, *e.g.*, Trefoil (*Medicago lupulina*), often called "hop clover"; Birdsfoot Trefoil (*Lotus corniculatus*) and others. These have less value than the true clovers.

Purchase of Seeds.—In buying seeds a guarantee should be obtained in regard to (*a*) percentage of purity (by weight), and (*b*) percentage of germination (by test), while (*c*) the absence of weed seeds (and for clover the seeds of dodder) should be ascertained (Fig. 127). The buyer then knows what he has got. Thus if a parcel of clover seed showed 90 per cent. purity and 81 per cent. germination, then 100 lbs. of the seed could supply only $\frac{90 \times 81}{100} = 72 \cdot 9$ lbs. of clover seed which would grow. This figure represents the "*Real Value*" of the sample. Seed of grasses and clovers sometimes supply even less viable seed than that.

A low percentage of germination in clover, lucerne, etc., is often due to the presence of what are called **hard seeds.** The number of hard seeds is greater under dry conditions of ripening. Moisture and air cannot penetrate their seed-coats, and they refuse to germinate in the ordinary time allowed for the test of clover seed,[1] but would eventually germinate in the soil —perhaps in the following year. By scratching the seed in a machine they can be made to germinate at once. Seedsmen do not like them. Hard seeds, however, sometimes play a useful part in pasture, because if the first crop from normal seeds should die or suffer injury before maturity, then any residue of hard seeds in the ground will give the crop a fresh start at a later date. In semi-arid countries the production of hard seeds does much to ensure the survival of a species, and particularly where the vegetation is composed chiefly of self-sown annuals.

Sowing Down Pastures.—Pastures are sometimes sown down in late summer, but the usual season is April or May. A fine tilth is necessary for such fine seeds. Broadcasting is the best method, and they must not be buried too deeply or else their small food stores will be exhausted before they can make their own food by photosynthesis in the sunlight. After sowing, the surface should be consolidated by rolling to assist capillarity. The seeds are usually sown with a *nurse crop* of cereals as described for Red clover in the previous chapter. The cereal provides some revenue for the farm while the young pasture is making a slow start. The seeds may be sown either before or after the nurse crop is through the ground. To avoid smothering by the nurse

[1] The time usually allowed for germination under optimum test conditions varies from 10 to 28 days according to crop—for clover and lucerne, 10 days.

crop before its own harvest, the protecting cereal should (*a*) be rather thinly seeded, (*b*) be of a strong-standing variety, and (*c*) not receive too much nitrogenous manure. Sometimes a thin seeding of rape, to be eaten off by sheep, is employed as a nurse crop.

Close grazing is to be avoided on **young leys** until the plants have established themselves. Moderation here is particularly important in the next spring after the seeds were sown.

FIG. 127.—*Corner of a Seed-testing Station.*

In the **maintenance** of a good pasture careful stocking must receive attention. With *insufficient stocking*, the large plants by undue shading crowd out the smaller species, and the pasture becomes coarse. On the other hand, *over-stocking*, especially in spring, tends to suppress commercial strains of the larger species like rye-grass and cocksfoot, whose special bent is seed production. The plants which best endure close grazing are those of creeping habit like wild white clover; also those with strong tillering activity in the production of leafy shoots—a character typical of the best indigenous perennials. Sheep or horses alone give unsatisfactory grazing, as both neglect the coarser grasses; a field grazed only by horses takes on a patchy appearance. Cattle are far less selective and graze more uniformly. Mixed stocking is always preferable where circumstances permit.

On second-rate pastures wonderful betterment can often be effected by suitable **manures.** *Phosphates* are generally the most needed, and the best results have been found on the heavier clays and loams. The clovers receive special encouragement. About 10 cwt. per acre of basic slag, or its equivalent, is applied at one dressing, but the results may remain apparent for many years. Thus at Cockle Park, Northumberland, one block of land so treated was still carrying nine sheep instead of the four on a similar untreated block at nine years after the slag was applied. To obtain the full benefit from such manuring, heavier stocking is necessary to cope with the increased herbage.

Sometimes phosphates by themselves fail for various reasons. On lighter or on peaty soils, *potash* may also be deficient, and then by the Law of the Minimum (Chap. V.) the phosphate must be supplemented by kainit or potash salts. For ordinary grazing, *nitrogen* manures are usually inadvisable; it is better to encourage the clovers with phosphates.

Lime is sometimes required on pasture, but as a general rule, where phosphates will increase the clovers, then liming will not pay. In other cases lime may pay well. Lime neutralises soil acidity and helps dead vegetation to decay. Contrariwise, sour lands sometimes become matted with undecayed herbage to the degree that they feel springy to walk on. Such a surface mat on the soil prevents the spread of useful plants like wild white clover, because the runners cannot take root on it. Either hot lime or the carbonate (Chap. XXII.) may be used, and not less than 3 tons of the carbonate per acre. Lime acts more slowly than phosphates. Three years may elapse before improvement is seen, but the effects of a heavy dressing may remain for half a century. It is, of course, no use liming land while it stands in need of drainage. That is just a waste of money.

CHAPTER XXXVIII

BENEFITS OF A ROTATION OF CROPS

UNDER cultivation, the same crop is rarely grown for two years in succession on the same land. To attempt to do so would usually be bad farming. Different crops follow one another in prearranged order upon the same field, and the order in which they follow is termed a **rotation of crops.**

There are many rotations in use in different parts of the country, but most of them are based on the famous **Norfolk four-course** rotation, introduced about 1730 by Viscount Townshend. It is adapted for light and medium soils, the sequence being—

First Year—Wheat (sown in previous autumn).
Second Year—Roots (sown in early summer).
Third Year—Barley (sown in spring).
Fourth Year—Clover (sown with barley in third year).

The Fifth Year is the same as the first, and the whole process is repeated.

One can see why this system of cropping became popular. Clover has usually finished growth in September (let us say in 1936), thus leaving time to plough up the land for wheat to be sown in autumn of the same year; the wheat benefits from nitrogen which the clover roots had " fixed " from the air. The wheat crop is harvested in the following autumn (1937) and there is ample time to plough the land deeply and then leave it to mellow during the winter. Then in spring (1938) it is torn up by cultivator and harrows and cleared of weeds; the root crop not being drilled until June, there is enough time to work the fallow well in dry weather. As the roots are grown in wide rows they offer further opportunity to destroy weeds by hand and horse-hoeing during summer. The root crop receives most of the manures for the rotation. It may not be removed from the land before the following winter, but this does not matter much because barley is not sown until spring (1939). The land after roots requires only shallow ploughing, because it would be unwise to bury manurial residues from the root crop too deeply. The clover or " seeds " is sown in the same spring (1939) and just after the barley. It remains small during the barley year (its nurse crop), but in the next year (1940) it yields two cuts of hay, or the second crop (the aftermath) may be eaten off by sheep. A new round of the clock is then started by ploughing up the clover stubbles for wheat again in the autumn of 1940.

Variations in the Norfolk rotation are often necessary owing to considerations of climate and soil, and for commercial reasons. Thus it may be desirable to substitute oats for wheat, and perhaps for barley as well. If the land be rich, another cereal crop is

[*Farmer and Stockbreeder.*

FIG. 128.—Ploughing near Mold, N. Wales.

sometimes taken after the roots and before the barley, which on too rich soil gives inferior quality for malting. Deep-rooting clovers succeed better in the warmer southern counties, while grasses flourish better in the moist climate of the north—with the result that grasses there form the major portion of the " seeds " mixture. In the more exposed northern districts several years of temporary pasture are usually taken after " seeds " hay, the rotation then being (1) oats, (2) turnips, (3) oats or barley, (4) " seeds " hay, (5), (6), etc., pasture, after which the land is again ploughed up for an oat crop. In the highly favoured county of East Lothian the following rotation is commonly practised on medium loams: (1) oats, (2) potatoes or beans, (3) wheat, (4) turnips, (5) barley, (6) "seeds" (rye-grass and clover), hay. On very heavy soils in the South of England an old rotation is (1) wheat, (2) beans, (3) bare fallow. Under bare fallow [1] the land is periodically cultivated during the summer to kill weeds, and no crop is attempted. It is practised usually on the heavy clays owing to the difficulty and expense of establishing root crops there.

The number of rotations actually practised in different parts of the country is very large, but those given may serve for illustration. They could be modified or extended almost indefinitely.

The following are the **advantages of a good rotation** of crops :—

1. *Larger Crops are Obtained.*—From or at the roots of all crops certain substances are produced which are poisonous to themselves but in a varying degree. Cereals can be grown year after year with less damage, but turnips suffer more from the effects of a previous turnip crop, and "clover-sick" or "bean-sick" soils refuse to grow those crops again until a number of years have passed. In some cases those poisonous substances, or *toxins*, may also be injurious to other crops, but in other cases they may seemingly be a positive advantage. The relation of one crop to another in this respect has not yet been fully investigated, but its effect is seen where one crop specially stimulates one kind of weed to grow beside it, and another crop other kinds. By introducing a change of crops, particularly of those belonging to different natural orders, the effect of poisonous residues is always diminished, and this probably furnishes one of the chief reasons for a rotation of crops.

These toxic substances are changed within the soil by oxidation. Good cultivation and light soil will help in the changes, which presumably also go on faster in a warm climate. Certain manures, and particularly lime, make the land more quickly able to again carry well a second crop of the same kind.

2. Rotations are *economical of manure.* Some crops require more of one constituent, *e.g.*, potatoes require much potash and cereals little, so that by interposing potatoes between cereals a fuller use can be made of the potash in the soil. Again, some crops are deeper rooted and draw supplies from the subsoil,

[1] The word "fallow," meaning brownish yellow, probably refers to the colour of land ploughed and then left unsown—*cf.*, fallow deer.

e.g., wheat or rape, while others are shallow, *e.g.*, barley or turnips, and thus in a rotation all horizons of soil are brought under contribution to maintain crops.

3. *Leguminous crops* can be grown at some place in the rotation, and thus a store of combined nitrogen is laid up in the soil for the use of future crops. The inclusion of legumes in a rotation may save much expenditure on nitrogenous manures.

4. *Humus* can be added to the soil by ploughing in farmyard manure, or by the growth of forage crops which may either be ploughed in as green manure or profitably consumed on the land

[*Farmers' Weekly.*

FIG. 129.—Young Cattle on Pastures at Jealott's Hill, Berks.

by stock. Forage crops are especially useful on the farm with an insufficiency of farmyard manure.

5. A useful variety of *root and forage crops* is made available for the farm live stock, and temporary pastures can be renovated.

6. *Weeds* are kept down when the rotation contains a bare fallow, or where crops like potatoes or turnips are grown in wide rows, so that hoeing becomes easy. Such a crop is sometimes called a " green fallow."

7. Damage by *insects and fungoid diseases* is less likely. Such pests usually have a particular victim or host plant which they specially favour, so that by rotating the crops the probability of attack is diminished ; in some cases it is entirely removed.

8. *Labour is distributed* throughout the year. Different crops have different seasons of sowing and harvesting, and on a one-crop farm certain seasons would be too busy and others too slack. Where constant employment cannot be found for hired help, the casual labour obtained only at busy seasons is often unsatisfactory.

It will be seen that many *technical* advantages arise from adopting a good rotation. While striving to obtain these to the fullest extent, it should not be forgotten that in planning a rota-

FIG. 130.—Lanark Auction Market. Blackface Ram Sale.

tion important **economic factors** also come in—including the probable trend of prices for produce, and the costs of requisite labour, seed, machinery, and fertilisers. As in any other commercial undertaking, **good business instinct is of essential importance in farming.** While studying the application of science to agriculture, one must not forget that the economic problem of "what to grow" is at least as important as the technical problem of "how to grow it." This matter is mentioned here—not to decry the value of technical knowledge but to view it in the proper perspective. The young college graduate frequently fails in farming, not from lack of scientific knowledge but because he fails to keep an eye on markets. Men of experience will endorse this view. Technical education is necessary for full success in farming, but it must be backed up in the individual by the wider view that farming is a *business* and must be conducted on business lines. The selection of the cropping rotation which is best suited to his needs is, in truth, one of the most important tasks which the farmer has to face.

CHAPTER XXXIX

INSECTS AND THEIR ATTACKS

IT sometimes happens that much damage is done to farm crops by the attacks of insects. In these attacks any part of the plant is liable to suffer injury. Some insects specially attack the roots of crops. In other cases the stems, foliage, flowers, or fruits may be destroyed. The damage is sometimes caused by the insect biting and eating away the plant part; other insects cause damage by sucking the plant juices. A number of troubles in farm animals and poultry are also caused by insects. The study of insects offers a large field, and the science which treats of insects is known as *entomology*.

Insects, of course, are not all injurious. Some of them perform a useful service in pollinating flowers, while others, again, furnish products which are of direct value, such as the silk-worm and the honey-bee.

Insects both useful and harmful flourish more vigorously in a warm climate, and particularly when their numbers are not checked by a rigorous winter. Besides extremes of weather, insects have many natural enemies. Insectivorous birds help to keep down the numbers, while the list of insects which prey upon other insects is very large indeed. Infectious diseases caused by bacteria are also common among insects, and the sudden lull in attack when an insect plague has become alarming is sometimes due to this cause. "Foul brood" is an example of an infectious disease of this class among bees.

Insects are animals without a backbone, and hence belong to the *Invertebrata* (Chap. XLI.). The skeleton of an insect is on the outside, and consists of a horny substance which gives the body rigidity. The body is built up of a number of rings or segments of this substance, and these rings are grouped in three regions forming the head, thorax, and abdomen. Fig. 131 shows the several parts of a dissected insect.

The **head** carries the eyes, antennæ, and the mouth parts. The antennæ, or feelers, are two in number and are used by the insect to investigate its surroundings. In different species the antennæ vary greatly in length and shape. The mouth in some insects, such as beetles, is furnished with powerful biting jaws, while in others, such as butterflies, the jaws are modified into a kind of sucking tube.

The **thorax** always consists of three segments which in the illustration have been dissected. Each segment carries two legs, and therefore true insects have always *six* legs. Spiders and wood-lice have more than six legs, and are therefore not, properly speaking, insects. The thoracic region also carries the wings. These are borne on the second and third segments of the thorax, each of which bears one pair of wings. An insect has thus four wings. Sometimes all four wings are membranous, as in bees; sometimes the front pair are hard and horny, as in beetles; sometimes the second pair of wings are not properly developed—leaving only two wings, as in house-flies; and some true insects have no wings at all—as in fleas.

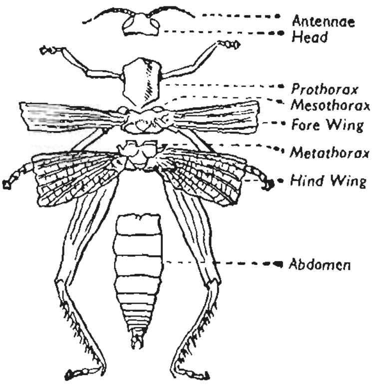


FIG. 131.—Parts of a Typical Insect.

The **abdomen** may consist of a varying number of segments up to fourteen, but none of these carry legs or wings. Sometimes the abdomen may terminate in a sting, and at other times in a tube through which the female deposits her eggs.

Insects do not **breathe** through their mouth, but by means of openings over the surface of their body. If these openings are closed by a sticky solution the insects will be suffocated, and this gives one method of dealing with insect pests. The buzzing of insects is caused by friction of the parts of the body, and in no case has an insect a voice.

Insects are male and female, and as a rule insects are reproduced from eggs. The **eggs** are usually deposited in contact with a supply of food which could nourish the young after the eggs are hatched. In the great majority of cases the young insect passes through certain changes or **metamorphoses** before it is fully developed, and ready to deposit a fresh set of eggs, viz.:

1. Egg. 2. Larva.
3. Pupa. 4. Imago, or perfect insect.

Insects which fly about have reached the final stage in their development. The length of time taken to pass through the complete set of changes may vary in different species from a few weeks up to six months, or a year, or several years. Warm weather is favourable to rapid development.

The **larva** is a worm-like creeping creature, and is known by different names in different orders of insects. In butterflies and moths (*Lepidoptera*) the larva is often termed a caterpillar; in the "fly" order (*Diptera*), a maggot; and in the order of beetles (*Coleoptera*), a grub. The larvæ have no wings; the legs may be absent or present, and sometimes the larvæ carry temporary "legs" on certain segments of the abdomen. The larvæ have often strong biting jaws, although these are not present in the mature insects, *e.g.*, in moths, and, generally speaking, it is during the larval stage that the insect does most damage. Fig. 132 illustrates the form of the larva in three important natural orders of insects.

When the larva is full fed it forms a cocoon in which it goes to sleep, and becomes a **pupa** (chrysalis). The pupa is a resting stage during which the larva is metamorphosed into the parts of the mature insect. When the time is ripe it emerges from the cocoon and is ready to fly about.

The last or **imago** stage is, then, that of the perfect insect (Fig. 132). There is no growth in this stage—a small fly does not become larger, nor does a moth increase in size. The adult stage is the period not of growth but of reproduction, and as a rule the female of an insect dies soon after it has deposited a new brood of eggs.

In some species of insects the metamorphosis does not follow the regular course, and in some cases the young are produced alive, as in aphis (green-fly). The great majority of species, however, go through the regular phases of insect life. In **combating attack,** treatment is directed to that phase of the insect which is most vulnerable. Sometimes the eggs are destroyed, and sometimes it is necessary to await the appearance of the larvæ ; in other cases the resting cocoons can be got at

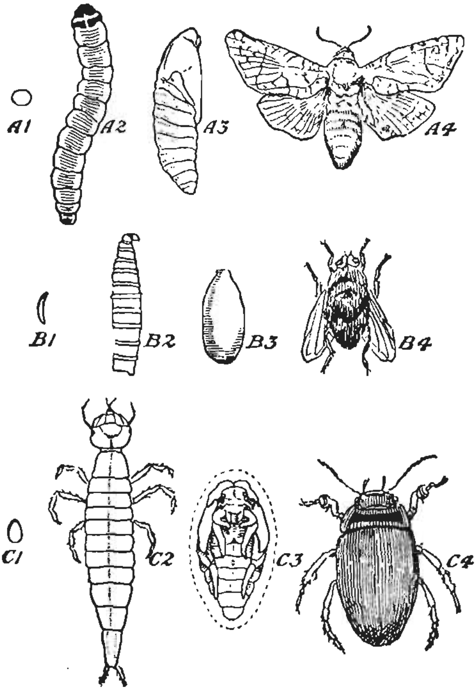


FIG. 132.—Illustrative Orders of Insects.

A, *Lepidoptera*—*A*1, egg ; *A*2, larva ; *A*3, pupa ; *A*4, imago. *B*, *Diptera*—*B*1, egg ; *B*2, larva ; *B*3, pupa ; *B*4, imago. *C*, *Coleoptera*—*C*1, egg ; *C*2, larva ; *C*3, pupa ; *C*4, imago.

and burnt ; one of the most satisfactory methods is that which kills the mature insect or prevents her laying her eggs.

It would be impossible here, nor is it wished, to catalogue even all the insects which attack farm and garden crops. It is sufficient for the student to grasp the leading principles of entomology. The following are the more important **measures adopted** to prevent insect attack, or, once started, to hold the attack in check :—

1. Good cultivation and manuring, as vigorous crops are better able to resist attack.
2. Selection of vigorous seeds or stocks, as in American vines resisting the phylloxera insect.
3. Not planting stocks actually carrying infestation, *e.g.*, the mite on black-currant bushes.
4. Practising a rotation of crops so that larvæ hatched from the previous crop do not find their special food. The

FIG. 133.—Spraying an Orchard. (Allen & Simmonds.)

trouble with insects in orchards is increased because it is impossible to crop in rotation.
5. Keeping down weeds which may sustain the insect between successive crops, *e.g.*, charlock (" wild mustard "), harbouring the turnip flea.
6. Burning up refuse straw and haulms of an infested crop which may contain eggs and larvæ.
7. Avoiding old bags or fruit-cases likely to harbour the pests.
8. Frequent cultivation and harrowing to unearth wire-worms and other grubs living in the soil.
9. Forming a trench round the crop to ward off creeping insects such as cut-worm caterpillars.

10. Encouragement of parasitic insects, *e.g.*, ladybirds, which destroy aphides.
11. Spraying with almost insoluble (not to harm foliage) preparations of arsenic, etc., to poison biting insects such as beetles and caterpillars.
12. Placing bundles of poisoned plants or bran to attract the insects—grubs, caterpillars, etc.
13. Spraying with a corrosive solution of soft soap, resin, alkali, etc., to suffocate and destroy sucking insects, *e.g.*, scale insects, aphides, etc.
14. Fumigation as by carbon disulphide (CS_2), or by carbon dioxide (CO_2), in a granary to destroy weevils.

Instead of liquid washes or spray fluids, fine dry powders such as soot, lime, hellebore, etc., are sometimes dusted on. There is an extensive literature, including " Leaflets " by the Ministry of Agriculture, giving formulæ for the preparation of spraying materials against different kinds of attack. In using these it is necessary to :

1. Apply them at the right time.
2. Apply them of the proper strength.
3. Apply them thoroughly.

Where a wash is too weak it may fail in its purpose, and where it is too strong it may damage the crop.

CHAPTER XL

FUNGUS DISEASES

ORDINARY crops form the great bulk of their dry substance from the carbon dioxide of the atmosphere. The starches, sugars, etc., which they then form are the **real food** of the plant, and they are formed in the process (Chap. VI.) of photosynthesis. Crops can make these things because they are green. Fungi are a lower form of plants. But fungi are not green, and therefore they are unable to make the necessary starches and sugars from the atmosphere. They must, however, get them in some way, and since they cannot make them for themselves they are forced to steal them.

Fungi are of two kinds. One kind gets its food supplies from *dead* and *decaying* plant or animal substances, and a fungus of this kind is called a **saprophyte.** The mushroom and many varieties of mould are examples of saprophytes. The other kind of fungi obtains its food supplies from *living* plants or animals, and such fungi are **parasites.** The result is to weaken or even to kill the plants or animals so lived upon. Many plant diseases are caused by fungus parasites. Thus a certain fungus living on wheat causes rust, a different fungus on wheat causes smut, and still another on wheat causes bunt. In the same way the "potato disease" is caused by a specific fungus. Fungus parasites are often particularly rampant in orchards.

The plant upon which a fungus lives is called the **host.** Fungi are rather fastidious in choosing their host, and as a rule each fungus has only one or at most two or three host plants upon which it will consent to live. Thus the "potato disease" fungus will live on potatoes and also on tomatoes, but will die before it will attack wheat or rape. It is unable to live upon those crops. The smut fungus of wheat will not even attack oats, but there is another fungus which causes smut in oats.

While fungi are divided into saprophytes and parasites, the line between them is not always a sharp one. Some parasites are able to live for part of their existence as saprophytes on dead matter, and then when a suitable host offers to function again as parasites. This power is a regrettable one where it occurs, because it makes it more difficult to starve the fungus out.

A **fungus** is a simple form of plant. It does not bear roots, stems, and leaves like the higher plants, and it is usually propagated by **spores,** which are much simpler bodies than true seeds. Fig. 134 represents a common fungus, the *green mould*, which lives as a saprophyte on damp bread, cheese, and fluids of many kinds. Under suitable conditions a spore of this fungus absorbs water and sends out a thread or *hypha.* Those threads continue to elongate and branch out, forming a matted network—the spawn or *mycelium* of the fungus. The mycelium is the vegetative part of the fungus through which it absorbs its food supplies. Before these can be absorbed they often require to be dissolved first, and the mycelium secretes ferments which can dissolve its food. If the mycelium meets with poisons it will die. Fungi prefer an acid medium, and in this they differ from bacteria, which are usually benefited by an application of lime. Crops on sour land seem particularly subject to fungus attack.

After a time some of the hyphæ grow out from the vegetative mycelium and produce spores (Fig. 134); these under favourable conditions will rapidly produce a new mycelium. Study of the spore formation in different groups of fungi is a matter of considerable complexity. It often happens that two kinds of spores are produced by the same fungus. One kind have only a *brief vitality*, but are produced in great numbers and serve to spread the fungus attack rapidly during the crop season. The other kind are produced under less favourable conditions, as towards the close of the season, and act as *resting spores*, being longer lived and harder to kill. The mycelium itself under certain conditions may cover a resting stage, *e.g.*, in diseased potatoes under storage.

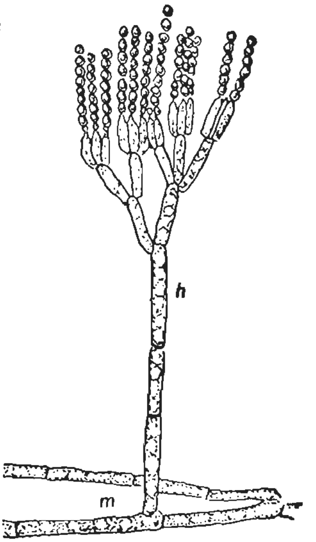


FIG. 134.—Green Mould (*Penicillium glaucum*).

m, mycelium; *h*, spore-bearing hypha.

In **parasitic fungi** the vegetative mycelium is usually hidden from view *inside* the tissues of the plant, and from these it draws its food. The spores, however, are often visible on the *outside* of the plant, and it is chiefly from the form and character of the spore-bearing parts that the *plant pathologist* is able to identify the particular fungus causing the disease. As with insects, so also with fungi, the methods of combating are regulated by a knowledge of the life-history of the pest. Sometimes the fungus can be destroyed in the spore stage, sometimes its ravages can be mitigated in the active vegetative stage, but very frequently once a crop has been attacked nothing can be done at all. With fungus diseases the aim is less to cure than to prevent an outbreak.

One or two specific diseases may be briefly considered to extend our knowledge of this subject.

Rust.—The leaves and stems of wheat in early summer often show orange-yellow patches (Fig. 135), and from these this disease takes its name. The patches consist of numerous spores of a fungus (*Puccinia sp.*), whose mycelium lives inside the plants and sucks their juices. The spores, called *uredospores*, are produced in immense numbers, and when mature are carried about by wind, and some are deposited upon the foliage of other wheat plants which may be at a considerable distance. Using any moisture upon a leaf the spore germinates, and the hypha produced enters through a stoma (Fig. 65) into the interior of the leaf. As moisture is necessary in order that the spores may germinate on and infect new plants, rust is worst in a close, damp season. It is also worse on good land, and after the liberal use of nitrogenous manures, both of which give larger and more succulent foliage and a better feeding material for the mycelium. A crop badly attacked by rust suffers greatly because the nutriment, which was intended for filling the grain later on, is consumed by the fungus for its own support. In such a case the grain will be of small size, and indeed the crop may be ruined.

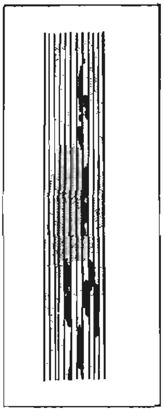


FIG. 135.—Rust of Wheat.

The rust fungus produces uredospores early in the summer. Later on, the same mycelium within the plant begins to produce a different kind of spores which are much darker in colour, and are termed *teleutospores*. These are thicker walled and more robust, and are resting spores whose purpose it is to carry the fungus safely over until next spring. They remain unchanged for months. Curiously enough, the teleutospores cannot directly infect wheat, but in spring they can infect the barberry plant, and from it produce yet another kind of spores which this time can produce rust in wheat. Back on its wheat host again, the fungus once more begins to produce uredospores, and so infection proceeds throughout the summer. Such a compulsory change of host is not the rule among the fungus parasites of the farm, but a number of other instances are known to pathologists.

Unfortunately the two common rusts in this country—yellow rust (*P. glumarum*) and brown rust (*P. triticina*)—may survive our winter in the uredo stage, so that no change of host appears to be necessary. Each year brings fresh attacks from these rust fungi. To avoid attack choice of *wheat variety* is an important practical measure, because some wheats, like Little Joss and Yeoman, are highly resistant to attack, while some other varieties are easily susceptible.[1] Phosphatic *manures* to some extent accelerate ripening in wheat, and may thereby reduce the damage by rust. Potash increases resistance to attack; as already mentioned, nitrogenous manures lower it.

Besides rusts attacking wheat, there are still others which attack oats, barley, clover, mangolds, and fruit trees.

Smut and Bunt.—There are many different fungi causing those diseases in cereals. In loose *smut* (*Ustilago tritici*) of wheat the ears are changed into a black mass of spores which easily shake out (Fig. 136 (*A*)) and blow about in the wind. (Another loose smut is particularly common among oats.) In stinking "smut" or *bunt* (*Tilletia sp.*) the grains of wheat remain apparently intact (Fig. 136 (*B*)), but are filled inside with a dark greasy mass of bad-smelling spores. In each case the spores are produced by the mycelium of a fungus living inside the plant, but it is a different fungus which produces smut from that which produces bunt.

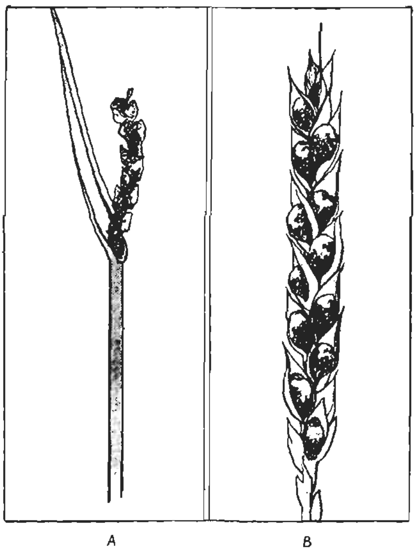


FIG. 136.—*A*, Loose smut; *B*, Bunt.

Let us first consider *bunt*. During threshing of partially diseased wheat, some of the bunty grains or "bunt balls" are broken, and the spores become scattered over the healthy grains. If such wheat be used for seed, the adherent spores germinate in the moist ground along with the healthy wheat grains. After they germinate, the fungus sends its hypha into the delicate wheat seedling, and it thereafter goes on living inside the plant and growing with it, all unnoticed, until the wheat begins to

[1] Common rusts are known in different "*physiological strains*," and immunity may often be due simply to absence of the particular strain of rust which is effective for the particular variety of wheat.

form grain. The fungus then produces spores which occupy the place which the grain contents should have filled.

Bunt can be **prevented** by treating the seed before sowing it with a solution of blue-stone (copper sulphate) in order to destroy the fungus spores adhering to the grain. Copper compounds are very poisonous to crop plants and fungi alike, and the blue-stone solution may lower the germination of the grain if sowing is delayed. Instead of blue-stone solution, a dry treatment with fine copper carbonate powder, or with mercurial dusts, is often now used instead; it does not lower the germination, and it is easier to carry out. Some varieties of wheat are more resistant to bunt than others.

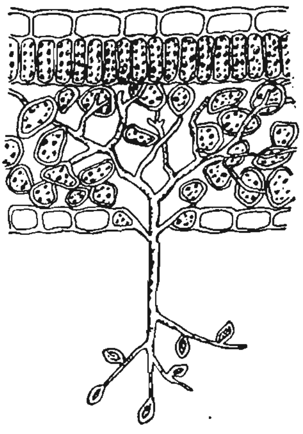


FIG. 137.—Diagram-section of Leaf of Potato, showing fungus growing in leaf and producing spores.

Disinfection by treating the seed is very effective in preventing bunt. This is not so with the loose *smut* of wheat, because here the plant is not infected at the seedling stage but at the flowering period of the previous crop. The fungus mycelium then develops *inside* the grain and it is impossible to poison it without poisoning the grain itself. The best way to avoid smut in wheat is to avoid seed from a crop showing the disease.

Potato blight, often called "**potato disease,**" is caused by a fungus parasite (*Phytophthora infestans*). When a spore falls upon the potato leaf, fungus hyphæ are ultimately produced which find their way into the leaf and live upon it. The leaf becomes permeated and killed by the mycelium absorbing its juices, and large brown to black spots are developed. Round the edges of these spots the fungus sends out little branches (Fig. 137) which bear spores ready to infect another plant. Some of these spores are carried by wind to healthy potato foliage; they are easily killed by dry conditions, but in moist, warm weather infection spreads very rapidly. The disease emits a peculiar and distinctive odour. Many of the spores also fall on the ground, and infection of young tubers results from spores washed down to them through the soil ; earthing up the crop when disease is noticed acts as a palliative. When foliage is diseased there is grave risk of infection to tubers during digging operations. It is not noticed, but tubers actually receive infection while harvesting, and they afterwards go bad during storage. This may be largely avoided by removing the diseased foliage a few weeks before the crop is dug. Tubers which have been infected show in the earlier phases a brownish colour through the skin, and ultimately they are destroyed. Tainted potatoes may be used for feeding, but should *never* be planted, as this is certain to reproduce a diseased crop. Some varieties of potato are more susceptible to blight than others, and especially when they are debilitated (Chap. XXXV.) by virus disease.

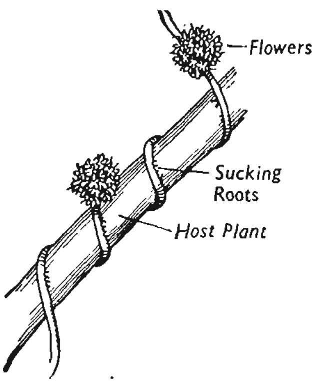


Fig. 138.—Dodder.

Spraying for fungus diseases of different kinds is often done with blue-stone, either alone, or more frequently mixed with lime. The lime renders the copper almost insoluble, so that it does not damage the foliage. "*Bordeaux mixture*" contains blue-stone, lime, and water in certain proportions. Good results have been obtained, especially in Ireland and America, by spraying potatoes with Bordeaux mixture, but its chief action is as a preventive. It is too late to spray a crop which is badly attacked, the fungus being already inside the plant.

The parasites attacking crops are usually fungus parasites. A few examples, however, are found of parasites which are not fungi attacking farm crops. **Dodder** (Fig. 138) is such a one, and it sometimes destroys clover, flax, and hops. There are different species of this parasite. Dodder forms flowers and seeds, and is therefore one of the higher plants. It feeds as a parasite because it has no leaves to build up food for itself.

CHAPTER XLI

THE ANIMAL

THE ordinary farm animals belong to the large group known as **Vertebrata,** or animals with a backbone. Fishes, amphibians, reptiles, birds, and mammals all have a backbone. All of these animals do not suckle their young, but the ordinary farm animals do, and hence they are further classified as **Mammalia.** "*Mamma*" is the Latin word for breast. Again, all of the mammals, such as dogs and mice, are not hoofed animals, but the ordinary farm animals are, and hence mammalia may be further subdivided. "*Ungula*" is the Latin word for hoof, and horses, cattle, sheep, and pigs are members of the order **Ungulata.**

The place of farm stock in the Animal Kingdom may therefore be represented thus :

Sub-kingdom	*Vertebrata.*
Class	*Mammalia.*
Order	*Ungulata.*

A man has five toes or digits. The Ungulata are further subdivided according as the digits in the hind-foot are odd or even in number :

(*a*) *Perissodactyla* (odd-toed) .	Horse.
(*b*) *Artiodactyla* (even-toed) .	Cattle, sheep, pigs.

In farm animals the five digits of man are not developed. In the horse the hind-foot is formed on the third or middle digit or toe, and in cattle (cloven hoof) it is formed on the third and fourth digits.

Some of the *Artiodactyla* chew the cud or ruminate, while others do not. They are therefore further subdivided into :

1. *Non-ruminantia*	Pigs.
2. *Ruminantia*	Cattle, sheep.

In ruminants the stomach is not simple, as in the pig, but comprises four distinct compartments. Ruminants have no incisor or front teeth in the upper jaw.

The **animal body** consists of the *soft parts* and the *skeleton*, which gives it support. The latter consists of bones, which are very rich (Chap. XVII.) in phosphate of lime.

The soft parts of the animal body consist largely of lean meat or **muscle.** A muscle is composed of fibres, and most of the muscles which move the body are swollen in the middle and taper at the ends. When a muscle is excited to contract, it becomes thicker in the middle, so that the two ends are brought nearer together. If one end is fixed (Fig. 139) (*a*), the other end (*p*) will be forced to move. Indeed, it is by repeated contractions of the muscles that limb movements are brought about. Muscles usually terminate in a strong connective tissue (*tendon*) attached to the bone on which the muscle works.

The animal body always contains **fat** as well as muscle, but this is not of a fibrous character, and has no power of contraction.

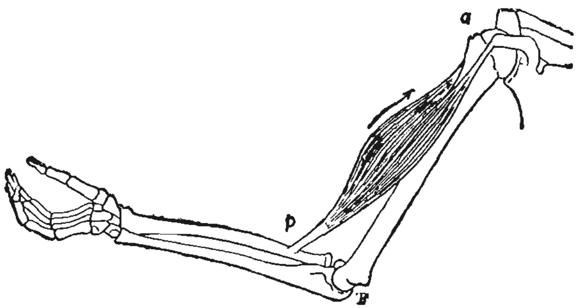


FIG. 139.—Illustrating Movement caused by Muscle.

Fat is rather a form of food or " fuel " for the future use of the working muscles within the body.

Inside the body there are **two** large **cavities**—the anterior cavity being the *thorax* or chest, and the posterior cavity the *abdomen* or belly. These two cavities are separated by a tense sheet of muscle called the *midriff* or diaphragm.

The **chest cavity** contains the *heart*, and on either side of it (Fig. 140) the *lungs* or " lights," which are concerned in respiration. The **lungs** receive air through the *trachea* (windpipe), which, on tracing back through the lungs, divides into numerous tributary branches or *bronchial tubes.* In the aggregate there is an enormous length of those air tubes surrounded by fine blood-vessels, and it is in the lungs that the blood receives fresh supplies of oxygen from the air.

The **blood** consists of a nearly colourless liquid—the *blood* *plasma*—in which are floating the *red* and the *white corpuscles.* Blood therefore contains :

(*a*) The liquid plasma.
(*b*) The corpuscles.

The liquid plasma contains in solution digested food materials obtained from the stomach and intestines. The floating red corpuscles (Fig. 141) are far more numerous than the white and have a special purpose. In form they are round like a penny, and usually appear as rolls of coins, but also occur singly. These

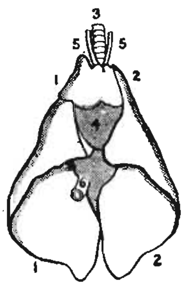


FIG. 140.—Lungs of Sheep.

1, right lung; 2, left lung; 3, windpipe; 4, heart; 5, arteries; 6, vein.

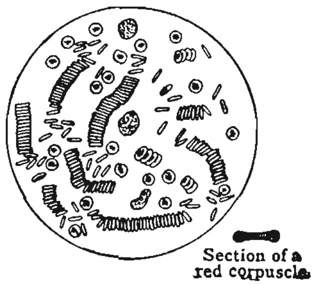


FIG. 141.—Blood under the Microscope, showing numerous red corpuscles, and three white corpuscles down centre of field.

red corpuscles consist of a spongy framework, and contain inside the red colouring matter of blood—*hæmoglobin*. This hæmoglobin easily absorbs oxygen from the air and easily parts with it again. It thus acts as an oxygen-carrier throughout the body, and that is its purpose.

The **heart** by involuntary contractions causes the blood to circulate. There is a right and a left side of the heart, which work together, but independently. From the right side of the heart the blood is forced through the lungs, where it receives fresh oxygen, and thence back to the left side of the heart (Fig. 142). From the left side it is sent all over the body, and back again to the right side of the heart after giving up oxygen to the living organs of the body. There is thus a *short* circulation (through the lungs) and a *longer* circulation which reaches to the extremities. The blood is forced from the heart through the

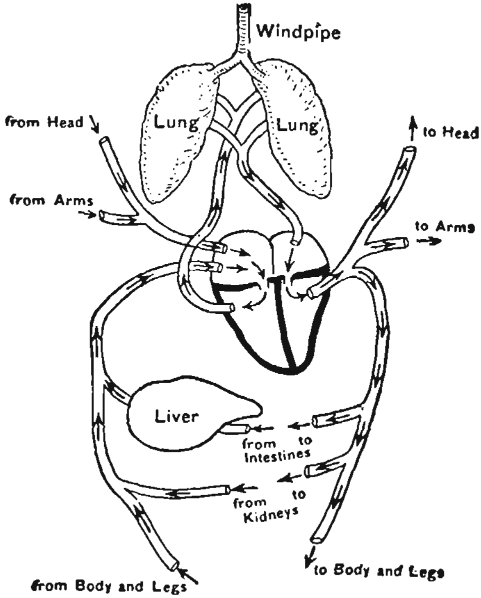


FIG. 142.—Diagram of Circulation of the Blood. (From Front.)

arteries, which are thick-walled tubes, and returns in the **veins,** which do not require to be so strong.

In its passage from the arteries to the veins within the body, the blood travels through very fine-walled vessels termed *capillaries.* Fig. 143 shows the blood passing along the capillaries in a frog's foot. Food materials easily soak or diffuse through the capillary walls, and the living cells (not shown) surrounding the capillaries select what they want. The red corpuscles themselves

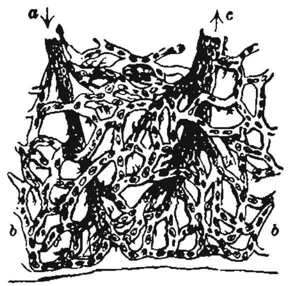


FIG. 143.—Web of Frog's Foot (Magnified).

(*a*) artery; (*b*) capillaries; (*c*) vein.

cannot pass out, but most of their cargoes of oxygen can, and thus the living cells also receive free oxygen from the blood stream.

The **cells** composing the various organs of the body—legs, ears, stomach, etc.—have **independent life.** The body might indeed be compared to a nation which has not only life as a whole, but its individual citizens have independent life. Individual citizens keep getting born and keep dying all the time, and so it is with the individual cells composing the animal body. Individual living things require food, and at the same time they require air (oxygen) to oxidise that food. In this way they develop (Chap. II.) necessary energy. The blood circulates in the body. The different organs have their requirements " delivered at the door." Their food is brought to them in solution in the blood plasma. Their oxygen is carried to them in the red corpuscles which float in the blood plasma.

After the blood has taken up oxygen in the lungs it is of a bright scarlet colour, but after giving up oxygen to the tissues it is much darker in colour.

The blood not only carries food and oxygen to the living parts, but it also brings away their **waste products.** Some of these are separated from the blood by the *kidneys*, and along with water are excreted as urine. The blood also brings back carbon dioxide gas, which results from the respiration going on all over the body, and this gas escapes from the blood into the lungs and is exhaled in breathing.

The **abdominal cavity** contains the stomach and intestines, besides the liver, pancreas, and certain other organs. Consideration will be given to these in connection with the digestion of foods.

CHAPTER XLII

RELATION OF FOOD TO THE ANIMAL

THE animal body is in a constant state of breaking down and building up. The breaking down is a necessary consequence of respiration, and is hastened during fevers, work, exposure to cold and wet, breeding, and milk production. Besides increasing breathing losses, breeding and milk production cause visible loss of animal substance.

The raw materials for the building up of an animal are the foods consumed. Good results in feeding do not, however, depend upon the chemical composition of the foods alone. The animal is not a " tub " into which certain materials have only to be emptied. The physical condition and digestibility of the food, its palatability, its supply of vitamins,[1] and the condition of the animal are all important factors. Chemical analysis cannot tell when a food will succeed.

It can tell, however, when it must fail. We shall go on, therefore, to examine the general composition of farm animals and the materials which are necessary to build them up.

Table XXII. gives the percentage **composition of animals** as determined at Rothamsted. The contents of stomach and intestines are not included in the table.

TABLE XXII

Composition of Whole Bodies of Animals (per Cent.)

	Store Sheep.	Fat Sheep.	Fat Ox.	Fat Pig.
Water . . .	61·0	46·1	48·4	43·0
Fats, etc. . .	19·9	37·9	32·0	43·9
Proteins, etc. . .	15·8	13·0	15·4	11·4
Ash . . .	3·3	3·0	4·2	1·7

There is most **water** in young animals. Looking to the sheep it will be observed that there is considerably less in fat stock than in similar animals in store condition. Fat animals are thus " drier " than stores, and gain of weight during fattening is made in spite of a relative loss of water.

Fats, etc., naturally form a greater part of the weight in fat animals. Such fats are always *mixtures* of different pure fats —principally stearin, palmitin, and olein. Stearin is a hard fat at ordinary temperatures, and olein is a liquid fat, and the hard-

[1] Vitamins of several kinds occur in most foods in *quite small* amounts, and are essential to growth and well-being. They cannot ordinarily be detected by analysis, but their presence or absence in a food may be ascertained by physiological tests in which an animal is fed on that food for a sufficient length of time to observe its effects upon health and growth. It appears that the rough stock foods of the farm are less likely to be lacking in necessary vitamins than the often refined and artificially prepared materials of human consumption.

ness of fat from different animals depends upon the proportion of stearin and olein in the mixture. Lard from pigs contains more olein than does beef or mutton suet. When all such fats are boiled with soda they are converted into *soaps*. Fats, of course, are insoluble in water, but they dissolve readily in ether and some other liquids. They are compounds of carbon, hydrogen, and oxygen. They do **not contain** nitrogen.

Proteins, etc.—The *proteins* proper form the actual substance of muscle and nerve, and are thus the principal constituent of lean meat. The *gelatinoids* which form the combustible part of bones, tendons, etc., and the *horny matter* of hoofs, hair, wool, etc., are somewhat closely related to the proteins, and are included in this group. These substances **all contain** about 16 per cent. of nitrogen, in addition to the carbon, hydrogen, and oxygen present in fats.

Ash.—About four-fifths of the total mineral matter or ash is found in the bones, which, as we have seen, are rich in phosphate of lime. Potash always occurs in connection with muscle. The red colouring matter of blood (hæmoglobin) contains a little iron.

The animal body is continually getting worn down, and must be **renewed** from fresh materials. *Carnivorous* animals obtain their supplies by devouring the bodies of other animals, while *herbivorous* animals seek their food among plants.

The animal body is built up of four main substances or groups of allied substances. **Plants contain** the same four groups, but have in addition the carbohydrates as present in starch and sugar, thus :

The Animal.	←	**The Plant.**
Water	————	Water.
Fats, etc.	————	Fats, etc.
	————	Carbohydrates.
Proteins, etc.	————	Proteins, etc.
Ash	————	Ash.

The lines indicate which constituents in the food may form which constituent in the animal body. The matter is simple when we reflect that proteins only and always contain nitrogen.

Water.—The amount of water varies in different foods. Details will be considered in the next chapter. With succulent forage and root crops there is sometimes more water than the animal is the better of; with dry foods like hay, the deficiency can be made good by supplying water to drink.

Fats, etc.—Plant fats closely resemble animal fats, and are easily changed to animal fats in the system. Fats contain carbon, hydrogen, and only a little oxygen. Fats will burn at a wick, and the animal can burn them slowly in the process of respiration (Chap. II.). In this way its animal heat is maintained. When more fat is eaten than is being destroyed in respiration, then the excess can be stored up as animal fat for use at a future date.

Carbohydrates.—These contain carbon plus the elements of water, *i.e.*, hydrogen and oxygen. Like fats, they contain no nitrogen. The principal carbohydrates are sugars, starch, and cellulose. These have nearly the same composition, but differ in the amount of work required to digest them.

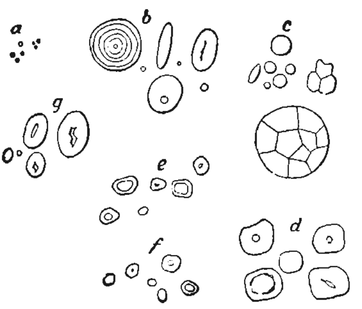


FIG. 144.—Form of Starch Grains in—(*a*) carrot; (*b*) wheat; (*c*) oats; (*d*) maize; (*e*) millet; (*f*) buckwheat; (*g*) bean. (×450; *g* ×300.) (After J. Kühn.)

Sugars.—These are soluble. The principal sugars are cane sugar ($C_{12}H_{22}O_{11}$) as in beet, sugar cane, and grasses. Glucose or grape sugar ($C_6H_{12}O_6$) is also widely distributed.

Starch ($C_6H_{10}O_5$) is insoluble, but can be readily changed into sugar by certain ferments. Malt contains a ferment called *diastase*, which readily converts starch into sugar. Starch occurs as little grains in the plant (Fig. 144), and the origin of the starch can be detected by a microscopic examination. In hot water the starch grains swell up and form a paste.

Cellulose forms the cells walls (Fig. 63), or skeleton of the plant. It occurs nearly pure in cotton wool. By long boiling with dilute acids, or by certain ferments, it also is changed into sugar, as was starch, but with cellulose the change is a more difficult one.

When carbohydrates are fully oxidised then carbon dioxide and water are produced. The same is true for the fats. But carbohydrates already contain a good deal more oxygen to begin with, so that in burning they require less oxygen to complete their oxidation than does an equal weight of fat. Less heat is given out from burning them (p. 250). About **2·3 lbs.** of carbohydrate matter are required to produce as much heat by burning as is produced by burning 1 lb. of fat. In feeding experiments with animals it has also been shown that 2·3 lbs. of starch are required to replace 1 lb. of fat in a maintenance ration, so that while the carbohydrates perform the same sort of service to the animal as do fats, they are not such a concentrated fuel.

If carbohydrates are consumed in excess of immediate requirements to sustain respiration, the animal can store the surplus up by converting it into fat. It is a matter of experience that pigs will fatten on barley meal which contains much starch but very little fat indeed.

Proteins, etc., include substances like the gluten of wheat. They are found in largest amount in ripe seeds, but are present all over the plant. Proteins contain not only carbon, hydrogen, and oxygen, but also **nitrogen.** It is useful to remember that they contain about **16 per cent.** of nitrogen.

Proteins are necessary to the animal to repair the wear and tear of muscular tissue. Fats and carbohydrates cannot do this. If fed in excess of " wear and tear " requirements, proteins may be oxidised as fuel to maintain the animal heat, or they may be converted into animal fat. When this occurs their nitrogen is dispensed with. Proteins can do anything in support of the animal (except supply ash), but they are not economical for those purposes where the same object can be attained by fat or starch. Proteins are sometimes referred to as " albuminoids "—thereby meaning the same thing.

Ash.—Cereal grains by themselves are very deficient in lime, but a mixed ration will usually supply sufficient mineral matter to meet animal requirements. In some cases " licks " supplying phosphate of lime are used with advantage, but this would never occur with stock grazing on good land. A little common salt (sodium chloride) will often improve the palatability of food and assist its digestion.

CHAPTER XLIII

COMPOSITION OF FOODS

IT is seldom that foods contain only one ingredient. Sugar, it is true, contains only one, but all of the ordinary foodstuffs contain a mixture of different *nutrients*. These are the proteins, fats, and other substances of which they are built up.

The principles underlying an ordinary **food analysis** are quite simple. The *water* is determined by weighing a small sample, drying it at steam heat, and weighing again ; loss between the two weighings is water, and may be calculated to a percentage. Similarly, the percentage of *ash* may be found by weighing the residue left after burning. The *crude fat* is that part of the food which can be dissolved out by ether. As *proteins* contain usually 16 per cent. of nitrogen, the percentage of nitrogen is found by analysis and then multiplied by $\frac{100}{16}$, or 6·25, to get the percentage of crude protein. *Crude fibre*, or woody fibre, is what remains undissolved in the food after successive boiling with dilute acid and dilute alkali—such material is more or less indigestible. Finally, when the sum of percentages of the above five groups is deducted from 100, the difference found gives the percentage of *carbohydrates*.

Table XXIII. gives the average **composition of some foods,** and will be useful for reference. Different samples of the same food are liable to vary, and, for practical purposes, the figures should be taken only as approximations. Such variations from the average are least in vital parts such as the seeds and grains. The vegetative parts of crops, such as hay, pasture, and roots, are liable to vary within rather wide limits, and this applies also to the by-products from manufacturing processes. Too close attention should not be paid to water-content in the foods tabulated, because in any of them the moisture is liable to fluctuate slightly, even from day to day.

Linseed cake is obtained by crushing the seed of the flax plant (linseed) in order to obtain linseed oil. The cake is the residue left after crushing. A percentage of oil remains in the cake. It is necessary to distinguish between " ground linseed " (whole seed) and " ground linseed cake," the former being much richer in oil. Other *oil cakes* are obtained by crushing other seeds or products for oil, such as cotton-seed cake, palm-kernel cake, coconut cake, soya-bean cake, and others. These are all specially rich in protein in addition to the oil which is left in them after pressing.

TABLE XXIII

Average Composition of Foods (per Cent.)

	Water.	Crude Protein.	Crude Fat.	Carbo-hydrates.	Crude Fibre.	Ash.
Linseed . .	7·1	24·2	36·5	22·9	5·5	3·8
Linseed cake .	11·2	29·5	9·5	35·5	9·1	5·2
Wheat (grain) .	13·4	12·1	1·9	69·0	1·9	1·7
Oats ,, .	13·3	10·3	4·8	58·2	10·3	3·1
Barley ,, .	14·9	10·0	1·5	66·5	4·5	2·6
Maize ,, .	13·0	9·9	4·4	69·2	2·2	1·3
Beans ,, .	14·3	25·4	1·5	48·5	7·1	3·2
Wheat flour .	13·2	10·3	1·4	74·2	0·3	0·6
,, bran .	13·0	14·7	4·0	52·1	10·3	5·9
Oatmeal . .	7·9	14·7	7·1	67·4	0·9	2·0
Malt coombs .	10·0	24·4	2·0	42·4	14·0	7·2
Brewers' grains (fresh) . .	67·6	7·5	2·8	14·6	6·1	1·4
Oat straw . .	14·0	2·9	1·9	42·4	33·9	4·9
Pea ,, . .	13·6	9·0	1·6	33·7	35·5	6·6
Clover hay . .	16·5	13·5	2·9	37·1	24·0	6·0
Meadow hay .	14·3	9·7	2·5	41·0	26·3	6·2
Clover (green) .	81·0	3·4	0·7	8·1	5·2	1·6
Rye-grass (green) .	75·2	2·9	0·7	11·5	7·1	2·6
Grass silage .	68·0	3·8	2·7	12·9	9·9	2·7
Potatoes . .	76·2	2·1	0·1	19·7	0·9	1·0
Turnips . .	91·5	1·0	0·2	5·7	0·9	0·7
Mangolds . .	88·0	1·0	0·1	9·4	0·7	0·8
Sugar beet . .	76·6	1·1	0·1	20·4	1·1	0·7
Carrots . .	87·0	1·2	0·2	9·3	1·4	0·9

The chief feature of the **cereal grains** is their high content of carbohydrate—chiefly starch. Owing to their husks, oats and barley have more crude fibre than the others. They all contain from 9 to 12 per cent. of protein. It has to be noted that oats and maize are distinctly richer in fats than the other cereals.

The seeds of **beans** and **peas** (pulses) are much alike. These are twice as rich in protein as the cereal grains—a fact probably connected with their command of atmospheric nitrogen through the generations. Common beans and peas are notably poor in oil or fat. Fat and oil are the same thing, but the latter happens to be melted.

Bran and Middlings.—In milling wheat, about 70 per cent. of the weight is obtained as **flour.** The interior of the grain (Fig. 145) is composed of cells (*d*) rich in starch and with a smaller

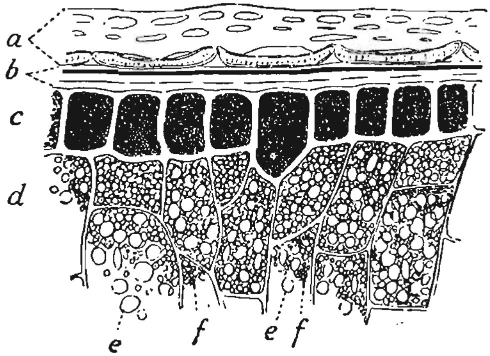


FIG. 145.—Part of Transverse Section of Wheat Grain.

a, pericarp or covering of the fruit; *b*, testa or coat of the seed; *c*, aleurone layer; *d*, central part of the grain, composed of cells chiefly filled with *e*, starch grains, along with some *f*, protein bodies. × 160. (After J. Kühn.)

quantity of gluten, and from this interior the flour is obtained. Bran consists of the outer coverings (*a* and *b*) of the wheat grain, and the rich aleurone layer (*c*), together with some of the starch particles adhering. Middlings contain the finer bran and more flour. In milling, the wheat embryo (Fig. 6), which is rich in protein and oil, is also removed, as it impairs the white colour of the flour. Bran and middlings contain more fat, protein, and ash than the original wheat, and the flour contains less. Bran contains a good deal of fibre, but is largely used for horses and cattle, and has a laxative action.

The husks removed in preparing **oatmeal** have little feeding value. Oats and oatmeal have a valuable percentage of oil which is not present in wheat products.

Malt coombs and **brewers' grains** contain protein derivatives of the kind very suitable for dairy stock. The former must be wetted before use, and fed in moderation. They are barley products.

Straws.—Cereal straws contain from 2 to 4 per cent. of protein, oat being commonly richest and wheat poorest. Straw

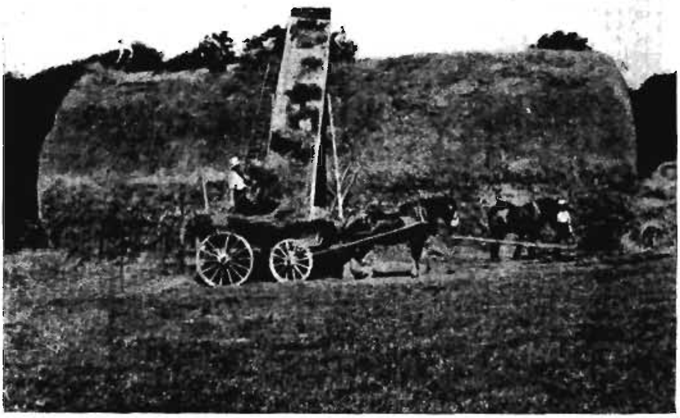


FIG. 146.—Stacking Hay. (Mr Fegan's Homes' Training Farm, Kent.)

is less digestible than hay, which was cut at the proper time, because in straw the more valuable parts had passed into the grain at ripening. Straw of legumes (pea) is much richer in protein than straw of cereals, and in this it resembles their respective grains.

Hays.—Clover hay, as would be expected, is much richer in protein than meadow hay, and when cut early enough has much less woody fibre than the straws. If *haymaking* is well performed in good weather, the hay is almost as good as the green fodder it was made from—the loss of weight in curing being mostly water. From 100 tons of green fodder there is obtained about 30 tons of hay.

Green fodders vary in composition according to the kind of crop. Poor land frequently yields fodder or pasture of low feeding quality—due to mineral deficiency. With increasing age fodder crops become less nitrogenous, while the proportion of carbohydrates increases. With old age all of them become woody and indigestible. For this reason the fresh young growth is the most nutritious.

Ensilage is the process of making *silage* in a *silo*. There is also stack silage. In either case the forage is stored in bulk while it is still green and sappy. Ensilage involves loss of the more soluble carbohydrates and proteins which undergo oxidation, the mass becoming hot. As one would expect, there is less loss when less air is admitted by packing the material firmly down. Some of the products, including acid substances formed during ensilage, stimulate milk production in cows. Stock would do better on the original green material, because the ensilage losses are considerable ; the chief value of the process is that it provides a *succulent* substitute for green fodder or " roots " at a season when none are available.

Potatoes and **roots** are very watery, and are valuable chiefly for their supply of easily digestible carbohydrates. The principal carbohydrate in potatoes is starch ; in turnips, mangolds, and in carrots it is sugar.

For commercial purposes **chemical analysis** can safely be **used** to compare different foods of the *same class*. It should, however, stop there. One reason is that widely dissimilar foods, such as maize corn and wheat straw, differ very much in the degree in which their various constituents are digested. But this matter must be considered in the next chapter.

Chapter XLIV

THE DIGESTION OF FOODS

Foods contain a variety of different ingredients. Some of these, such as sugar, are already soluble, but the great majority of the ingredients of a food are not soluble substances. One object of digestion is to bring the food ingredients into soluble forms so that the animal may be able to absorb them into its system.

Ferments can bring about changes in matter. There are two kinds of ferments. One kind is represented by the cells of the yeast fungus which can produce alcohol from grape sugar, also by the lactic bacteria (Chap. XLIX) which induce the souring of milk. These are **organised** or living **ferments.** The other class of ferments are the **unorganised ferments** or **enzymes.** They are not alive, but their chemical character enables them to act. Unlike the living ferments, the enzymes have no definite shape, and they are usually soluble in water, and they do not multiply as a result of their own activity. They may be produced by living ferments like yeast, but large plants and animals also produce enzymes in great variety. Each of them has a special work which it can perform. The diastase of malt can change starch into sugar, but it cannot act upon proteins or fat. These have their own special enzymes which act upon them, and bring about definite chemical changes. The digestion of food is caused chiefly by special enzymes which are secreted by the animal for this purpose.

The **alimentary canal** comprises all those organs, beginning with the mouth, through which the food travels in its passage within the body. These include the mouth, gullet, stomach, and intestines. Enzymes are secreted by the animal, and passed in succession into the mouth, stomach, and intestines. In the presence of water they act upon the constituents of the food, thereby rendering them soluble so that they can be absorbed into the blood. Without entering into detail the chief facts of digestion may be summarised :—

Organ of Digestion.	Enzyme causing Digestion.	Food Constituent Digested.
Mouth .	Ptyalin (of saliva)	Carbohydrate (starch).
Stomach .	Pepsin (of gastric juice)	Proteins.
Intestines	Amylopsin (of pancreatic juice)	Carbohydrates.
	Trypsin (,, ,,)	Proteins.
	Steapsin (,, ,,)	Fats.

In the intestines, digestion is also aided by *bile* secreted by the liver, also by other digestive juices.

In **ruminant** animals it is so arranged that the food does not immediately arrive in the digesting stomach. Here the stomach is divided into four compartments, and the fourth of these (Fig. 147) alone secretes the gastric juice and has the digesting action of a stomach. The first stomach, or ***rumen***, is a capacious bag and stores the food when first swallowed, thus giving the saliva longer time to act. In " chewing the cud " the food is brought up again and mixed with saliva before finally passing to the fourth stomach. Ruminating animals are thus best equipped for dealing with bulky fodders, and can digest more of their carbohydrates than can the horse or pig.

In digestion the work of enzymes is to some extent helped by **bacteria,** also present in the alimentary canal. Their effect is more particularly exercised upon the crude fibre which is largely present (Table XXIII.) in some foods. In ruminating animals the bacteria are more effective for various reasons, and on this account sheep and cattle can digest very considerably more of the fibre of coarse foods than can the non-ruminating animals of the farm.

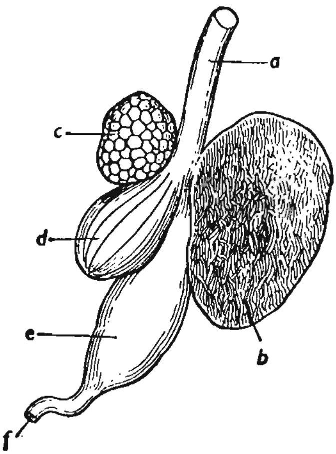


FIG. 147.—Diagram of Ruminant Stomach.

a, gullet; *b*, first stomach (rumen or paunch); *c*, second stomach (reticulum); *d*, third stomach (manyplies); *e*, fourth or true stomach; *f*, beginning of intestines.

During and after digestion the food in the stomach and intestines is mixed up with a large quantity of water. The digested materials pass into solution. From this comparatively weak solution the digested food materials are **absorbed** through the coatings of the stomach and intestines, and finally circulate in the blood stream. Water also passes by *osmosis* (Chap. XXV.) into the blood. If an animal swallowed an excess of salt, then absorption of water into the blood would be impeded or stopped (*cf.* " Soil Alkali " on crops), and it would instinctively desire to drink. To help absorption into the blood the intestines are very long, and in sheep and cattle are about twenty times the length of the whole animal.

After the digested food has entered the blood stream it is carried round in solution in the blood plasma (Chap. XLI.), and is available to **nourish** any of the organs of the body which want it.

Ordinary foods are **never completely digested.** Those parts of the food which are not digested gradually pass along by the movements of the bowels and are excreted in the fæces. The undigested food has not helped to nourish the animal.

In appraising the value of different foods it is desirable to know **how much** of each constituent can be digested. The following method has been adopted by investigators. A weighed quantity of the food is supplied daily to the animal, and after a week the daily weight of fæces also begins to be determined. The experiment continues for another fortnight. During this time the weighed food and weighed fæces continue to be analysed by the same methods, and the amount of each constituent digested can then be calculated out. For example, if the daily food contained 5 lbs. of carbohydrates and the daily fæces contained 2 lbs., then the difference between these figures, viz., 3 lbs., would represent the amount of carbohydrate which had been digested. Three lbs. digested, out of 5 lbs. given, represents a digestibility of 60 per cent. for the carbohydrates in this particular food. Similarly, the quantity digested may be separately ascertained for the protein, fat, and crude fibre of the food, and also reckoned to a percentage of the amount given. The **digestibility coefficient** states the percentage of each constituent in a food which is digestible.

In Table XXIV. are given the digestibility coefficients for representative members of each class of food—the composition of which was given on Table XXIII. The figures here given were determined for *ruminants*. Sheep and cattle digest considerably more of the fibre, and somewhat more of the carbohydrates in coarse fodders, than does the horse, but they make practically no difference in regard to proteins. On consideration, such a result would be expected, and separate tables of digestibility have to be used for horses and for pigs.

Looking to Table XXIV. it will be noticed that concentrated foods like oil cakes and grain are more thoroughly digested than hay or straw. Roots are digested well. Haymaking does not impair digestibility if the weather were favourable, and haymaking was skilfully conducted. Cooking of stock foods generally lowers the digestibility, particularly of the proteins. The common feeding meals have given better results with pigs when fed dry than when previously cooked. In other cases, *e.g.*, potatoes, cooking may make the food more palatable. Rest after feeding promotes digestion by permitting more copious production of digestive juices. It has been found that an actual excess of food diminishes the percentage digested, but an animal will not digest more than ordinary by half starving it.

TABLE XXIV

Digestibility Coefficients of Representative Foods (Ruminants)

	Crude Protein.	Crude Fat.	Carbo-hydrates.	Crude Fibre.	Total Dry Matter.
Linseed cake	89	89	78	57	79
Oats . .	78	83	76	20	70
Maize . .	76	86	93	58	91
Wheat bran .	79	68	69	22	61
Wheat straw .	11	31	38	52	43
Clover hay .	65	63	70	49	...
Turnips .	90	98	97	100	93

It is the digested part of its food that an animal lives on. From the analysis of a food (Table XXIII.), and the digestibility coefficients (Table XXIV.) of the same food, the **percentage of digestible constituents** in it may be calculated. For purposes of illustration this is done for maize in the following table :—

TABLE XXV

Calculation of the Digestible Constituents of Maize (per Cent.)

	Crude Protein.	Crude Fat.	Carbo-hydrates.	Crude Fibre.	Total Dry Matter.
Total constituents .	9·9	4·4	69·2	2·2	87·0
Digestibility coefficients .	76·0	86·0	93·0	58·0	91·0
Digestible constituents .	7·5	3·8	64·4	1·3	79·2

The figures of the bottom line differ from those in the top. The results show the necessity for taking digestibility into account, especially when comparing such widely different foods as maize and straw.

Starch Equivalent.—The figures for digestible constituents in the last table are certainly useful, but for everyday purposes they are troublesome, in that there are so many items. Percentage of protein, fat, carbohydrate, and fibre are each stated separately. Clearly it would be a convenience if one could indicate the value of a food by a *single figure*, and this is now usually done by calculating its starch equivalent.

The calculation is based on the researches of Kellner with fattening cattle. Taking digestible starch and digestible fibre as being each equal to 1 in producing fat in oxen, he found that fat was 2·3 times better, and protein only 0·94 times as good. Applying those factors to the percentage of *digestible* nutrients in maize (Table XXV.) we get :—

Crude protein . . .	$7{\cdot}5 \times 0{\cdot}94$	= 7·1
Crude fat	$3{\cdot}8 \times 2{\cdot}3$	= 8·8
Carbohydrates . . .	$64{\cdot}4 \times 1$	= 64·4
Crude fibre	$1{\cdot}3 \times 1$	= 1·3
Total . . .		81·6

The corresponding value may be calculated for other foods in the same way. Kellner found, however, that a deduction must always be made on account of the **work involved in digesting** the food. This work increases with the amount of crude fibre in the fodder. In maize (Table XXIII.) there is little fibre, and therefore to find the starch equivalent in this case little deduction is necessary—only about 2 per cent. The starch equivalent for maize is therefore $81{\cdot}6 \times \frac{98}{100}$, or 80. Starch equivalents for some other foods are given in Table XXVI. Such figures for the common feeding-stuffs are officially published each month in *The Journal of the Ministry of Agriculture*, along with the current prices, to assist farmers in judging how their purchased food requirements can be most cheaply met.

The starch equivalent of a food represents the number of lbs. of starch which would be required to produce as much **fat** as 100 lbs. of the food will produce. Properly speaking, it should be applied only to the *extra* food given to animals when they are placed aside to fatten, but in practice it is widely used in feeding all classes of live stock. But a clearer view of this subject will be gained in later chapters.

TABLE XXVI

Starch Equivalents and Nutritive Ratios

	Starch Equivalent.	Nutritive Ratio. 1 :		Starch Equivalent.	Nutritive Ratio. 1 :
Linseed cake	74	2·0	Oat straw	20	39
Cotton cake (dec.)	68	1·2	Barley straw	23	52
Oats	60	7·0	Meadow hay	37	8
Maize	80	9·9	Silage	13	9
Beans	66	2·5	Pasture	12	4
Wheat bran	43	4·0	Potatoes	18	16
„ middlings	70	4·5	Mangolds	7	13

Arising out of Table XXV. another useful figure may be calculated. It is not enough to know only the total available nutriment of a fodder in terms of starch, because a certain quantity of proteins is required in feeding for any purpose. In practice, it is thus necessary to regard another figure besides that for starch equivalent. This has reference to the nutritive ratio.

Nutritive Ratio, or albuminoid ratio, is the ratio of the *digestible* proteins to the *digestible* non-proteins in a food. To work this out, the fat is multiplied by 2·3, then added to the carbohydrates and the fibre, and their sum divided by the percentage of proteins. Referring to Table XXV. for the figures we calculate for maize :

$$\frac{3{\cdot}8 \times 2{\cdot}3 + 64{\cdot}4 + 1{\cdot}3}{7{\cdot}5} = \frac{74{\cdot}5}{7{\cdot}5} = 9{\cdot}9.$$

The ratio of digestible protein to digestible non-protein is therefore as 1 : 9·9. This is rather a " wide " ratio. Data for some other feeding materials similarly calculated are stated for illustration in Table XXVI. There it will be seen that oil cakes and beans show very *narrow* ratios, while on the contrary cereal straws and potatoes show very *wide* ratios indeed. If potatoes and straw were fed to animals it would be necessary to mix with them some feeding stuff showing a narrow ratio in order to increase the protein content of the mixture. A ratio of about 1 : 8 is commonly required.[1]

CHAPTER XLV

FEEDING FOR MAINTENANCE

AN animal requires food to keep it living. If it is doing something useful, such as working or giving milk, or laying on fat, it requires still more food. But it requires food in any case whether it is useful or not. The amount of food required simply to keep an animal alive, so that it neither gains nor loses weight, is called its **maintenance requirement.**

The food required for maintenance is spent in maintaining the animal heat and in moving the internal organs of the body. A dead body soon becomes cold. A living body does not become cold because the animal is constantly developing fresh heat from within. It cannot produce this heat out of nothing. To produce heat it must transform some other kind of energy (Chap. VII.) into heat. This happens during respiration. Respiration is a slow form of burning, and during respiration the chemical energy of the fats and carbohydrates and proteins of the food is converted into heat.

It will be seen, then, that food is necessary to keep an animal alive. The food may be viewed as **fuel.** If the daily allowance of food is not sufficient for this purpose, the animal will lose in weight, because the fats and proteins of its body will then be drawn upon to make good the deficit. If, on the other hand, the

[1] *Protein Equivalent* is another method of expressing the protein content of foods, and like nutritive ratio it also is based upon the amounts digested. Its calculation is a little complicated. "Crude protein" (Chap. XLIII.) equals (N × 6·25). "True protein" equals crude protein *minus* the amides, etc., which also contain nitrogen. "Protein equivalent" is used to indicate the percentage of digestible true protein contained in a food *plus* half the difference between the percentages of digestible crude protein and digestible true protein. Thus for linseed cake the protein equivalent is 24·6, beans 19·7, oats or maize 7·6, meadow hay 4·6, potatoes 0·8, and barley straw 0·7. These will serve as examples. Along with the starch equivalents, figures for the protein equivalents of foods are published monthly in the *Journal*; like nutritive ratio figures (Table XXVI.), they can be used to ensure that mixed rations will supply sufficient digestible protein.

daily allowance of food is in excess of the amount necessarily destroyed by respiration, then the live-weight of the animal will increase. If the daily food exactly balances the daily requirements, then the weight will remain constant.

The value of a fuel depends upon the amount of heat liberated in burning it. In considering the value of foods, this fact should not be forgotten. The heat values of foods can be determined. Heat is required to raise the temperature of water. The unit

[*Photo, G. S. M'Cann.*

FIG. 148.—Horses resting in Stable.

quantity of matter is the 1-lb. weight, and the unit quantity of heat is the heat which is required to raise 1 lb. of cold water 1° F. in temperature. This amount of heat is the British Thermal Unit (B.Th.U.).[1]

The calorific value or **heat value** of foods can be measured by burning 1 lb. of them and finding out how many lbs. of water will be raised 1° in temperature. Determined in this way, starch has a heat value of 7,380 thermal units.

For purposes of comparison, if we assume for starch a heat

[1] The *calorie* equals the heat required to raise 1 grm. of cold water through 1° C. One B.Th.U. equals 252 cals. See also p. 152.

value of 100, then the respective heat values of the chief constituents of foods are nearly as follows :—

Fat	230
Protein	140
Starch	100

It is apparent from the figures that 1 lb. of fat liberates 2·3 times as much heat as does 1 lb. of starch when it is burnt.

From experiments with animals it has been found that the various constituents of a food liberate the same amount of heat during respiration as they would have done in burning—provided, of course, that they had been digested. Certain deductions, it is true, must be made for combustible urea and for certain combustible gases excreted from the live animal, but it is not necessary here to discuss them in detail.[1]

The amount of food required to keep an animal alive so that it will neither gain nor lose in weight represents its maintenance requirement. The ultimate effect of the maintenance diet is to maintain the animal heat.[2] The food digested must therefore have a definite heat value ; for an ox of 1,000 lbs. live weight it must develop something like 44,000 thermal units (lbs. Fahrenheit) per day.

As would be expected, an animal requires **more food** for purposes of maintenance in cold weather. Under such conditions, also, small animals require more food in proportion to their size than do large animals, because small animals expose a greater surface of skin in proportion to their live weight. Sheep in proportion to their weight require considerably more food for maintenance than do horses and cattle, because even when underfed they persist in growing wool.

The main test of a maintenance diet is the heat value of its constituents. Starch and fat produce heat as a result of respiration, and at first sight, therefore, it might appear that an animal could live on starch and fat alone.

[1] From the digested proteins nearly 19 per cent. falls to be deducted from the heat value owing to urea excreted by the kidneys, and about 8 per cent. from starch owing to loss as methane gas. There is a greater loss as gas from cellulose. Real fats suffer no deduction losses of this kind. From the heat value of all fodders a deduction must of course be made in the first place for the undigested portion, *i.e.*, the heat value of the fæces.

[2] Part of the energy of the maintenance diet is necessarily spent in moving the internal organs, but as this work is performed *inside* the body, the energy so spent finally goes to raise the body temperature.

This is not so, however. Respiration is always accompanied by a slow breaking down of the muscular tissue, or protein, of the animal frame. This contains nitrogen. Fats and starch contain no nitrogen. A small quantity of **digestible protein** must therefore be present in the daily ration to repair the waste of muscular tissue, and thus maintain the animal in condition. We can therefore now go further and fully define a maintenance ration. It is one which will enable the animal to develop from it daily the necessary number of thermal units, but part of the heat must be obtained from protein contained in the food. A maintenance diet must not only have a sufficient heat value, but part of this value must be contained in proteins.

Many experiments have been conducted with resting adult animals to discover exactly **how much food** was required to keep them alive at constant body weight, and at a temperature of about 60° F. From these it would appear that for an ox of 1,000 lbs. live-weight there is required daily about 6 lbs. of digestible food (reckoned as starch), and this must include about 0·6 lbs. of digestible protein. These amounts would be furnished by 12 to 14 lbs. of good meadow hay.[1] For animals of 900 or 1,200 lbs. live-weight, the maintenance requirements can be calculated approximately by proportion. Horses require somewhat less, and sheep somewhat more in relation to their weight.

The amounts of food required for maintenance raise an important **point in practice.** It is seldom that a farmer keeps an animal simply to see it living. Animals are kept for profit. They are kept for work, or to lay on fat, or to produce milk. With what part of the food which they consume will they be able to do this? With that part only of the daily ration which is *in excess* of what they require for maintenance.

The food consumed by an animal in profit is used in two ways. Part of it is utilised for maintenance, and this may be debited to the working expenses of the farm. The other part of the food is that which yields a direct return.

There is a limit to the amount of food which an animal *can* digest and assimilate. A **profitable animal** is one which can

[1] Meadow hay is a fibrous material, and owing to the work involved in its digestion (p. 246) it yields very considerably more heat *within* the body than would be estimated from (Table XXVI.) its starch-equivalent figure—starch equivalents being based on fat-producing power (net energy), and not on maintenance value (gross energy), which is a different matter.

utilise daily in some useful way (work, milk, etc.) an amount of food which is largely in excess of its maintenance requirements. A bad animal, on the other hand, may be able to utilise little more food than what it requires for maintenance. Stock of this class can never pay.

An interesting experiment at Missouri with two Jersey cows may be quoted to illustrate this point. The cows were half-sisters, and one had been known as a good milker and one was not. Next year they calved in the same week, and steps were taken to investigate their food consumption. The cows were fed so as to keep each of them at approximately a constant live weight. In the results it was found that the good cow was consuming two and a half times as much food as the poor milker *after* making an equal allowance to each for maintenance. In accordance with this the good cow was also producing two and a half times more milk than the poor one. Indeed it is only the food consumed in excess of maintenance that yields a profit. Ten bad cows may give as much milk as five good ones, but the ten will consume about twice as much food for unremunerative maintenance while they are performing their job.

CHAPTER XLVI

HORSES

THE horse (*Equus*) belongs to the Perissodactyl section of the Ungulata (Chap. XLI.). For industrial purposes horses are usually **classified** into (*a*) draught, (*b*) driving, and (*c*) riding horses. There are various well-defined breeds of each.

Mares carry their young for eleven months, but the time may be longer or shorter by several weeks. At birth the weight of the **foal** is usually about 10 per cent. that of its mother. Foals have a long way to grow, and the first part of life is characterised by a rapid formation of bone and muscle (protein). The materials are supplied in the milk.

The solids of milk are easily digestible for the young animal. Compared with cows' milk, the milk of the mare contains more water and more sugar, and definitely less of the other constituents. Where a foal has to be hand-fed with cows' milk, it is therefore usual to dilute it with water and add a little sugar.

TABLE XXVII

Percentage Composition of Milks

	Water.	Proteins.	Fat.	Sugar, etc.	Ash.
Mares' milk .	90·8	2·0	1·2	5·6	0·4
Cows' milk .	87·1	3·4	3·9	4·8	0·7

Horses are kept **for work.** Work requires the expenditure of energy by the horse, which, in consequence, must receive more food than when it is standing idle.

We have already seen that for maintenance a horse must receive a daily ration which, with digestion, yields about 44,000 heat units (B.Th.U.) for a 1,000-lb. horse. When the horse is at work, the daily ration must supply more energy than this.

Work can be measured. The *unit of work* is that done in lifting a 1-lb. weight vertically against gravity to a height of 1 ft. The unit of work is called a **foot-pound.** Ten lbs. lifted through 1 ft. equals 10 ft.-lbs., and 1 lb. lifted through 10 ft. also represents 10 ft.-lbs. of work. Twenty lbs. lifted through 30 ft. represents 600 ft.-lbs. Work, of course, may also be done horizontally, and a horse pulling a load over 60 ft. of road with a draught on the traces equal to a weight of 100 lbs. does $60 \times 100 = 6{,}000$ ft.-lbs. of work.

James Watt estimated the **rate of work** of a horse at 33,000 ft.-lbs. per min., and this value is employed in determining the working capacity of an engine, which is then described as being of so many **horse-power.** In practice, a draught horse does not work so hard as Watt's estimate over long periods, and 22,000 ft.-lbs. per min. is a good achievement at steady work. Calculating on eight hours' work at 22,000 ft.-lbs. per min., the actual day's work of a draught horse is equal to 10,560,000 ft.-lbs.

Energy (Chap. VII.) is defined as the "*capacity for doing work.*" Heat is a form of energy. The maximum amount of work which might be performed by the expenditure of 1 unit of heat is 778 ft.-lbs. This is the **mechanical equivalent of heat** in English units.

A good day's work for a horse was seen to equal 10,560,000 ft.-lbs. If 778 ft.-lbs. are the equivalent of 1 heat unit, then $10{,}560{,}000 \div 778$, or 13,573 heat units, should be a sufficient working *addition* to the maintenance ration which the horse would have required anyhow while at rest. The oxidation of 1 lb. of starch (Chap. XLV.) provides 7,380 heat units, and therefore about 13,573 ÷ 7,380, or 1·84 lbs. of starch (given in addition to maintenance) should provide all the energy necessary for a good day's work.

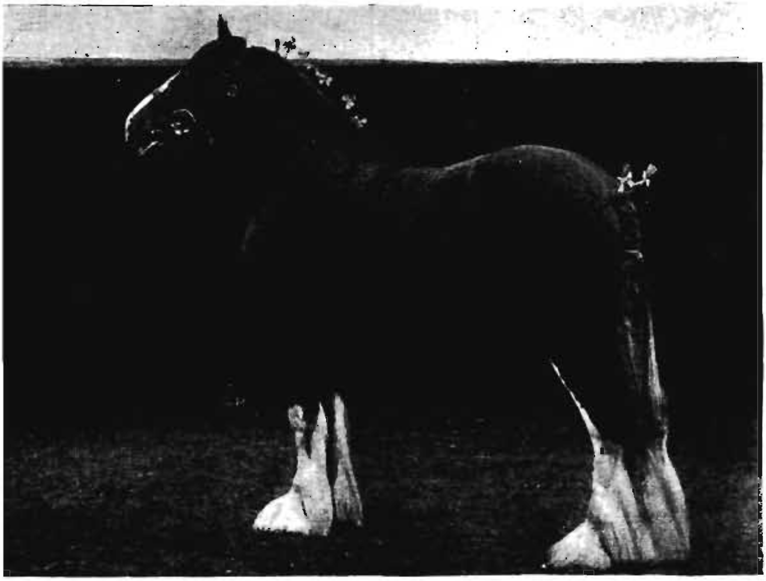


FIG. 149.—Clydesdale Colt. (High. and Agric. Soc.)

It cannot do so, however. It is easy to convert mechanical energy wholly into heat as by friction, but in practice it is **impossible** to convert all the heat back into mechanical energy. There are leakages. A good steam engine cannot convert into mechanical energy more than 14 per cent. of the heat obtained by burning the coal. An animal can do much better with the energy of its assimilated food, and a net efficiency of 33 per cent. is calculated for slow work. The balance of energy is chiefly spent in raising the body temperature, and in evaporating a considerable excess of moisture from the skin.

Much more **energy is dissipated** uselessly in this way when the work is quickly performed. At rest, a horse evaporated from his body 6·4 lbs. of water per day; at work, walking, 12·7 lbs. water; and at work, trotting, 20·6 lbs. In accordance with this, a horse walking 12½ miles per day was kept in condition by 19·4 lbs. of hay, but 24 lbs. was insufficient when the same distance was covered daily at a trot. Work is always performed at greater expense of energy when the animals are unduly hurried.

A horse cannot work satisfactorily on grass or hay alone; it requires some corn or other concentrated food in addition. As we have seen, the value of a food depends on:

1. Its percentage composition.
2. The digestibility of its constituents.
3. The energy required to digest it.

Reference was made to the third in connection with starch equivalents, and also with maintenance requirements. It is also important in the feeding of horses at work.

Some foods require so much of their own energy to digest themselves that little surplus is left to enable the horse to do external work.

The following table, which is calculated from the work of Zuntz on the horse, shows how much of the energy originally present in the digested portion of typical foods was found to be consumed in digesting those foods. The results are stated as percentages of the total energy.

TABLE XXVIII

Percentage of the Value of Foods consumed for their own Digestion

	Used for Digestion Work.		Used for Digestion Work.
	Per Cent.		Per Cent.
Maize . . .	10·4	Lucerne hay . .	48·3
Beans . . .	15·4	Meadow-hay . .	53·5
Linseed cake . .	18·1	Wheat straw . .	164·1
Oats . . .	20·2	Potatoes . .	11·9

The energy cost of digesting foods is very considerable, but it is much greater with fibrous foods than with concentrated foods which contain little fibre. The fibre in various foods was stated in Table XXIII.

The great cost of digesting the long or fibrous foods has a direct **practical bearing.** The wheat straw used (Table XXVIII.) was of poor quality, and a horse restricted to it would ultimately die. But the lucerne or meadow hay could keep an animal living, because they easily contained more than enough energy for their own digestion. It is probably necessary that they should contain at least one-third more. Such hay foods are economical foods where the object is simply to keep the horse alive (*i.e.*, maintenance), because while so much work must be performed to digest and break them down, still this work is done inside the body, and the energy so spent, therefore, ultimately goes to keep up the animal heat. When the horse is put to work, however, the hay must be supplemented by some *cheaply digestible* foods which leave a large surplus of energy after their own digestion is accomplished. The energy already spent in digestion work cannot be used again to pull a plough or a cart. Hay, or hay mixed with good straw, are thus cheap maintenance foods, but they are *not efficient* foods for topping up the maintenance diet when the horse is required to do work. Oats, and more particularly maize, are highly suitable, because they leave a large surplus of energy available for *external* work.

In considering the relative values of different foods for horses at work it is not enough, therefore, to look to the composition and digestibility only, but the cost of digestion must also be considered. Taking everything into account, the following amounts of food are required to supply as much *working* energy to the horse as does 100 lbs. maize :—

TABLE XXIX

Quantities of Foods supplying the Same Energy for External Work

	Lbs.		Lbs.
Maize . . .	100	Lucerne hay . .	256
Linseed cake . .	110	Meadow hay . .	265
Beans . . .	123	Potatoes . .	455
Oats . . .	137	Wheat straw . .	...

It is not suggested that a working horse should be fed on any one of those foods alone. Some coarse feed such as hay or straw is necessary to regulate digestion. What the figures show is the relative values of the foods for *supplementing* a ration of hay and straw when a horse is brought in to do work. As a rule a *mixture* of the best foods would be desirable.

Work does **not** require a **specially nitrogenous** diet, and no reference has been made to the protein content or nutritive ratio of the foods. As a rule the ordinary mixed rations contain sufficient protein, but a diet of very poor hay with maize might be too low in protein. It is usually sufficient to look to the available energy supplied by the foods. Horses put to sudden exertion require a rather more nitrogenous diet than do horses at slow steady work, and consequently maize is less desirable for them than it is for the latter.

Chapter XLVII

CATTLE; SHEEP; PIGS

These animals are kept to supply meat, and hence we go on to consider a few facts bearing on fattening. Cattle are also kept for milk production, and sheep for wool.

Cattle.—Domestic cattle are sprung from the *Bos primigenius*, which was widely distributed in Europe during the Ice Age. In modern cattle distinct varieties have been produced by selection and breeding. Cattle are usually **classed** as (1) dairy breeds, (2) beef breeds, (3) dual-purpose breeds—according to their particular aptitudes.

Young Cattle.—The weight of calves at birth is about one-twelfth that of the cow. The *period of gestation* in cows is about forty weeks. The composition of cows' milk was given in Table XXVII. As a food it is noticeable for a high percentage *of easily digested protein and ash constituents, required* respectively for the formation of muscle and bone. The first milk after calving is called *colostrum*, and it has a necessary laxative action on the calf's stomach. It is specially rich in albumin, and therefore, like white of egg, it coagulates on heating.

In young calves a certain proportion of the daily food is required for maintenance; on the balance of the food the calf increases in weight. Such young animals have the power to digest and assimilate much nourishment in excess of their maintenance wants. On this account they grow fast in proportion to the total food consumed; during the first few weeks a well-fed calf will gain 1 lb. in weight for each 10 lbs. of milk consumed. With growing age an ever-larger proportion of the food which it *can* consume goes for maintenance, and a smaller surplus is consequently left for growth. For older calves, 20 lbs. of milk is required to give 1 lb. increase in live-weight.

Tendency to grow is powerfully present in young animals, and gradually weakens with increasing age. If young stock of any kind is insufficiently nourished during the first few months it becomes dwarfed or stunted, and no amount of suitable feeding in later life will enable it to retrieve a bad start.

With growing cattle the amount of food eaten at two years is greater than in one-year-old cattle. The **daily increase,** however, is less, because with the older cattle a larger proportion of the food which *can* be consumed daily is required for maintenance, and a smaller balance remains for growth. The younger animals thus show a better return for their food. On poor pasture, animals of either age may not be able to obtain more nourishment than is required for maintenance only, and in this case there is no increase. The grazing, consequently, is unproductive. Under such conditions a few lbs. daily of good hay or oats may have a value far above its cost by enabling the owner to reap a benefit from the consumption of herbage which by itself would be used unproductively—simply in keeping the animals alive.

In **fattening cattle** the main object is increase in *live-weight*, which should average about 2 lbs. per day during a period of intensive feeding. To ascertain just how much food is required to produce this increase has been the subject of much research. It has been found that to provide for a 2-lb. daily gain there is required—in addition to current maintenance needs (Chap. XLV.)—about 6 lbs. starch equivalent (Table XXVI.), and including 0·8 lb. digestible protein for average cattle. Young cattle are cheaper to fatten, and may produce 2 lbs. live-increase from 5 lbs. starch equivalent, but require not less protein. On the other hand, older cattle have been found to require over 7 lbs. From the monthly published tables of starch equivalent and protein content, along with the food prices, it has become possible to calculate with tolerable accuracy what—and how much—purchased feeding-stuffs are required to supplement home-grown produce. Some foods, such as cotton cake and beans, when used in considerable amounts, have a constipating action, while too much of roots or linseed cake are laxative, and due care should always be given to regulating the action of the bowels.

Dairy Cattle.—To produce a large supply of rich milk, cows must be well fed. They must, however, be of good milking

FIG. 150.—Shorthorn Bull. (High. and Agric. Soc.)

qualities. No amount of suitable food will change a bad cow into a good milker. It will simply fatten her.

Dairy cows have, of course, the same maintenance requirements as fattening cattle. The food required for milk production must be in addition to this, and it has been found that $2\frac{1}{2}$ lbs. of starch equivalent, including 0·6 lb. of digestible protein, is required to produce 1 gal. of milk. Deficiencies in the home-grown produce may be rectified by purchase of suitable feeding-stuffs as in the case of fattening stock. In the national sense, dairying is economical, and human food is produced about 26 per cent. more cheaply by milk cows than it is by fattening bullocks.

Cows prefer a succulent or sloppy food of fairly laxative character. *Amides* are half-formed proteins, and are largely present in roots, immature herbage, brewers' grains, and silage. Such foods specially stimulate the flow of milk. Nothing excels a young and quickly growing pasture on good land. The diet for cows must be more nitrogenous than is necessary for fattening stock in order to produce the casein (Chap. XLIX.) or curd of milk, which is a protein. It was at one time believed that the fat of milk was formed from protein in the food which was broken down for the purpose, but this is not necessarily the case ; fats and carbohydrates in the food can also be used for the production of milk fat.

The **lactation period** is the period of milking after each calf, and where suitable food is available it usually lasts for about ten months. In town dairies supplying fresh milk, recourse must be had largely to purchased foods, and cows start milking all the year round. In butter and cheese dairies it is so arranged that cows calve before the season of year when the best supply of herbage is just beginning.

Sheep belong to the genus *Ovis*, and are generally grouped into (*a*) Longwools, (*b*) Shortwools, (*c*) Mountain Sheep ; the last-named carry horns. Inside each group there are many well-defined breeds, and an endless variety of crosses between the different pure breeds. The period of gestation in sheep is about twenty-one weeks. Twins are frequent, and a 150 per cent. yield of lambs is not uncommon in a flock of low-country ewes.

Lambs are usually weaned at three to four months. The primary purpose of sheep in this country is **mutton production,** and—except for breeding flocks—they are often fattened for market before reaching their first birthday. Mutton is more economically produced by young sheep. The maintenance requirements of sheep in proportion to live weight is somewhat larger than in cattle, but the principles involved in fattening and the calculation of rations follow on the same lines. Owing to their wool, sheep tend to become infested by ticks and other parasites which they cannot rub off, and it is usual to *dip* them periodically in dilute preparations of arsenical or carbolic poisons in order to destroy the pests.

The production of actual **wool** is no greater under a full diet than on one which simply maintains the condition of the sheep. Indeed a sheep may lose somewhat in live weight without much effect on wool production, but with a starvation diet both yield and quality are seriously impaired. The wool hair (Chap. XLVIII.) is allied to the proteins, and like them has about 16 per cent. of nitrogen. In some foreign breeds, up to 20 per

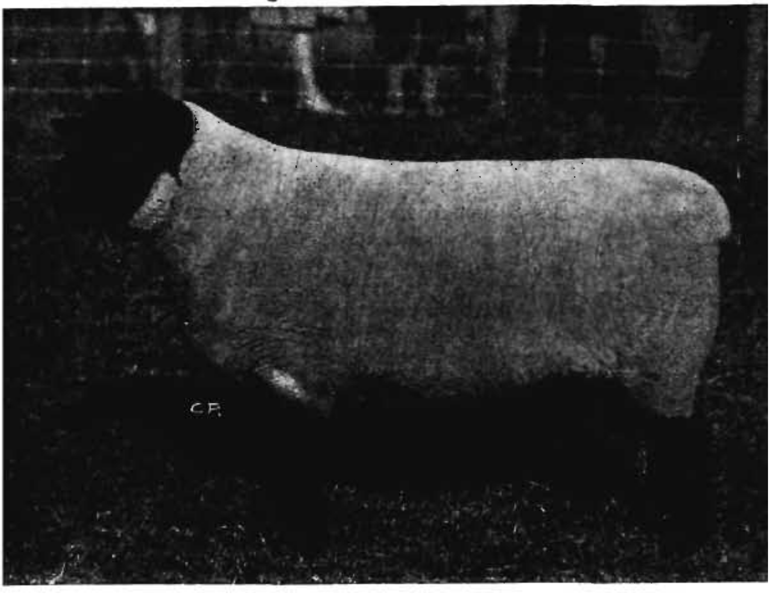


FIG. 151.—Suffolk Ram. (High. and Agric. Soc.)

cent. of the whole nitrogen of the sheep may be present in its wool.

Pigs.—There are a number of pure breeds of pigs (*Sus*), including Black breeds, White breeds, and the Tamworths which have a golden-red colour. Crosses commonly show the mixed colours of the pure breeds.

A sow usually produces from six to twelve at a litter, and these are weaned about eight weeks old. The sow carries her young for sixteen weeks, which—with eight weeks suckling her young—allows of two litters in each year. **Pig-breeding** is most advantageously combined with dairying, as the by-products of the dairy mixed with wheat offals or barley meal form the most effective food. Fat pigs are often sold as porkers weighing about 100 lbs., or as bacon pigs at 200 to 300 lbs. The fashion in these matters varies in different centres of consumption.

Fattening.—Pigs are usually fattened on a mixture selected from such materials as skim milk, whey, barley and maize meals, wheat middlings, fish meal, and boiled potatoes. Feeding standards can be calculated from the published tables. Fish meal has a nutritive ratio of 1 : 0·2, and meat meal 1 : 1, and a little of one of these is useful along with maize or potatoes, which by themselves supply too little protein. A **mixture** of foods is always preferable because of probable *defects in constitution* [1] of the plant proteins in any single foodstuff ; this rather important fact applies to all kinds of farm live-stock as well as in feeding pigs. Pig meals are more effective when not previously cooked. A little milk or whey has a value apart from its heat value (possibly in providing enzymes), and where the supply of dairy products is limited, more total benefit is obtained when it is distributed among a large number of pigs. A little green forage each day is desirable to guard against lack of vitamins. Where several pigs feed together from the trough one gets the impression of rivalry, but it is a mistake to offer more feed than can be cleaned up at each meal. Young pigs, in relation to food eaten, are more economical meat producers than old ones.

As pigs fatten their power to consume food in excess of the maintenance requirement steadily declines. In accordance with this the Rothamsted experimenters found with store pigs that 1 lb. of live-gain was obtained at an expense of 3·86 lbs. of food during the first fortnight of fattening, but that 6·18 lbs. were required during the fifth fortnight. As animals become

[1] Proteins are split up during digestion into about twenty simpler compounds called amino acids, and the animal uses these "*cleavage products*" as the building stones to build up its own proteins. It uses them in definite proportions. But different plant proteins differ in the proportions, and even if to a less degree in the kinds, of amino acids which they yield on digestion. From the animal's point of view some plant proteins yield too little of one kind of cleavage product and too much of another to be economical as a source of protein, and the advantage of mixed herbage and of variety in feeding-stuffs lies in the probability that an amino acid deficiency in one kind of plant protein will be made up by the surplus in another. Carnivorous animals do not require such variety of diet because meat and milk supply cleavage products in just about correct proportions to meet the animal needs. Compare "law of the minimum" (Chap. V.) in plant nutrition.

fatter, therefore, they become less and less profitable to the owner, and yield an ever smaller return in proportion to food consumed.

In fattening all classes of stock, and particularly with pigs which are usually hand-fed, the most profitable results are obtained by **forcing** the feeding. This is of particular practical

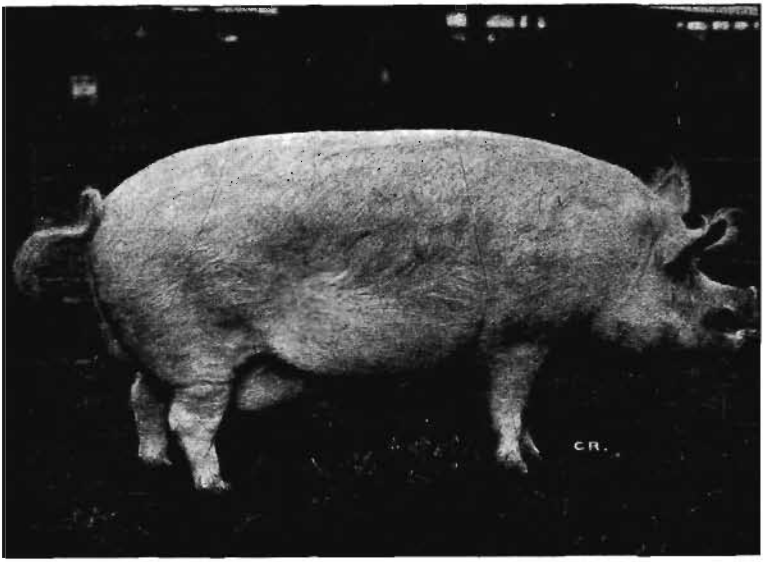


FIG. 152.—Large-white Boar. (High. and Agric. Soc.)

moment with purchased foods. If a pig is brought to 100 lbs. weight in five months instead of seven, there is a clear gain of two months in the food which it would have spent on maintenance.

The maintenance waste is greatest in **cold weather.** Thus in Danish experiments 5·16 lbs. of meal were required to produce 1 lb. live-increase in winter, but in summer, with pigs of similar size and fatness, only 4·57 lbs. of meal were needed. Some such result would be naturally expected.

CHAPTER XLVIII

WOOL AND OTHER FIBRES

ONE chief aim of agriculture is to provide the human race with food. The other is to provide it with **fibres.** Fibres are the raw materials in the manufacture of textile fabrics, and a host of other industries such as cordage and rope, brush and wicker work, matting and paper. With the advance of civilisation the world's demand for fibres is increasing faster than its population. Only a few of the commercial fibres can be referred to in this chapter.

Fibres may be grouped according to their origin as follows :—

I. Vegetable Fibres.—Cotton, Flax, Hemp, Jute, Ramie and China Grass, New Zealand Hemp.

II. Animal Fibres.—Wool (sheep), Mohair (goat), Alpaca (llama), Camel Hair, Silk.

Vegetable fibres have a coarser internal structure than have the animal fibres. They also differ from them in composition, being composed of cellulose ($C_6H_{10}O_5$), while animal fibres are nitrogenous, being allied to the proteins. The animal fibres are relatively heavier, and when sufficiently soaked they sink in water while vegetable fibres tend to float.

Cotton.—The cotton fibre is formed as a *hair* on the *seeds* of certain species of *Gossypium* belonging to the natural order of Mallows. The object of the hair is to act as a protection to the young seeds, and afterwards to help their dispersal by the wind. Wild cotton is a perennial of the tropics but is cultivated as an annual in warm temperate climates, such as the southern States of America, India, and Egypt. When ripe, the cotton fibres are easily detached from the seed by a machine (ginning) ; the seed is then pressed to obtain a valuable oil, and the residue after pressing is used as cotton cake for fattening stock. The cotton fibres usually measure from 1 to 2 in. in length, and when magnified (Fig. 153) appear like deflated cycle tubes. Cultivated varieties have numerous twists or curls, which enable the fibres to lock together when spun into a thread. Fibres like thistle-down have no twist, and consequently have no value for spinning.

Flax consists of the *bast fibres* from the *stem* of the flax plant (*Linum usitatissimum*), and, unlike cotton, is in no way connected with the seed of the plant. The seed of flax (linseed) is usually pressed to get oil and feeding cakes (Chap. XLIII.), but that is another matter. Flax is a crop of cold temperate climates, and can be grown in this country. The fibre is obtained from the stems by steeping in water (retting) for about ten days or until the tissues enclosing the fibres decay, when they can be easily separated by mechanical means. The fibres of flax vary round about 2 ft. in length, and $\frac{1}{1500}$ in. in diameter. The walls are thick and strong, and form projections at the joints (Fig. 154) which enable the fibres to catch hold of each other when spun

FIG. 153.—Short Lengths of Cotton Fibres (Mag.).

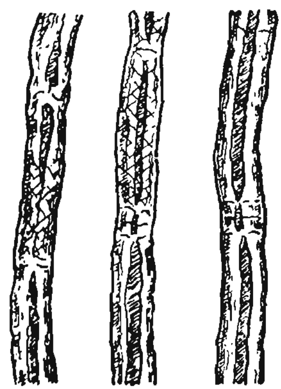


FIG. 154.—Short Lengths of Flax Fibres (Mag.).

into threads. Flax is the strongest of the commercial bast fibres, and is extensively used in making linen cloth, thread, net, and other articles.

Hemp and **jute,** like flax, are the *bast fibres* of plants. The latter is very extensively grown as a fibre crop in India and China. The true hemp plant (*Cannabis sativa*) is largely cultivated in the warmer parts of Europe and in the United States; incidentally, its seeds also are rich in oil. The fibre of some other plants not related to true hemp is also called hemp. **Manila hemp** is got from a species of *Musa* (banana), and New Zealand hemp is obtained from a large-leaved plant (*Phormium tenax*) of the Lily order.

Silk is an animal fibre, and, like these, is nitrogenous. Silk is secreted by the caterpillar or larva of the moth (*Bombyx mori*)—the silk being wound round the body as a wrapping to the future cocoon. When unwound, many cocoons are said to yield 1,500 ft. of silk fibre, which is unequalled for lustre, strength, and flexibility. The fibres (Fig. 155) vary from about $\frac{1}{2000}$ to $\frac{1}{1000}$ in. in diameter. Mulberry leaves are the food of the cultivated silk-worm. The silk is formed from a fluid secreted by the " worm," which passes out at its head and coagulates on contact with the air.

Artificial Silk or Rayon.—Cellulose (p. 235) is very abundant in the plant kingdom, and it is quite insoluble in water. It can,

FIG. 155.—Short Lengths of Silk Fibres (Mag.).

FIG. 156.—Section of Skin (Mag.), showing the Hair Follicles and the Sebaceous Glands.

a, epidermis; *b*, true skin; *c*, hair bulb; *d*, sebaceous glands; *e*, muscle of the hair sheath.

however, be brought into solution by various active chemical reagents. (Wood-pulp is commonly used to supply cellulose for this process.) When such a solution of cellulose is forced through nozzles in fine streams, these coagulate into solid threads —usually by simple contact with the air. Such manufacture of artificial fibres has attained large proportions in recent years, and in 1937 world production was estimated at over 800,000 tons; of this total just under 9 per cent. was made in the United Kingdom.

Wool.—In mammals there are always *hairs* on the skin, and true hairs are never seen in other animals. There are many modifications of hairs, beginning with short, delicate, woolly hair, and ending with the spines of the porcupine. A hair is formed in a little pit or depression in the skin (Fig. 156) called a *hair follicle*, from whence it grows and draws nourishment.

Growth proceeds from below, and the shaft of the hair is pushed out until it has reached the length natural to it. Emptying into the cavity of the hair follicle are the ducts of the *sebaceous glands*, which secrete certain fatty substances to lubricate the hair and keep it soft.

When cut across, a hair is usually found to be cylindrical, but oval shapes are also common. When a length of hair is examined under the microscope, the hair appears as a solid rod covered with irregular-shaped horny **scales.** By their overlapping, those scales (Fig. 157) recall the roofing tiles on a building. They always point towards the tip end of the hair.

In the nature of those scales is found the chief **distinction** between hair and wool. In hair, the overlapping scales are

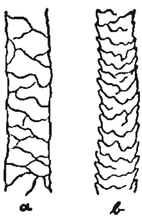


FIG. 157. — Short Lengths of (*a*), hair; (*b*), wool (Mag.).

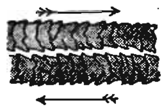


FIG. 158.—Diagram showing Grip of Two Wool Fibres.

FIG. 159.—Kempy Wool Fibre (Mag.)

attached to the under layer right up to the margin of the scale, and thus resemble a roof on which the tiles are fixed down both top and bottom. In wool, on the contrary (Fig. 157 (*b*)), the ends of the scales are free—often to about two-thirds of their length—and are also to a certain extent curved outwards. The scales always lie towards the tip, and after spinning wool, those fibres lying tip to tail **grip** one another firmly. Fig. 158 will indicate how this happens—the result of spinning wool being a strong yarn. Hair cannot be spun into yarns like wool because the fibres do not grip. The felting and matting of wool and woollen fabrics, when wetted and worked up, also depends upon the interlocking of the projecting scales of the wool fibres.

Kemps are hair-like fibres, and are principally found in coarse wools from badly bred sheep, or where exposed to inclement weather. They appear chiefly about the head, tail, and legs. In some cases the kempy character does not extend over the full length of the fibre (Fig. 159), but is found in combination with true wool scales.

Wools from **different breeds** of sheep vary in fineness, and in the number and shape of the surface scales. The long Lincoln and Leicester wools are comparatively thick in the fibre, and possess large flat scales which reflect light well—giving the wools a high lustre. Merino wool, on the other hand, has a fine fibre and small scales with protruding edges, and such wool, although softer, has a duller appearance to the eye. In diameter, fine merino fibre ranges around $\frac{1}{2000}$ of an inch; Southdown, $\frac{1}{1200}$, and in long, lustrous wools, at about double that thickness. The wool of many mountain breeds is still coarser, and is used chiefly in making carpets.

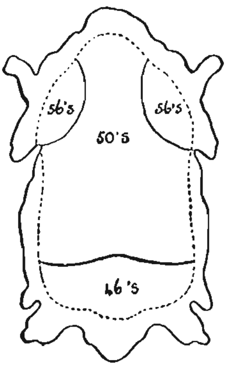


FIG. 160.—Relative Qualities at Different Parts of Cross-bred Fleece. Skirtings outside dotted line.

Apart from breed and natural environment, the wool also varies in character on account of its **position on the fleece.** This is indicated in Fig. 160, where the *count numbers* indicate the relative fineness of the parts.[1] The higher counts represent greater fineness. The wool is finer about the shoulders and neck than from the haunches. Differences due to position on the fleece are greatest in the long and coarse wools. At the wool mills, the different qualities of wool within each fleece require to be *sorted* out prior to their manufacture.

In addition to some moisture and dirt naturally present, an ordinary fleece is made up of **suint, fat,** and pure **wool fibre.** Suint is dried-up sweat excreted by the perspiration glands of the skin, and is rich in potash salts. It is soluble in water, and in this country sheep are often given a short swim a few days before shearing in order to remove the greater part of the suint. The wool, thereafter, fetches a better price per lb., but there is less weight. The fat, secreted by the sebaceous glands, varies from 8 to 30 per cent. of a washed fleece, and is removed later by scouring in soap and mild alkali. Fats are insoluble in water.

[1] The "count number" represents the number of hanks—each of 560 yds.—contained in 1 lb. of yarn spun from that wool.

The various foreign matters removed in washing and scouring are sometimes referred to as "wool yolk," and the amount may vary from 20 up to over 60 per cent. of the raw fleece in some imported wools. Buyers must estimate how much wool fibre the raw wool will "yield" before making their purchases—a task requiring good practical experience.

CHAPTER XLIX

MILK AND ITS PRODUCTS

MILK is not present in the blood of the cow, but is *prepared* from food materials in the blood by the cells of the mammary gland. These glands, together with their coverings, form the udder or milk-bag.

The **composition** of cows' milk may be stated as follows :—

TABLE XXX

Composition of Cows' Milk (per Cent.)

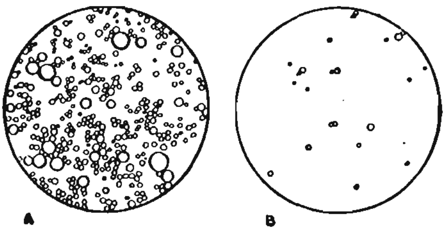
	Average.	Extreme Range.
Water	87·10	83·0 to 90·0
Fat	3·90	0·8 ,, 8·0
Casein	3·00	2·0 ,, 4·5
Albumin	0·40	0·28 ,, 1·5
Milk sugar . . .	4·75	3·0 ,, 6·0
Minor constituents .	0·10	...
Ash	0·75	0·6 to 0·9
Total . .	100·00	...

The extremes in composition are seldom reached, and indeed the composition of cows' milk is tolerably constant. As would be expected, greater uniformity is found in the mixed milks of large herds than in the separate milks of individual cows.

The **water.** Milk contains less water than do turnips or cabbage. Water may be added to milk. In condensed milk part of the water is driven off by evaporation until 1 lb. of milk contains the solids in about 3 lbs. of the original milk. In milk powders the solids of 7 to 8 lbs. of milk are present. Sugar is often added to condensed milk as a preservative, but this is not necessary with milk powders.

The **Fat.** Oil does not dissolve in water, but when vigorously shaken with water it breaks up into little globules forming an *emulsion*. In milk the fat is present, as an emulsion. Fig. 161 (A) shows the appearance in a milk which contained 3·6 per cent. of fat. The globules are variable in size and very small.

Specific Gravity (S.G.) means the *weight* of a substance divided by the *weight* of an equal volume of water. For milk this may be accurately found with the specific gravity bottle (Fig. 162). The bottle (dry) is first weighed empty, then full



A B

FIG. 161.—Fat Globules.

A, in natural milk; *B*, in skim milk. (× 200.)

FIG. 162.—Specific Gravity Bottle.

of pure water, and finally full of the well-mixed milk. The S.G. of the sample may then be calculated out. By convention, the S.G. of milk is always taken at 60° F.

The S.G. of water equals 1, and of whole milk it is usually about 1·032. The S.G. of the actual fat in milk is only 0·93. The fat is thus " lighter " than the rest of the milk, and when left standing the fat globules tend to rise to the surface as *cream*. This may be skimmed off, and the " skim milk " (Fig. 161 (B)) has only a few fat globules left.

In the cream separator, " centrifugal force " is used instead of the force of gravity to take the fat out of milk, because it can be made stronger, and thus acts more quickly. It also gives a more complete separation of the cream. About 80 per cent. of the fat in milk is usually recovered by ordinary cream raising, and 95 per cent. with a good machine.

The **Casein.** This is the chief protein constituent in milk, and in cheese-making it yields the curd. The casein in milk is not quite in solution, but in the modified form of dispersion termed the colloidal state. Compare with colloid clay in Chapter XXVI.

The casein of fresh milk is in union with lime. Acids unite with lime. When *acid*—even weak acid—is added to milk it takes away the lime from the casein, which then cannot remain dispersed in the colloidal form, so it separates out as curd. This effect is seen when fresh milk is poured on stewed fruit which contains free acid. *Rennet*, which is extracted from the stomachs of calves, contains an enzyme which can also coagulate casein, but it does it in a different way ; it splits up the casein itself, and the larger fraction then separates out with lime, forming a curd. Rennet curd, as in milk junket, is thus different from acid curd. Coagulation by rennet is used in cheese-making.

The **Albumin** of milk is somewhat closely related to the casein, but it has points of difference. It is soluble in water; also, it is not coagulated by rennet, nor by weak acids. Eggs contain albumin. When eggs are boiled their albumin coagulates, and when milk is boiled the albumin in it coagulates. This forms the "skin" on boiled milk, and a good many of the fat globules are entangled in this skin. Casein is not coagulated by boiling as is the albumin.

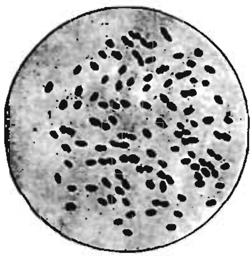


FIG. 163.—*Streptococcus lacticus*. × 800. (Percival.)

The **Milk Sugar** much resembles cane sugar, but it is less soluble than cane sugar and it is not so sweet. The milk sugar is in true solution in the milk.

The presence of this sugar makes it troublesome to *keep milk sweet*. There are certain bacteria which are specially plentiful in the atmosphere of dairies and cow-sheds. These bacteria (Fig. 163) fall into the milk after milking, and break the milk sugar up into *lactic acid* :

Milk sugar and water yield lactic acid.

$$C_{12}H_{22}O_{11} + H_2O = 4C_3H_6O_3.$$

This happens when milk sours. The action will not go on of itself, because the special organisms are required to make it go ; there are several kinds, but the one shown has probably most importance. Lactic acid, because it is soluble, tastes sour. But the sourness cannot be boiled out of milk, because it is not volatile under ordinary atmospheric conditions. When sufficient lactic acid has been produced in souring milk, the acid coagulates the casein (see under " Casein ") and the milk curdles.

The bacteria grow most quickly in warm milk, and therefore milk can be kept longer sweet by cooling it. By heating, in order to first kill the bacteria present and then cooling it afterwards, the milk can be kept still longer sweet. This is done in **Pasteurised** [1] milk.

The **Minor Constituents** include various chemical ferments or enzymes, odoriferous principles, vitamins, colouring matters, and gases. The yellow colouring matters are soluble in fat but not in the skim milk, and for this reason the skim milk is whiter.

The **Ash.** The principal constituents are potash, lime, and phosphoric acid. Dairy farming—more than most systems of farming—imposes a heavy drain upon the mineral resources of the soil, and the loss has to be replaced by the purchase of concentrated fodders for the dairy herd, and by the free use of commercial fertilisers.

Variation in Quality.—In considering quality, attention is chiefly directed to the percentage of fat—partly because the percentages of other things (except the water) tend to move up and down in harmony with it. Of the various factors influencing quality the *individuality* of the particular cow is the most important. Some cows habitually give better milk. Taking *breeds* as a whole, the Jersey gives richer milk than the Shorthorn, and this than the Friesian. Jersey and Guernsey cows produce much of the yellow colouring matter, and on this account their milk appears relatively richer than it really is. The character of the *food* has far less influence on the richness of milk than is popularly supposed, but the condition of the cow may ultimately be affected by insufficient feeding, and then the quality of her milk suffers. At any one milking, the *last-drawn milk* or " strippings " is very much the richest and may even contain over 10 per cent. of fat.

[1] Pasteurisation in England means heating milk to between 145° and 150° F., holding it there for thirty minutes, and then cooling at once to 55° F. or below.

Cleanliness in Dairying.—Milk is an excellent breeding ground for most kinds of bacteria (Chap. L.), and especially when it is warm. Within the cow's udder it is almost free from bacteria, but after milking, it is liable to rapid contamination from the air. At the best this only lowers the keeping qualities of the milk ; at the worst it causes the milk to become an active source

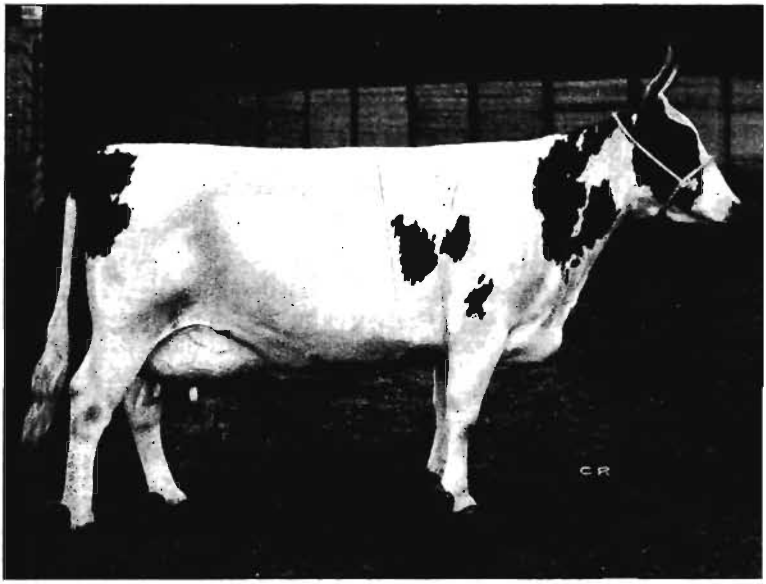


FIG. 164. —Ayrshire Cow. (High. and Agric. Soc.)

of disease infection to persons drinking it. To avoid this, cow-houses, cows, milkers, dairy utensils, everything, must be kept scrupulously clean ; and the milk should be at once removed from cowhouse to dairy, strained, and cooled by running water. Space does not permit a fuller discussion of this important subject. It is said that " cleanliness comes next after godliness " ; someone has pertly suggested that in the dairy it comes before it.

Whole **milk** offered **for sale** has sometimes been tampered with, so by law such milk should come up to a certain standard. Refer for a moment to the average milk of Table XXX. As this milk contains 87·1 per cent. of water, therefore its **total solids** equal 100 minus 87·1, or 12·9 per cent. Again, the **fat** is given as 3·9 per cent., so that the **solids-not-fat** equal 12·9 minus 3·9, or 9 per cent. The legal standard for milk expects it to contain at least 8·5 *per cent.* of solids-not-fat, and 3 *per cent.* of fat (= 11·5 per cent. total solids). In fairness, it was necessary that such a standard should be lower than the figures for average milk, and the reason for this will be apparent. If a sample of milk is in doubt, its *total solids* and its *fat* must be ascertained by analysis. The necessary calculations can be made from those items. Any deficiency of solids-not-fat by comparison with the legal standard (8·5) is used to estimate the percentage of added water; and any deficiency of fat by comparison with the legal standard (3) is used to estimate what percentage of the natural fat had been abstracted.[1]

Herd-testing.—Some cows are much more profitable than others, and it is desirable to identify them. By weighing at regular intervals (of three to four weeks) the day's yield of each cow, and then finding its percentage of butter-fat, the approximate quantity of fat given by each member of a herd during the year can be calculated out. Thus if a cow produces 7,070 lbs. of milk during the year with an average test of 3·96 per cent. fat, then her butter-fat yield for the period equals $\frac{7070 \times 3 \cdot 96}{100}$, or 279·97 lbs. This is about the minimum output for a Class I. cow in Scotland. When it is remembered that good milking qualities are largely hereditary, and also that a farmer naturally wishes to dispose of his worst milkers, the value of herd-testing is at once apparent. The system was first elaborated in Denmark about 1895, and is now practised extensively in this country with great benefit to the industry.

Butter.—Sometimes a liquid can be kept liquid below its freezing point. If perfectly pure water in a very clean glass be cooled down below 32° F. without shaking it, it may remain liquid when it ought to freeze at the low temperature. The water is then in a state of *superfusion*. If some sharp dust particles be thrown in, these will serve as a nucleus, and ice crystals will

[1] Sometimes quality in milk is roughly tested by finding its specific gravity. This test can also be made by quicker methods than by the one already described in this chapter. By itself, the test is useless for purchased milk because abstraction of cream raises the S.G. from perhaps 1·032 to 1·036, while the addition of about 10 per cent. of water will bring it back again.

immediately form.[1] The same effect will be facilitated by shaking the glass of water.

In milk or cream the little fat globules are in a liquid condition, and maintain (Fig. 161) their spherical form. Melted butter fat, however, solidifies at about 77° F., and below that temperature one might expect the fat globules to be solid and irregular in shape. They are, however, in a state of superfusion. During *churning*, the concussion first causes the globules to solidify. Churning cannot bring butter if conducted at a temperature above that at which the cream globules can solidify. That is the first phase. In the second phase of churning, the small solidified globules begin to stick together until they form visible " grains " or little lumps of butter. Unlike the solidification phase, however, this does not proceed well if the temperature be too low. Soft butter sticks together better than does chilled hard butter. In churning, therefore, the temperature must neither be too high nor too low, and is usually arranged somewhere between 55° and 64° F., depending on circumstances. Under ordinary conditions about 94 per cent. of the fat in cream will go into butter, and it is chiefly the smaller globules which escape.

Butter **contains** about 84 per cent. of fat, about 14 per cent. of water, and a little ash (often including salt), and 1 to 2 per cent. of curd. When butter becomes **rancid,** part of the fat is broken up by bacteria. The presence of curd hastens the development of rancidity, because curd (protein) supplies nitrogen, and the bacteria, like other plants, require nitrogen. About 23 lbs. of milk are required to produce 1 lb. of butter. To improve the flavour, cream is usually ripened, *i.e.*, slightly soured by bacteria, before churning.

Cheese.—Butter uses only the fat of the milk ; cheese uses the casein in addition. When the casein has been coagulated by rennet, the curd formed encloses the fat globules as in a net. The residue of the milk—including the milk sugar and albumin —finally drains away as whey. It is usually reckoned that 1 gal. of whole milk (about 10¼ lbs.) will yield 1 lb. of cheese.

Whole cheddar cheese **contains** about 35 per cent. of water, 32 of fat, and 28 of curd. When made from separated milk there is practically no fat present. The ripening of cheese before marketing involves a partial digestion of the curd, and is brought about by **ferments.** The particular course followed by the

[1] Compare dust particles and condensation of water vapour (p. 35).

ripening process depends upon the conditions observed in making the cheese, and upon the temperature and humidity of the store-room.

The **by-products of the dairy** furnish valuable feeding materials. *Separated milk* can be obtained perfectly fresh just after milking (important in calf-rearing), and is equal to the whole milk except that it contains almost no fat. *Skim milk* is closely akin, but it had developed some measure of acidity during cream raising; it also contains more fat—usually over 0·4 per cent. Butter *milk*—got after churning—is liable to contain still more fat (perhaps 1 per cent., or over); and it also has developed lactic acid at the expense of some milk sugar, but the flavour differs from that of sour skim milk. The reason for this difference is obscure. *Whey* is of considerably less value than the others, because it has also lost casein, in addition to most of the fat present in the original mil[k]

CHAPTER L

MICRO-ORGANISMS AND DECAY

"**Micro-organisms**" is a name applied to the smallest living things. These are invisible to the naked eye, and can be seen only when strongly magnified under the microscope. Some micro-organisms have not been seen even through the microscope, but their existence can be inferred.

Micro-organisms include a very large number of species. Their chief representatives are the bacteria. Yeasts and moulds are larger forms of micro-organisms.

Bacteria are present everywhere in air, soil, and water. They are more abundant in the air of inhabited places, and in the atmosphere of Paris their number has been reckoned at 4,000 per cub. yd.

Bacteria are now generally regarded as belonging to the vegetable kingdom. They are plants of one cell. They vary in form, and this fact furnishes one of the means of identification. When spherical, the individual is termed a *coccus*; when slightly longer than broad—a *bacterium*; if still longer—a *bacillus*; and when slightly curved upon itself—a *comma* (Fig. 165). The name "bacterium" is, however, used also in a general sense in allusion to any of those forms. Instead of occurring singly, different forms often occur as a *chain* (Fig. 165 (*e*)), or as a surface, or as a cell mass like a bunch of grapes, and are named accordingly.

Bacteria are very small. Many of them are so small that 20,000 of them placed side by side would be required to cover a line 1 in. in length. It has been estimated that 1,000 millions of them could be packed into a little cube with edges $\frac{1}{25}$ in. long.

There are two **methods of reproduction.** In the commoner method the bacterium simply splits up into two parts, each of which goes on growing until it again splits up. This is reproduction by *fission*. Certain species, but not all, when conditions are adverse, reproduce themselves by means of *spores* formed inside the bacterium. Under suitable conditions these spores develop into full-grown bacteria. Spores are much more difficult to kill by unfavourable conditions than are the bacteria which

FIG. 165.—Some Forms Assumed by Bacteria.
a, coccus ; *b*, bacterium ; *c*, bacillus ; *d*, comma ; *e*, chain of cocci.

produced them. Reproduction is extremely rapid, and it has been calculated that a single individual could give rise to 16 millions in the course of twenty-four hours.

Different bacteria have a different **temperature** at which they grow fastest, and this is generally between 86° and 95° F. In most cases the temperature must not be below 40° nor higher than 112° F., else activity ceases. There are, however, exceptions. As the temperature is gradually raised from the optimum the organisms first slow down, then cease working or become *inhibited*, and are finally killed. Adult forms usually perish between 140° and 158° F., but in most cases where spores are formed a much higher temperature is necessary. Moist heat is more effective than heat in a dry atmosphere. Freezing inhibits, but it does not kill the germs as heat does.

Bacteria vary in the **kind of food** which they require. Some species draw their nourishment from a living plant or animal, and are termed parasites. Forms which feed upon dead and rotting matter are termed saprophytes.

Parasitic bacteria are the cause of numerous infectious diseases such as anthrax, typhoid, tuberculosis, and cholera. A particular kind of bacterium is required to produce a particular kind of disease in the patient. Many parasitic forms are able to live as saprophytes when no living host is available, and thus dirt harbours the cause of infectious disease. Direct sunlight has a weakening and then killing effect upon bacteria, and thus acts as a disinfectant. Therefore it is that darkness, dirt, disease, and death often go hand in hand.

Saprophytic bacteria also play an important part. It is a matter of everyday experience that when organic substances or mixtures such as milk, beer, flesh products or wood are exposed to ordinary atmospheric influences they gradually become unwholesome or useless. The reason for those changes was for long misunderstood. They are now known to be due to the action of bacteria and other low forms of life.

Remembering that bacteria are plants, it will easily be understood how perishable **commodities can be preserved** in various ways. As all plants—including bacteria—require water, it is apparent that dried milk or dried fish can be kept indefinitely. Again, as all plants have a temperature at which they grow quickest—generally between 80° and 90° F.—decay is quicker in warm weather. Then, again, each plant, including bacteria, has a temperature below which it cannot grow, therefore freezing prevents decay. Boiling kills all kinds of plants, and a tin of meat sealed up while hot is free from bacteria and will keep indefinitely; but if a cold tin be opened, live bacteria get in from the air and it soon goes bad.

Other analogies may be referred to. Plants may be poisoned just like animals as by using weed-killers, and antiseptics are things which are harmful to the bacteria, causing decay. Borax, formalin, or carbolic acid are used to prevent decay in foodstuffs or timber respectively—they are germ poisons. Then, again, crops cannot grow in alkali soils where the soil is too salty, because the soil water has too much dissolved matter—it is too strong a solution to pass into the roots by osmosis. It is for this reason that putrefactive bacteria cannot work in meat that has been made too salt for them; and also why jam and preserves keep all right when enough sugar has been used in the making. Lastly, animals or plants can be killed by a powerful electric shock, and it is not surprising that electricity has been applied with success to the preservation of milk in England. Altogether, the many and different methods of preventing putrefaction and decay have just the same immediate object—it is to render the conditions of life unfavourable to the growth of the little plants that cause the damage.

While it is difficult to see that the bacteria causing disease are of any advantage to mankind, the germs of putrefaction and decay are **indispensable.** Organic manures would be of little use unless they decayed in the soil, and indeed the soil would gradually become covered with a deposit of dead plants through which no crop could root. The animals of bygone ages would litter the world.

When plant and animal substances decay, the ultimate products are just those which are required by the green plant. Bacteria thus play an essential part in the **Cycle of Nature,** and by their activity the effete matters of one generation are brought into general circulation for the use of the next.

APPENDIX

DATA FOR CONVERSION OF UNITS

In the preceding pages British weights and measures have been usually employed, and temperatures given on the Fahrenheit scale as being the one in common use. To the student familiar with the Metric system of units and the Centigrade thermometer, a statement of the following relationships may at times be useful :—

Units of Length

1 metre = 39·37079 inches = 1·09363 yards.
1 kilometre = 1,000 metres = 0·62138 miles.
1 inch = 2·53995 centimetres = 0·02540 metres.

Units of Area

1 hectare = 10,000 square metres = 2·47114 acres.
1 square inch = 6·45137 square centimetres = 0·00065 square metres.

Units of Volume

1 litre = 61·02705 cubic inches = 0·22009 gallons.
1 cubic inch = 16·38617 cubic centimetres.

Units of Weight

1 gram = 15·43235 grains = 0·03527 ounces (avoirdupois).
1 kilogram = 1,000 grams = 2·20462 lbs. (avoirdupois).
1 ounce (avoirdupois) = 28·34954 grams.

Cropping Figures

Kilograms pro hectare × 0·892 = lbs. per acre.
Lbs. per acre × 1·121 = kilograms pro hectare.

Thermometric Scales

$$C^\circ = \frac{5(F^\circ - 32)}{9}.$$

$$F^\circ = \frac{9\,C^\circ}{5} + 32.$$

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