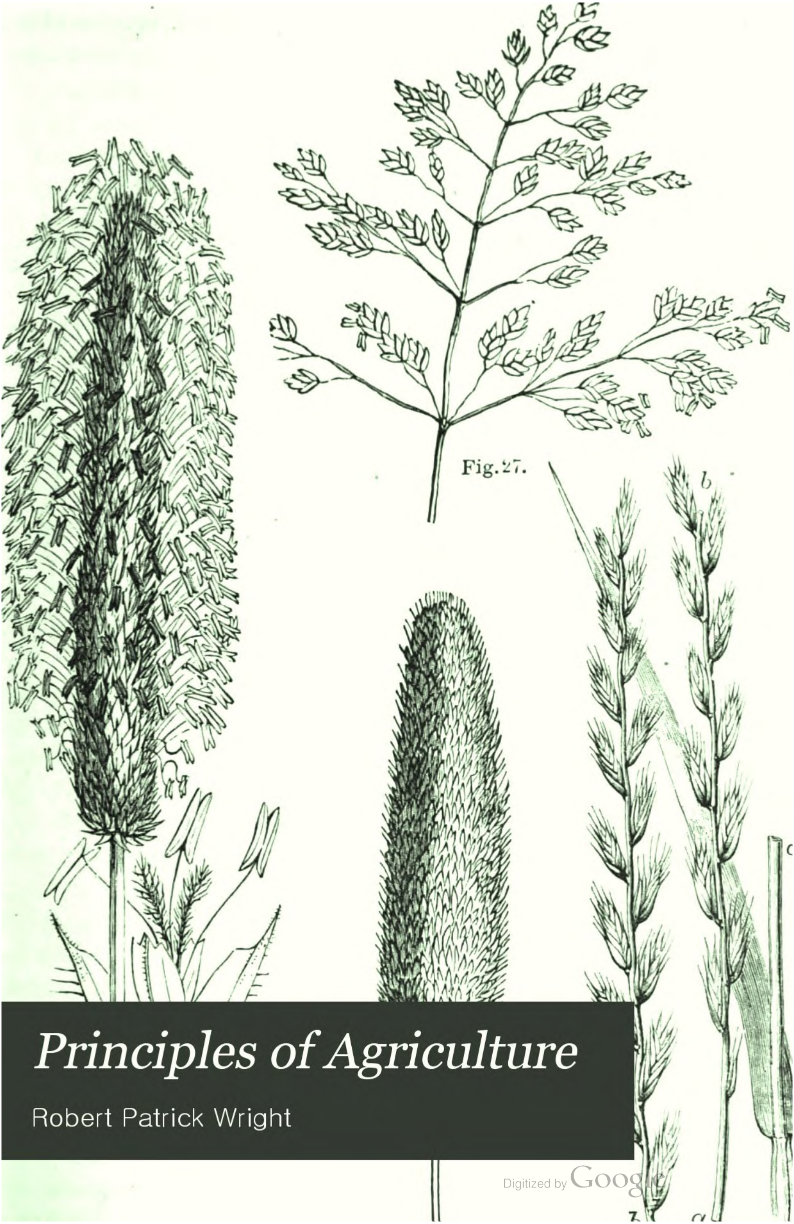

Principles of Agriculture

Robert Patrick Wright

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BLACKIE'S SCIENCE TEXT-BOOKS.

PRINCIPLES

OF

AGRICULTURE.

EDITED BY

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PREFACE TO ORIGINAL EDITION.

This little work is intended as an introduction to the study of the Principles of Agriculture, for the use of pupils in our Elementary Schools. The writer has endeavoured to treat the subject in as simple a manner as possible, without descending to puerility; and to give a straightforward and definite account of the plant and the soil, well within the reach of an ordinarily intelligent boy.

A series of questions is appended to each Division, which the teacher can use or modify at his discretion.

PREFACE TO REVISED EDITION.

At the desire of the Publishers no attempt has been made in this edition to alter the general plan and arrangement of the first three Parts of this book. They have been, however, carefully revised, and changes have been made on the text of nearly every page, while a number of paragraphs have been wholly rewritten. Part IV. is entirely new, and contains such additional matter as seemed best fitted to make the text-book still more helpful to students beginning the study of the science of Agriculture. In preparing it reference has been made to the best text-books on the subjects treated, but special acknowledgment is due to Miss Ormerod's *Manual of Injurious Insects*, and to Smith's *Diseases of Field and Garden Crops.*

A list of questions set by the Science and Art Department at recent examinations has been appended.

October, 1891.

CONTENTS.

PRINCIPLES OF AGRICULTURE.

PART I.

I.—THE PLANT.

Introduction. Agriculture (from the Latin words *ager* = a field, and *colo, cultum* = to till) is the art of cultivating or tilling the land so as to make it produce the greatest quantity of plants useful to man. But plants cannot be produced from nothing; they, like animals, require to be fed, and although in a natural wild state they can get all the food they require from the air and from the soil in which they grow, yet when they are grown in particular places, and in large quantities for the use of man, it is necessary to take great care that they shall be supplied with proper and sufficient food. The principles which regulate the supply of this food to the plant, and the manner in which cultivation is able to assist the plant in obtaining it and using it to the best advantage, will be simply explained in this little book.

Structure of Plants. As the first object of agriculture is to produce and multiply plants, it will be necessary for us first to inquire what plants are composed of, and how they grow. In the first place, it will be seen that all agricultural plants, such as wheat, clover, beans, flax, rye grass, &c., consist of two principal parts: (1) **The Root,** which is pale-coloured, grows downward into the ground, and becomes irregularly branched; and (2) **The Stem** or "top," which is mostly green, grows up into the air, gives off branches in a more regular manner, and bears leaves, flowers, and fruit with seeds. Some plants are grown by the farmer for their **roots,**

as turnips, carrots, and mangolds; others for their **leaves and stems**, as clover and grass; others for their fruit or **seeds**, as wheat and other grains, beans and peas. Farmers thus talk of root crops, forage crops, and grain or cereal crops.

The Root. Some roots are thick and grow straight downwards, giving off small branching fibres, as carrots and parsnips, others are fibrous from the first, as wheat and grass. The uses of the root are to fix the plant in the soil, and to take in nourishment. Roots are sometimes much longer than the stem. The roots of wheat have been known to reach to a depth of seven feet, and maize roots have been traced to a distance of fifteen feet. The ends of the root fibres are fine and delicate, and covered with minute hairs. The food enters the plant through the extremities of the finest rootlets or fibrils, and through the root hairs, and finds its way up into the stem.

The Stem generally grows upward from the ground, or lies on the surface. Sometimes, however, it runs partly underground, as in couch grass and raspberry "suckers." The potato also is a thickened part of an underground stem; the "eyes" are buds. The stem is sometimes hollow, as in wheat, barley, and oats; or may be solid, as in rye, rape, and some clovers. The water and other matters taken in from the soil by the roots pass up through the stem into the leaves.

The Leaves are very important organs connected with the life and growth of the plant. Leaves consist of layers of minute cells spread out to the air, strengthened with ribs or veins made up of bundles of longer and stouter cells and vessels, and covered on both sides with a fine nearly transparent membrane. In these membranes are tiny openings or pores, through which the plant takes in air, and gives out water and gases.

Flowers and Fruit. When a plant is full grown, flowers appear upon its branches. Some plants, as the carrot and turnip, take two years to produce their flowers. The first year the roots grow thick and fleshy, and the tops bear only leaves. The second year the plant "runs to seed," the store of nourishment laid up in the fleshy root is used up in producing a flowering stem with fruit and seed, after which the root will be found stringy and spongy, and of little use for food. All agricultural plants have flowers, though some are small and dull coloured. When the outside of the flower falls off, the middle part grows into fruit, which contains the seed. A grain of wheat or barley is properly a fruit containing one seed; a pea or bean pod is a fruit containing several seeds.

The Seeds. A seed (Fig. 1) contains an **embryo** or young

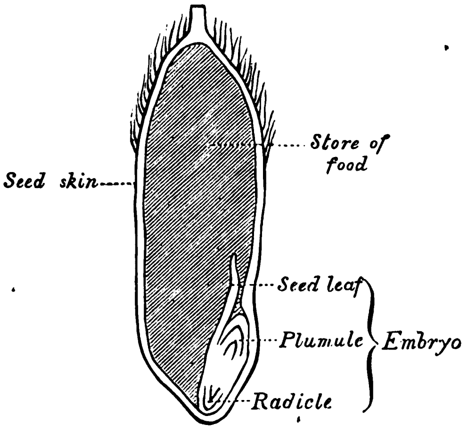


Fig. 1.

plant, and a store of nourishment, consisting usually of starchy matters, oil and albuminoids, to support the young plant until it is able to support itself. The embryo consists of a **plumule** or young bud, from which the stem will grow up into the air; a **radicle** or young root, from which the main root will grow down into the soil, and one or two **seed leaves,** which may hold the store of nourishment, and in some cases push up above the soil and become the first green leaves of the plant.

Growth of Plant from Seed.[1] Three things are necessary to enable a seed to begin to grow—(1) **Moisture,** which

[1] See also Part IV., pp. 145–147.

soaks into the seed, causing it to swell up and burst its hard skin; (2) **Warmth**, of which some seeds need much more than others; and (3) **Air**, from which the seed absorbs oxygen gas. When a seed, therefore, is kept moist and warm in the air it will begin to grow; but as it has to obtain its food from the soil as soon as its store is exhausted, it is sown in the earth at once, care being taken that it can obtain sufficient moisture, warmth, and air. It then becomes swollen, the embryo enlarges, and bursts through the outer skin, the plumule rises up into the air carrying with it the seed leaves, or opening out its young green leaves to the light, while the radicle descends into the soil, giving off minute branching fibres. At the same time chemical changes take place in the seed by which the oil and starch are converted into a kind of sugar. The young plant is nourished by the seed till it begins to absorb water from the soil by its roots, and to feed upon the substances dissolved in that water. The food of plants, unlike that of animals, cannot be taken in a solid form. The plant has no actual mouth; it can only feed by means of its roots and leaves. Therefore all the food which a plant requires must enter it either in the form of a gas, or dissolved in water.

Solution in Water. It is difficult for the young student to realize the fact that solid substances can be dissolved in water without our easily perceiving any difference in the water. Yet we see instances of it every day in the case of such easily soluble substances as sugar and salt. A lump of sugar dropped into a glass of water soon disappears. Still we know it is there, and can prove it by the taste. But a lump of chalk dropped in would not so disappear, because chalk is not very soluble in water. Nevertheless, if there were no chalk already in the water a small quantity would be dissolved off the lump, and would remain in the water without any visible sign of its presence. So most of the water which we drink has chalk, magnesia, iron, and other substances dissolved in it, although it may look clear and bright and sparkling to the eye. All the substances which form the food of plants must be dissolved in water in this clean and complete manner before they can be taken up by the plants.

How Plants feed. Loosen the soil around and under any young plant, and then pull it up carefully by the root. Wash off the soil by shaking it gently in a pan of water. On looking at the root it will be seen to consist of a number of whitish fibres, growing finer and whiter towards the tips. These fibres put under a strong magnifying glass will be seen to be covered with minute delicate hairs, which a microscope will show to be hollow tubes, closed at the ends, and having very thin walls. It is through these hairs, and through the delicate skin near the ends of the root-fibres that the plant sucks in the water in which its food is dissolved. Fig. 2 represents a young seedling mustard plant, which has been pulled up gently, after the two seed leaves were developed. Its root is thickly set with delicate hairs, except just at the tip, which has to push its way down into the soil, and which is therefore covered with a layer of loose scaly cells too small to be represented in the figure. As the roots grow older and thicker they lose their hairs, and the outermost layer becomes hard, and forms a rind, while the taking in of the water containing the dissolved food is carried on by the hairs and cells upon newer fibres, branching out and spreading wider and deeper into the soil. Root-hairs are more abundant on plants growing in poor soils, where there is a difficulty in finding a sufficient supply of plant food. The plant has to make more effort, as it were, to collect its food, than in a good soil, where the materials which it requires are plentiful and close at hand. But if there are no openings in these hairs and fibres, how can the water get in? An easy experiment will show you. Take a small glass funnel (an acid or "thistle" funnel, to be bought at a chemist's for 2*d.*, is suitable), and tie tightly over the mouth of it a piece of bladder, or of very thin india-rubber, such as is used for children's air

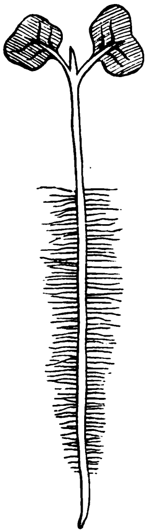


Fig. 2.

balloons (Fig. 3). Now pour in at the small end some strong syrup (sugar and water) or brine (salt and water), and dip the wide end into a basin of clean water. After a time it will be seen that the liquid is rising in the tube of the funnel, and on tasting the water in the basin some sugar or salt will be found to have come out through the membrane. Thus it is shown that fluids separated by a membrane are able to pass through and **diffuse** into one another though there are no holes to be found in the membrane even with the most powerful microscope. Now, a plant is wholly made up of little cells, or chambers, or bags, separated from each other by thin membranous walls, through which liquids are able to pass. In the same way, as shown in the experiment, the liquid or sap in the delicate rootlets and hairs, being thicker than the water outside, draws that water in, and with it, the food dissolved in it. The cells into which the plant food first enters then hold a liquid which is different from that contained in the next cells of the plant. In the same way as before, some of the plant food passes from the cells that first receive it into cells higher up, and from these again into cells higher still. But in the millions of little cells of which the plant is built up, changes are constantly going on, so that the sap is probably seldom quite the same in one cell as in another. In some the sap is thicker and in others thinner, so that there is a continual passage of fluid from cell to cell, by which food is conveyed to all parts of the plant where it is needed.

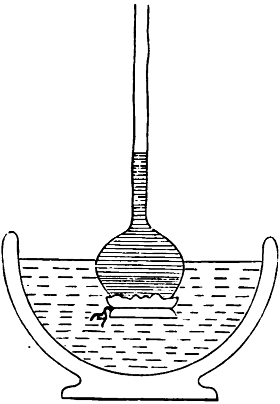


Fig. 3.

The Composition of Plants. It is necessary now to look a little more closely into the composition of plants. In a fresh green plant by far the most abundant substance is **water.** Of fresh meadow grass about 75 per cent is water, while in turnips more than 90 per cent, that is, nine-tenths of the root, consists of water. Thus 100 lbs. of grass when made into hay weighs only about 30 lbs., and when completely dried in an oven weighs only 25 or 26 lbs. This large quantity of water is not stationary in the plant, but is passing rapidly through it from cell to cell until it reaches the leaves, where, being spread out to the air, it rapidly evaporates through the cells and the tiny openings found in the covering membranes. A cabbage has been found to exhale or evaporate more than half a pint of water in six hours, and it has been calculated that an acre of cabbages in the course of twelve hours may give out in this way as much as six tons weight of water.

Organic Compounds.[1] The framework of the plant, of which the walls of the minute cells are made, consists of a substance called **cellulose,** the most familiar form of which we see in paper. Paper, as you know, is made from various vegetable matters—cotton, linen, straw, &c., which consist chiefly of cellulose. So that we may consider the plant to be built up of millions of tiny paper boxes closed on all sides; and the water oozes through the walls of these boxes from one to another, carrying with it the dissolved substances, and leaving them wherever they are required. Another very abundant substance is **starch.** This is, in the form of minute grains, stored up in many of the little boxes or cells, which are often packed full of them (Fig. 4). In the potato tuber, for instance, nearly the whole dry substance is composed of starch granules. Starch can very easily be converted into **sugar,** and in many plants sugar is very plentiful, as in the sweet fruits, in the sap of the sugar-cane and sweet maple, and in the cells of beet-root. When barley is made into malt, a large part of the starch in the seed is turned into sugar, and this gives its sweetness to malt. There are many other substances laid up in the cells of plants, but we need only refer to **oil,** which occurs in many seeds, as linseed, castor-oil, colza, rape, &c.

[1] See also Part IV., pp. 147-151.

All the substances we have mentioned, namely, water, cellulose, starch, sugar, and oil, are found by chemists to be built up of three elements or simple substances—**Carbon, Oxygen,** and **Hydrogen.** Water is oxygen and hydrogen. Cellulose,

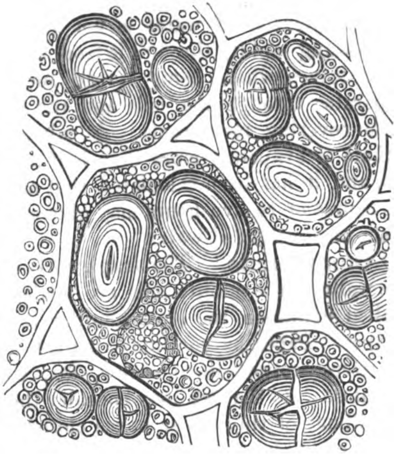


Fig. 4.

starch, sugar, and oil are each composed of carbon, oxygen, and hydrogen. But there are two substances in the plant which must be specially mentioned, because of the important duties they discharge in the plant. Their exact composition is obscure, but in addition to the three elements named, they contain the fourth organic element **Nitrogen.** These two substances are:—1. **Protoplasm,** a kind of jelly-like material found in all living cells, which is really the life-substance of the plant; and 2. **Chlorophyll** or leaf-green, which is formed only in the presence of sunlight, and is found in all the green parts of the plant. If a plant is deprived of light it turns yellow and then white. Potatoes in a dark cellar will grow with white shoots and leaves, and the stalks of celery, when earthed up, become blanched, because in the absence of light no leaf-green is formed.

All the matters we have been considering in the plant, whether formed of three elements or more, are called organic compounds, because they go to make up the principal part of all organized beings, that is, plants and animals, having special parts or organs.

Inorganic Compounds. If a plant is dried up and then carefully burnt, all these organic substances disappear. The water goes off in steam, and the other substances are converted chiefly into carbonic acid gas (carbon and oxygen) and ammonia gas (nitrogen and hydrogen) and are lost. But a few ashes are left behind which will not burn, and these when analysed are found to consist of a number of substances which are found also in many minerals, and not only in animals and plants, and are called mineral or inorganic substances. The most important of these are:—

Potash.	Phosphoric acid.
Soda.	Sulphuric acid.
Magnesia.	Silica.
Lime.	Chlorine.
Iron oxide.	

Carbonic acid is an organic compound, but it is also found in the plant ash united with some of the minerals. **Potash** is so called because it was first obtained by burning plants in a "pot" or stove and then washing the ashes. **Iron oxide,** in one of its forms, is the red rust seen upon iron when it has been exposed to the oxygen of the air. **Silica** is the substance which we see in the form of flint, and also of quartz crystals. It forms the hard flinty coating upon straw and grass. Common window glass is made of silica combined chiefly with potash and lime. All the substances mentioned above, except chlorine, contain oxygen. **Chlorine,** when free, is a yellow choking gas, but in the plant it is combined with potash or soda—in the latter case forming chloride of sodium or common salt.

The substances in the second column above, especially the first three, occur in the plant combined with any of those in the first column, forming what chemists call phosphates, sulphates, and silicates.' They also unite with carbonic acid to form carbonates. Thus we have phosphate of potash, phosphate of soda, phosphate of lime (a very important compound found also in bones). So also sulphate of potash, sulphate of lime (known as gypsum and plaster of Paris); carbonate of soda, carbonate of lime (the same substance as chalk or marble), &c. There are likewise silicates of the same substances, though silica also exists by itself in the living plants.

Food of Plants. Now, as all these substances are found in plants which have grown from tiny seeds, it follows that the plants must have obtained them from without—they form in fact the food of the plants, and to enable plants to grow and thrive they must be supplied with all these necessary substances. The food of plants, therefore, which they require as soon as they have used up the store of nourishment provided for them in the seed, consists of the following substances:—(*a*) **Organic**; required to build up their soft parts:—oxygen, hydrogen, carbon, nitrogen. (*b*) **Inorganic**, to build up their mineral parts or skeleton:—potash, magnesia, lime, iron, phosphoric acid, sulphuric acid, silica, soda, chlorine. The first six of these are essential, and plants cannot grow without them. The last three do not appear to be essential, but they are commonly found in plants grown under natural conditions, and they are probably useful to the plant.

It is possible to grow full-sized healthy plants without any soil at all, by suspending them with their roots dipping into a vessel of water, in which is dissolved a supply of all the essential articles of plant food. But for the purposes of agriculture, plants must be grown in large quantities in the soil, and must obtain all or almost all their food from the natural sources around. Now, let us inquire where the plants can obtain these necessary articles of food. There are plainly only three sources whence they can be derived, viz. the **air**, the **water**, and the **soil**.

Plant-food derived from the Air. The air is mainly composed of the two gases, **nitrogen** and **oxygen**, with a small proportion of **carbonic acid** gas, which is itself a compound of oxygen and carbon, and still smaller quantities of **ammonia** and **nitric acid**, each of which contains nitrogen and hydrogen. Careful experiment has shown that none of the free nitrogen of the air is taken in by the leaves of plants, and that, small as the proportion of carbonic acid is in the air, it is the source of almost all the carbon found in plants. The leaves absorb carbonic acid from the air, and then, under the influence of sunlight in the presence of chlorophyll or "leaf green," the carbonic acid is split up into carbon and oxygen, the carbon is kept by the plant and used by it in forming cellulose, starch, wood, &c., while the oxygen is given out to the air. Oxygen is also absorbed from the air, especially when the plants are growing rapidly and coming into flower. The leaves of plants also absorb a small quantity of ammonia from the air. The remaining nitrogen required by plants is obtained by them from the soil, as will be subsequently explained.

Plant-food derived from Water. Pure water consists of **oxygen** and **hydrogen** combined together, and of nothing else. When water enters the plant its office is chiefly to carry other matters in solution, but some of it is also itself split up and used by the plant in forming the starch and other organic matters. Rain-water is the purest natural water known, having nothing dissolved in it but what it has washed out of the air in its fall, but as soon as it enters the soil it begins to dissolve out the mineral matters there and carry them to the roots of the plants.

Plant-food derived from the Soil. We see then that from the air and pure water the plants can only obtain oxygen, hydrogen, and carbonic acid, with some nitrogen, therefore the rest of the nitrogen and all the mineral or inorganic substances—lime, potash, iron, phosphoric acid, silica, &c.—must be obtained from the soil, and taken in by the roots clearly and completely dissolved in water. Our next point, therefore, will be to ascertain how these substances exist in the soil, and how they can best be made available for the use of the growing plant.

II.—THE SOIL.

It is evident that of the three sources of plant food—air, water, and soil—the soil is the one which requires from the farmer the most attention, and is the most under his control; for fresh air and rain-water can generally be obtained by plants with very little assistance, and are of the same quality and contain the same ingredients wherever they may be found, while soils vary very much and are sometimes almost useless for the supply of plant food.

Formation of Soils. Almost all soils have been formed by the breaking and wearing down of hard rocks. All over the world there is a continual waste going on, by which the whole surface of the land is being gradually washed down into the valleys, or deposited along the level banks of rivers or in lakes, or finally washed quite down into the sea. The sea is in many places encroaching on the land. The coasts of Yorkshire and Essex are wasted away at the rate of about a yard every year. Rivers too cut out their own valleys, and gradually broaden and deepen them, until they run at the bottom of a wide valley formed by their own action. On the sides of these valleys are evidences of the former height of the rivers in the existence of terraces of soil lying one above and beyond the other, the oldest at the top. Then in mountainous countries the snow gradually collects and is squeezed down by its own weight and formed into ice. This is forced down by the weight of more snow above it, and moves slowly down the valley, breaking off projecting masses of rock, and gradually wearing and grinding out a channel in the hard rock. The material broken and ground off by the **glacier** (as this moving mass of ice is called) is carried down with it and dropped in the plain below, where the ice melts away. The finer mud is washed out from under the glacier by the melted ice, and carried further down the country, or perhaps quite into the sea.

Action of the Atmosphere. But the great agent in producing soils fit for vegetation is the atmosphere, especially the oxygen and carbonic acid gases, assisted by freezing water. If you notice the stones of a building when first put up, you will see that the corners are sharp, and the surfaces smooth and close. But after a few years the sharp edges of the stones become rounded off, and the surfaces are dotted over with little holes or pits, and sometimes flakes of stone peel off and fall to the ground. Just in the same way the hardest rocks, even granite and basalt, are broken to fragments by this "weathering" action of the air. You know that a piece of bright iron or steel, say a knife blade, left out in the air soon becomes coated with a layer of **rust**. This rust is oxide of iron; the oxygen of the air seizes on the particles of iron on the surface of the blade and forms this loose red powder, which can easily be brushed off, and if the process went on long enough the whole blade would be eaten away and turn to red **iron oxide**. Again, if a lump of fresh burnt lime be exposed to the air it will attract to itself first water and then carbonic acid, and become powdered carbonate of lime or **chalk**. Many other substances are acted upon in a similar way by oxygen and carbonic acid, especially when water is present.

Decay of Crystalline Rocks. All the older rocks on the earth are of a hard and intractable nature. Yet from these, by the gradual but steady action of the weather, almost all soils have directly or indirectly been formed. A well-known type of these rocks is **granite**, so called because, as you can easily see, it is made up of little **grains** of three minerals—quartz, felspar, and mica. The quartz is almost pure silica, but the felspar and mica are complicated minerals, being composed of the following substances:—**silica, alumina, potash, soda, lime, magnesia, iron oxide, phosphoric acid,** and **sulphur.** You will notice that all these, except alumina, are the very substances found in plants. Now, when granite is exposed to the air, the oxygen and carbonic acid of the air seize upon the iron and potash of the felspar and mica, and convert them into a powder which is easily washed out by the rain, leaving little holes in the granite. Into these more oxygen and carbonic acid penetrate, and combine with more iron and potash, tunnelling the hard rock and making it at last crumble to pieces. The grains of quartz being thus set at liberty from the felspar and mica form **sand**, while the finer particles of the other materials are washed together into beds by the rain and form **clay**. In granite countries there are often in the valleys large quantities of fine clay which has been formed in this manner from the weathering of the granite rocks of which the mountains are composed.

Action of Heat and Cold. Variations of temperature also assist this crumbling process. Heat causes the rocks to expand, and cold causes them to contract, and that with immense force, so that one part being heated more than another by the rays of the sun, the rock loses its cohesion, and cracks are made in the stone, just as a glass cracks when hot water is poured suddenly into it, one part expanding and breaking from another.

Action of Frost. Frost also plays a great part in breaking up the rocks. When warm water cools down, it goes on contracting until it gets nearly to the freezing-point, when it begins to expand again, and at the moment of freezing it suddenly expands with very great force. Cast-iron bottles an inch thick can be easily burst by filling them with water tightly fastened in, and then allowing the water to freeze. So also water-pipes are burst by the sudden expansion of the water they contain at the moment of freezing. When the rain finds its way into the minute cracks and holes of the granite and other hard rocks and is there frozen, it expands with such force as to split off portions of the rock and to widen the cracks. These getting filled again with water, which again freezes, the cracks are made wider and wider, until great blocks of granite are broken off, exposing fresh surfaces to be acted upon in the same way.

Action of Plants. The roots of plants also help to break up even hard rocks. If a piece of perfectly smooth marble be covered with a layer of clean sand, and a few seeds of mustard or cress sown therein, and the whole placed in a warm moist atmosphere, the seeds will soon germinate. After a few days, on sweeping off the sand and young plants, minute holes and grooves will be found in the surface of the marble, caused by the acid sap of the young roots eating into it to obtain a supply of food. The roots of trees too, entering crevices in the rocks, often split off great blocks as they expand in thickness; and heavy paving stones have been known to be broken and lifted by the growth of mushrooms or other fungi under them.

Distribution of the Waste Matters. The broken and powdered rock formed in these various ways is then washed down the slopes by the rain and rivers, forming the surface soil. In many flat plains the rivers frequently overflow their banks and spread the materials over the land. But in this case we see a sorting action take place. When a river rushes as a torrent down the mountains it carries with it mud, sand, gravel, and even large stones. But when it slackens its speed on reaching the plain, the stones and coarse gravel are first dropped, then further on the finer gravel is deposited, then the sand sinks to the bottom, and lastly the fine mud is carried out over the plain by the flood, and only deposited where the current has almost or quite ceased. In this way beds of gravel, sand, and clay are sorted out and formed into soils differing much from each other.

But vast quantities of this waste of the rocks are washed quite down into the sea, and are there spread out upon the bottom and sorted by the currents into beds of sand, clay, gravel, &c. These of course are lost to us for the present, but beds which were formed in the same way ages ago have been since lifted up by earthquakes and other movements of a similar nature, and from these beds many of our soils are formed.

Local and Transported Soils. Thus we see that some soils have been brought a long distance from the place where they were formed, and may therefore be very different from the rocks upon which they now lie, while others have been spread out by the rain upon and among the rocks from which they were derived. The latter are called **native** or **local** or **sedentary** soils, while the former are said to be **transported.** All over the eastern counties of England lies a thick irregular sheet of transported soil, which was brought by icebergs and glaciers in former ages from the mountains of Cumberland and the north of England, which were then covered with perpetual snow and large ice-masses, while the eastern counties were below the level of the sea. The soils of the midland counties, on the other hand, have been mostly formed by the action of the atmosphere out of the red sandstone and other rocks which lie under them.

Soil and Subsoil. If a hole be dug in a field to a depth of two or three feet, it will generally be clearly seen that there is a good deal of difference between the soil at the surface and that at the bottom of the hole. The top soil is generally darker, from the greater quantity of decayed vegetable matter which it contains, while the under soil or **subsoil**, as it is called, is usually lighter in colour and closer and harder to dig. Where the soil is a transported one, the subsoil may be totally different from it in colour and in quality. But in soils of any depth the difference between the soil and subsoil is partly due to the different amount of stirring they have received from the ordinary tillage of the farm. The subsoil has not been at all stirred, and indeed is sometimes hardened on the top into a firm cake by the treading of the horses and the weight of the plough in the furrows. This is called by farmers a **pan**, because it holds the water like a shallow basin or pan.

Mechanical Analysis of Soils. We have seen that although all soils have been derived from the decay of the ancient rocks, yet the materials have been so sorted out and washed down into separate beds that very different kinds of soil are found in different places. To tell of what a particular soil consists it is necessary to distinguish between these various materials. All soils may be considered to be mixtures, in various proportions, of five proximate constituents, viz. sand, clay, lime, humus, and stones or rocky fragments.[1]

Common Sand is made up of little grains of a glassy substance called quartz, of which flint is a variety. This is composed of pure silica, and is known under another form as rock-crystal. It forms the clear glassy grains which can be seen in a piece of granite, and is so hard as to scratch

[1] See also Part IV., pp. 151–155.

glass. It therefore only wears down into partly rounded grains, and not into a fine powder. Flint is also composed of the same substance. Bear in mind that quartz, rock-crystal, flint, silica, and clean sand are all in reality the same substance under different forms.

Clay, strictly speaking, is a chemical compound of **silica** and **alumina.** Alumina, you may remember, is the one substance found in granite which is not also found in plants. But the name clay is used for that part of the soil (whether entirely composed of silicate of alumina or not) which can be crushed into a state of fine powder when dry, but clings together into a sticky mass when wet. Clay which has very little sand or other substances mixed with it can be moulded into bricks, which are hardened by firing in a kiln or oven, and the fine and pure kinds are used for making pottery.

Lime is a well-known substance, which generally occurs combined with carbonic acid, and is then called carbonate of lime. Chalk, limestone, marble, and oyster-shells are all composed of carbonate of lime. The lime in these substances was originally derived from the old granite and volcanic rocks, but the thick masses of chalk and limestone which underlie many parts of the country are chiefly made up of the shells and skeletons of multitudes of minute organisms, which lived in the seas and left their remains at the bottom, to be afterwards hardened into rock. When carbonate of lime is burnt in a limekiln the carbonic acid is driven out into the air by the heat, and **quicklime** is left. If water is poured on this, or if it is left in the damp air for a time, it absorbs moisture and falls to powder, being then **slaked lime.** This being still left exposed to the air absorbs from thence carbonic acid gas, and returns to the state of carbonate of lime. These changes are very important to agriculture, as we shall see farther on.

Humus, or vegetable matter, or organic matter, is that part of the soil which is formed by the decay of plants which have lived and died upon the surface. It is of a dark colour, sometimes almost black. The decaying plants give off ammonia and carbonic acid, and various other dark coloured organic acids are formed. These acids are less highly oxidized than carbonic acid, and they are solid bodies which remain in the soil. Some soils are almost entirely made up of vegetable matter which has been formed by the growth of plants in hollow and damp situations. Some kinds of mosses especially grow very rapidly in such places, and as the old plants die new ones spring up upon their remains, until the hollow is filled up with vegetable matter, forming a **bog** or **peaty** soil. All fertile soils contain some vegetable matter.

Separation of Sand and Clay. Take a small quantity of soil from a field, pick out all the stones or sift it through a wire sieve. Weigh out, say a pound of this fine soil, and put it into a vessel of water. Let it soak for some hours, or boil it to make sure it is thoroughly softened by the water. Now stir it up well and pour off the muddy water into another vessel, leaving the sand which sinks to the bottom in the first vessel. Put clean water on this, stir it and pour off again into the second vessel. In this way the sand will be washed clean and left in the first vessel, while the fine particles of clay will settle in the second. After some hours the water can be carefully poured off from both vessels, and then the sand and clay can be dried and weighed separately, giving a **mechanical analysis** of the soil. For ordinary purposes a skilful farmer can tell by its appearance and by various signs whether his soil is chiefly sand or clay.

Classification of Soils. If a soil consists of more than three-quarters sand it is called a sand or **sandy soil.** If, on the other hand, more than three-quarters of its weight is clay it is called a clay, or a **clay soil.** A mixture of about half sand and half clay is called a **loam.** If there is rather more than half sand it is a **sandy loam,** if rather more than half clay it is a **clay loam.** All these soils may contain a quantity of lime and vegetable matter which makes them richer. A soil which contains nearly a quarter of its weight of lime is called a **marl,** if the rest of the soil is mostly sand it is a **sandy marl,** if mostly clay it is a **clay marl.** Soils which contain a larger quantity of lime are called **calcareous soils** (*calc-* = chalk). A soil which contains a considerable proportion of vegetable matter is called a **peaty soil**. These differences among soils are shown in the following table, but it must be borne in mind that the relative quantity of the constituents may vary a little in different soils, only the **average** amount of each being shown here :—

Sandy soils,	Sand, ...	$\frac{3}{4}$ to all sand.
	Sandy marl, . .	$\frac{3}{4}$ sand : $\frac{1}{4}$ lime.
Loamy soils,	Sandy loam, . .	$\frac{2}{3}$ sand : $\frac{1}{3}$ clay.
	Loam, ...	$\frac{1}{2}$ sand : $\frac{1}{2}$ clay.
	Clay loam, . .	$\frac{2}{3}$ clay : $\frac{1}{3}$ sand.
Clay soils,	Clay, ...	$\frac{3}{4}$ to all clay.
	Clay marl, . .	$\frac{3}{4}$ clay : $\frac{1}{4}$ lime.
	Calcareous soil, .	$\frac{1}{4}$ to all lime.
	Peaty soil, . .	$\frac{1}{4}$ to all humus.

Each of these soils can be again divided into poor, middling, and rich according to the quantity of the other matters present. Thus, a loamy soil containing lime and vegetable matter, as well as sand and clay, is richer than one containing sand and clay only; and generally speaking, the richest soils, that is, those yielding the greatest amount of plant food, are those which are composed of a fair mixture of all the proximate constituents.

Density or Weight of Soils. In our analysis of the soil we saw that the sand sank to the bottom of the water first, showing it to be heavier than the clay, and on weighing a measure of each we find the same thing. A cubic foot of dry sand weighs about 110 lbs., while a cubic foot of dry clay weighs only about 75 lbs.; yet a farmer calls a sandy soil light and a clay soil heavy. This is chiefly because he thinks more of the ease or difficulty of moving or working in the soil than of the actual weight. The particles of sand are comparatively large loose hard grains, with no tendency to stick together, or to the implements with which the soil is worked, so that a fork or a ploughshare easily pushes between the grains, and the soil is called light because the working of it is light, though its true weight, bulk for bulk, is greater than that of clay. In a clay soil, on the contrary, the particles are so fine and soft, and have such a tendency to stick to one another and to the implement passing between them, that much greater difficulty is found in moving and separating them. The clay, therefore, though really lighter than the sand, makes heavy work for the farmer, who therefore calls it a heavy soil. In some soils large quantities of **stones** are present; but unless they be present in such a quantity or of such large size as to hinder the work of tillage, the stones do more good than harm, and they are very useful in opening up some heavy soils, and making them lighter and easier to work. In light soils stones are also useful, as they are gradually reduced into soil by the natural dissolving agencies.

Capillarity of Soils. If one end of a fine glass tube be dipped in water, the water rises in it; the glass attracts the water and lifts it above the surface against its own weight, and if the tube is very small its walls are then very close around a small weight of water, so that they are able to attract it very strongly and raise it several inches above the surface. This is called **capillary attraction** (from *capillus*= a hair), because of the small size of the tube. The same thing takes place wherever there are small spaces between substances, as in a sponge, the wick of a lamp, and a piece of loaf-sugar, all of which have the power of drawing up and holding water in the little spaces they contain. Now this is a very important property in soils. The water in a saucer under a flower-pot containing soil is absorbed in this way, rising up in the soil to a greater or less height according to the size of the spaces between the particles, and staying there without falling back. In coarse sand it would rise but a short distance, while in fine clay, where the particles are close together and therefore capillary attraction is greater, it would rise much higher. Suppose 100 lbs. of soil to be placed in a vessel with holes at the bottom, and water to be poured on at the top until it begins to drop out at the bottom. Then it is found that if the vessel be filled with 100 lbs. of sand it will receive and hold 25 lbs. of water before beginning to drop; 100 lbs. of loam will hold about 40 lbs. of water; 100 lbs. of clay loam holds about 50 lbs. of water; and 100 lbs. of clay about 70 lbs. of water. In the same way clay soils are able to absorb more moisture from the atmosphere than sandy soils; 100 lbs. of sand spread out in the moist but rainless air during twelve hours in the night has been found to absorb only a few ounces of water, while 100 lbs. of loam absorbed 2 lbs.; 100 lbs. of clay loam 2½ lbs.; and 100 lbs. of clay took in nearly 4 lbs. of water.[1]

Influence of the Mechanical Condition of the soil upon the growth of plants. We are now able to see something of the importance of the state of the soil with regard to the needs of the plants. We have seen that plants require air, water, and warmth to enable them to begin to grow. In order that the seeds and roots may obtain air, a loose condition of the soil is necessary. For this condition sand is better than clay, because the spaces between the grains are larger, and thus allow more air to enter. But if these spaces are too large, a sufficient supply of water will not be retained in the soil, and the young plants will suffer for want of moisture. On the other hand, if too much moisture is retained in the soil it not only shuts out the air but becomes cold and stagnant, chilling the soil, and therefore depriving the seeds and young plants of their third requisite, namely, warmth. Thus we see that the best kind of soil, in this respect, for a seed-bed is a mixture of sand, clay, and organic matter, such as we find in a loam, not so close as to prevent the free access of air and warmth, and not so open as to allow the water to run through too quickly.

Chemical Analysis of the Soil. When the seed has sprouted and the first green leaves appear above the ground, then the young plant requires good food, and in sufficient quantity to build up its framework of tiny cells, and to fill them with the starch, protoplasm, &c., which we have seen to exist in them. On a former page you will remember we had a list of the substances required to build up this framework and its contents, and therefore necessary for the life and health of the plant. If one of these is absent the plant cannot live, even though there may be an abundance of all the others. Or if they are all present, but one or several of them are not in sufficient abundance to feed the plant as rapidly as it requires, it then droops and becomes sickly, and if it manages to live to

[1] See also Part IV., pp. 155–157.

the end of the season it will yield very poor and insufficient food for man or beast. It is very important, therefore, to discover whether the soil contains all the substances which the plants cannot obtain elsewhere.

The **carbon, oxygen,** and **hydrogen,** and a little **nitrogen** can be obtained from the air and water. The rest of the nitrogen is obtained from the soil, which has derived it from the decay of organic matter, and from the atmosphere. The following substances taken by the plant can only be obtained by it from the soil:—**phosphorus, sulphur, potash, soda, lime, magnesia, iron, silica,** and **chlorine.** To find whether these substances are present in any specimen of soil a chemical analysis of it must be made; this is a more difficult matter than a mechanical analysis, and can only be carried out by a chemist; but when this has been done it is found that in all good and fertile soils the above substances are present, while in barren soils it will generally be found that one or more of them are absent, or are so small in quantity that a mere trace of them can be made out.

Artificial soils have been made, for the purpose of experiment, of powdered quartz or fine sand, to which the above matters have been added; and plants grown in these artificial soils, thus made chemically fertile, have succeeded as well as those grown in a naturally fertile soil.

It will be seen further on, however, that barrenness may result from other causes than deficiency of plant food, such as the presence of poisonous matters in the soil.

The following table represents a chemical analysis of three different specimens of soil. The first is a fertile soil, containing a fair share of all the necessary substances. The second is a moderately fertile soil, which needs to be carefully cultivated, and assisted with manure; and the third is a barren sandy soil containing mere traces of many of the important ingredients of plants. A weight of 1000 grains may be supposed to be taken of each soil and the weight of each substance given in grains. The word "trace" means that so small a quantity of the ingredient was found that it could not be weighed by the chemist who analysed the soil:—

	FERTILE.	MODERATE.	BARREN.
Potash,	10	trace.	trace.
Soda,	20	trace.	trace.
Lime,	41	18	trace.
Magnesia,	1	8	trace.
Iron oxide,	94	30	20
Alumina,	14	51	5
Phosphoric acid,	5	2	trace.
Sulphuric acid,	9	1	trace.
Carbonic acid,	61	4	0
Chlorine,	12	trace.	0
Silica,	600	833	960
Ammonia,	1	trace.	0
Organic matter,	120	50	15
Water, &c.,	12	3	...
Total,	1000	1000	1000

You will notice the great amount of silica in all the soils, but especially in the barren one. Silica may be looked upon as forming the main bulk of all sandy, loamy, or clay soils, to which the other matters—potash, soda, &c. give fertility; just as water forms the main bulk of all our drinks, to which tea leaves, coffee-berries, alcohol, or meat give flavour and nourishment.

Active and Dormant Constituents. But now we come to an important point which must be carefully borne in mind. All the substances required by plants may be present in the soil and in sufficient quantity, and yet may not be available for the use of the crops. We have seen that the plant food must be dissolved in water before it can be taken in by the roots. But only a small proportion of the substances existing in the soil are in this **soluble** condition. If some soil be soaked in a glass of water for a time, a small quantity of the contained substances will dissolve out into the water, where they may be detected by chemical means. This represents the most readily soluble part of the plant food. But if the same soil be then dried and directly afterwards soaked in some fresh water, no more matters will dissolve out; the most soluble plant food has been washed out of it. If, however, this same soil be kept exposed to the air and frost for some weeks and then again soaked in water, the water will again be found to contain plant food. The insoluble substances have been made soluble by the action of the atmospheric agents oxygen and carbonic acid assisted by frost. If acids had been used in the water, a larger quantity of the plant food would have been dissolved out. In the analysis of a certain fertile soil it was found that in 1000 lbs. of soil the substances existed in the following state:—

Substances soluble in water, . .	2 lbs.
Substances soluble in acids, . .	88 ,,
Substances insoluble, ...	783 ,,
Organic matter, ...	127 ,,

That part of the soil which is soluble in pure water, or in water containing carbonic acid or weak organic acids, is said to be in an **active** state, because it is already in a condition in which plants can make use of it for food. The insoluble substances forming the great bulk of the soil are said to be in a **dormant** state (L. *dormire*, to sleep), because they can only become useful to the plants after a long course of exposure and chemical action, except in so far as they can be reduced by the corroding action exercised by plant roots. It is in this relation of soluble to insoluble matters that we see the great necessity for the cultivation of the soil. The farmer by ploughing and breaking up the soil, especially in the autumn, exposes it during the winter to the influence of the weather. Frost and thaw, acting alternately, break up the lumps and clods, and expose them to the oxygen and carbonic acid of the air, which then act chemically upon the dormant and insoluble matters, rendering part of them active and soluble, and useful for the next year's crop.

The Double Silicates. In the chemical analysis of the soil given above, silica and alumina are mentioned separately; but in the soil a part of the silica is chemically combined with a part of the alumina forming a **silicate of alumina.** This substance is the essential ingredient in pure clay, such as the fine white clay used by potters in making china. Now alumina does not enter the plants at all. You will remember that it is the only substance given in the analysis of the soil which does not also occur in the analysis of the ash of plants. Look back and compare the two lists once more. Yet though alumina thus remains always outside the plant, it is found to serve a very useful purpose. It does so by combining with silica and at the same time with one other substance of plant food, forming what chemists call **double silicates.** The following are some of the double silicates:—

Silicate of alumina and **soda,**
Silicate of alumina and **lime,**
Silicate of alumina and **potash,**
Silicate of alumina and **ammonia.**

Now it has been found that if a solution of a salt, such as the chloride of potassium, be applied to a soil containing one of the double silicates, such as, for example, the double silicate of alumina and lime, a part of the lime is set free from the silicate and is replaced by a corresponding quantity of potash. This potash remains fixed in the soil in a double silicate of alumina and potash, while the lime and the chlorine may be washed away into the drains. A great many experiments like this have been made with a large number of salts in solution, and in every case a part of the base in the salt has been retained by the double silicate in the soil. Effects of the same kind are produced also by a similar series of bodies —the **double humates.** These are formed where organic matter is decaying by the union of humic acid with bases. The double silicates and double humates are therefore of great use in the soil, as they are the means of receiving and of holding in chemical union the most valuable kinds of plant food, which they give up to the plant when required. This action of the double silicates and double humates we shall find to be of great importance when we come to consider the action of manures, in the second part of this work.

III.—CULTIVATION OF THE SOIL.

Necessity for Cultivation. For the successful growth of crops it is necessary that the soil should contain a sufficient supply of plant food in a soluble form. If the soil should be deficient in any of the substances required by plants, or if these substances be locked up in an insoluble state, the soil will be barren, and can only be rendered fertile by the addition of these substances in the form of manure, or by waiting until they become soluble. The use of manure to supply deficiencies in the soil will be considered in the second part of this work. To allow time for the insoluble matters in the soil to become acted upon by the atmosphere and rendered soluble, the land is sometimes allowed to rest or remain in **bare fallow** for a year. This is only done on very stiff clays that are not suitable for growing green crops, and during the year of fallow the land is constantly tilled to help the atmosphere to perform its work more speedily.

Presence of Poisonous Matters. But a soil may be barren because, although it may contain the necessary plant food and in a suitable condition, yet it may also contain various injurious substances which act as poisons to plants, and prevent their proper growth. Some yellow clays, for instance, contain an oxide of iron, called by chemists **ferrous oxide,** in which there is only a small proportion of oxygen. This substance, if present in large quantity, is very injurious to plants, but when it has been exposed to the atmosphere it absorbs more oxygen gas and becomes the common red oxide of iron or **ferric oxide.** In this condition it is a valuable food for plants. In some soils, especially peaty soils, there may be an abundance of sour and hurtful **organic acids,** formed by the decay of vegetable matter. These are also to be rendered less hurtful by good cultivation and liming. So again there may be too much **salt** in the soil, which must be washed out or otherwise disposed of before the soil can become fertile.

Climate. Another essential condition of success is that the climate should be suitable for the crop. The farmer has no power over this, but he can choose such seeds and crops as he finds suitable for the climate in which his farm is situated. Thus, some kinds of wheat cannot be grown successfully in the north of England, while oats succeed better in the north than in the south. Turnips do better in a cool and moist climate than in a warm and dry one, and so on.

But supposing the plant food in any soil to be sufficient, injurious and poisonous substances to be absent, and the climate to be suitable, we still require a proper tillage or cultivation of the soil to bring out its dormant capabilities, and to make the most of all these advantages, so as to produce the greatest yield of crops at the least possible expense, and yet leave the land in as good or better condition for the next crop.

The Farmer's Friends. In the cultivation of the soil there are certain natural agencies which we have already glanced at once or twice, and which are always ready to assist the cultivator if he will be careful to give them every opportunity of doing so. The first of these agencies is the **weather**, including rain, snow, and frost. **Rain** is absolutely necessary to supply the water, which makes so large a proportion of the weight of the plants grown, and in which also the plant food must be dissolved before it can be taken in by the roots. Without rain a country becomes a desert, unless, as in the basin of the Nile, water is brought from a distance and spread over the land by the overflow of a large river or by artificial watering or **irrigation**. The western counties of England and the whole of Ireland receive much more rain than the eastern parts of this country, and are therefore more suited for crops of grass, turnips, and forage crops; while the east of England, as a rule, is more suited for wheat and other grain crops. In the winter the rain takes the form of **snow**, and is then useful as forming a protection to young plants from too great frost. But **frost** itself is a great friend to cultivation, as we have already seen. Acting upon the moisture in the soil it causes it to expand and burst asunder the tough particles of clay, exposing them on all sides to the action of the air.

Another of the farmer's friends is the **oxygen** of the air. This gas, which forms one-fifth part of the atmosphere, is always ready to combine with other elements, and to form compounds called oxides, which are usually more soluble than the simple elements. Thus oxide of iron or iron rust will dissolve readily in water, which pure iron will not do. Then, as we saw in speaking of the waste of the granite and other hard rocks to form the soil, the washing out of these oxides by the rain leaves holes, weakening the rock and causing it to fall to pieces; so this action still goes on in the soil, and the hard clods and masses of clay are softened and crumbled in this way. But for the oxygen to get at all parts of the soil it is necessary that it should be laid open and turned over some time before it is wanted. This is one object of digging and ploughing.

The next substance waiting to assist in the cultivation of the soil is **carbonic acid.** This exists in small quantity in the air, 10,000 gallons of air containing only about 4 gallons of carbonic acid gas, yet as it is being continually breathed out of their lungs by men and animals, besides being thrown out by fires, volcanoes, &c., this small quantity is being continually renewed as fast as it is used up in the soil and by the growing plants, so that really an immense quantity passes through various chemical changes in the air, the soil, and the crops. Carbonic acid acts in the soil in two ways. In the first place, like oxygen, it combines with various substances, such as quicklime, causing the clods to be broken and crumbled to pieces. It also combines with the soda, potash, &c., of the soil, forming carbonates of those substances, which then dissolve in the water together with some free carbonic acid, and thus enter the delicate roots of the plants, forming part of their food.

Another important gas which exists in the air, though in still smaller quantity, is **ammonia,** the strong-smelling, pungent gas which is generally kept by the chemists dissolved in water, and may be bought under the name of **hartshorn.** This gas consists of nitrogen and hydrogen combined, and when it enters the soil it is held there, and forms an important part of plant food. You will remember that plants cannot absorb nitrogen directly from the air, although four-fifths of the air consists of this gas. To be of use to the plant the nitrogen must be combined with other elements, as in ammonia or in **nitric acid.** This latter substance also exists in the air in exceedingly small quantities, but it supplies the soil with very valuable plant food. After thunder-storms nitric acid is found to have been formed. The flashes of lightning cause the nitrogen of the air to combine with the oxygen, and in the course of a year a considerable quantity of nitric acid is carried down by the rain into the soil.

Another friend of the farmer of a very different kind is the common **earthworm.** Very few people have any idea of the immense number of worms in the soil, or of the benefit which it derives from their presence. The earthworm lives by swallowing earth containing vegetable matter, from which its digestive organs extract nourishment. This soil it then brings to the surface of the ground and casts out in a finely divided state. Darwin has calculated that in many parts of England more than ten tons of earth on every acre of ground passes annually through the bodies of worms and is brought up to the surface, so that the whole top layer of the soil passes through their bodies every few years. They also drag into their burrows great quantities of leaves and other vegetable matter, break them up small and mix them with the soil, forming a dark rich humus. The worm-burrows, too, which are often five or six feet deep, assist in draining the soil, and form passages into which the air and the roots of the plants can enter. The action of worms, in fact, prepares the soil in an excellent manner for the growth of fibrous-rooted plants and of young seedlings of all kinds.

Autumn Cultivation. It follows, then, that for the proper growth of crops the ground should be opened up and exposed to the air as much as possible, especially if the soil be a clay one. For this reason the land is ploughed up in the autumn, and left with a rough and irregular surface. The oxygen and carbonic acid then do their work during the winter. Assisted by frost they gradually but surely break up the close clods of earth and reduce them to a finely powdered state; they combine with the dormant or insoluble constituents of the soil, making them soluble and fit for plant food; and they also combine with the hurtful acids and organic matters which make the land "sour," converting them into harmless compounds or into useful ingredients of the soil. Autumn ploughing is also more effectual in destroying weeds than ploughing at any other time, for the weeds are not so likely to spring up again just as winter is coming on.

By these means the land, by the time spring comes, will be in a soft and powdery condition, free from weeds and fit to form a good seed-bed, sweet and nourishing for the young crops.

Drainage.[1] In some soils there is an obstacle to the entrance of the air to the lower parts of the soil, and that is the presence of standing water. If a soil is close and tough the rain which falls upon it cannot easily pass through it. It soaks into it till the soil is full of moisture, then it stands in little pools on the surface or runs off into the ditches, carrying with it the finer parts of the soil. However much such land may be ploughed and stirred on the top, the air cannot enter to any depth on account of the presence of this water, and the oxygen and carbonic acid have no opportunity of acting on the particles of the soil. But standing water is hurtful in other ways. It makes the land very cold for three different reasons—first, by preventing the entrance of warm air; second, because water is much longer in being warmed by the rays of the sun than dry soil is; and third, by **evaporation**. Water has a great **capacity** for heat, that is, it can receive and retain a large amount of heat before it becomes sensibly warmer. If a pound of dry soil and a pound of wet be put in an oven together, the dry soil will become hot much sooner than the wet one. Water standing in the air constantly evaporates, that is, turns into vapour or steam, but in doing so the vapour absorbs and carries off a great deal of heat, chilling the water which remains behind and all substances near it. The cold caused by evaporation may be felt by putting a little water on your hand in a warm room and letting it dry off. If spirit be used the cold will be greater, because the evaporation is more rapid, and a few drops of ether poured on the hand will evaporate almost instantly, and cause a greater cold still.

[1] See also Part IV., pp. 157-163.

Then, again, besides causing cold, stagnant water becomes foul and unwholesome, causing the formation of various organic acids in the soil very injurious to vegetation. Water of course is very necessary to plants, and must be present at all times during their growth, but it must **keep moving** gently through the soil past the roots of the plants, bringing them the food they require and then passing on to make room for a fresh supply. But to keep water passing in at the top and through the soil, a way must be made for it to pass out at the bottom, that is, the land must be **drained**. Some soils, sandy ones for instance, are so loose and open that the water finds its way through them without any help--these do not require artificial draining, unless the subsoil is of quite a different nature and holds the water, in which case the upper soil, however porous in itself, will be full of stagnant water. In these cases, and with almost all clay soils and clay loams, it is necessary to provide a channel for the water through the soil. Trenches are dug across the fields, about a yard deep, and from six to twelve yards apart; the more sandy the soil the wider they may be apart. Along the bottom of these trenches, which all lead to the lowest part of the field, are laid hollow tiles or pipes with open joints, and the trenches are then filled up again. The superfluous water in the soil finds its way into these drains, and running down them by its own weight into the ditches, leaves room between the particles of the soil for the air to enter. The air is, we may say, **drawn** into the soil by drainage, for as the water leaves the soil below, the air lying above is bound to follow, or rather is forced in by the immense weight of the atmosphere above. We have already seen how important is the presence of air in the soil. The oxygen combines with the organic acids and with the lower oxides of iron, &c., converting them into useful compounds; the carbonic acid also combines with many inorganic substances, and assists in breaking up the clay and setting free the dormant supplies for future use. The vegetable matter in the soil decays much more rapidly when air is present, and becomes fit for use by the crops; and ammonia and nitric acid are formed to provide the plants with nitrogen.

Another reason why soils should be drained is this—in some cases injurious substances, or a larger quantity of salts of various kinds than are good for the crops, may collect in the subsoil. When the land is drained, these are washed out of the subsoil by the rain descending into the drains, and are so carried away. The great thing in drainage is not entirely to get the soil dry—for a moist soil is most beneficial to the crops—but to make the rain go **through** the soil, passing gently among the roots with its supply of dissolved food, more in the form of a moist misty air than of a stream of water, and this can only be got by having a constant **way out** for the water underneath the soil.

Over-drainage. There is not much fear in a moist climate of draining the soil too dry, for as we have seen, most soils, especially clays and loams, have great power of holding water between their particles by capillary attraction, and if the air and sun should dry up their surface, the water will rise by this attraction from the lower parts of the soil, as it does in the soil in a flower-pot standing in a saucer of water. But if a soil be so open, as in some loose sands, that the spaces between the particles are too large to allow it to hold a sufficient supply of water, and if it be so situated as to subsoil that rain-water passes freely through it, then drainage is not necessary. The capillary action in such soils is weak, and they are apt to be left so dry that the crops are burnt up during dry weather. In such cases a mixture of peaty or other vegetable matter with the soil, such as rotted straw or a crop of grass or clover ploughed in, increases its capillary power, and enables it to draw up from beneath, and hold within reach of the roots, a sufficient supply of water for their constant use.

Spade Husbandry. One of the most important objects of tillage being the loosening and turning of the soil to allow air and rain to enter, and frost to act upon the particles of yet unbroken mineral matter, we see the necessity of digging or ploughing. On a small piece of land the tillage may be done by hand with a spade or fork, and if carefully and thoroughly done, this is a better means of cultivation than ploughing. This mode of turning over the soil has been sometimes made use of even on a large scale. The soil is dug to a depth of eight or nine inches, and thrown forward with a spade, leaving a trench. Sometimes a layer of the undersoil is taken out of the bottom of this trench and laid on the top. By this means the soil is completely broken and turned over.

Ploughing.[1] But on large farms, and for ordinary occasions, the method of spade culture by hand labour is too slow and expensive, and therefore various kinds of ploughs are made, to which the power of horses or steam-engines can be applied. In old times the plough was simply a forked and

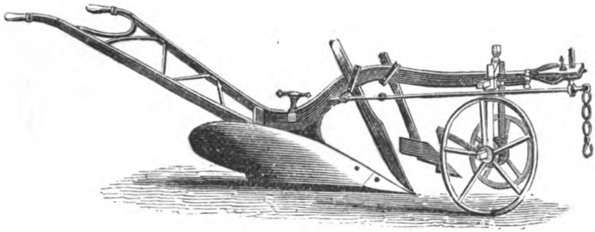


Fig. 5.

pointed log of wood dragged through the soil. After a time the point entering the ground was shod with iron, to give it greater power and endurance; and then the whole was made of iron, and a "mould-board" was added of such a shape as to work under the layer of soil into which the point or "share" has entered, and throw it over on one side (Fig. 5). A layer of soil about six inches deep is thus turned over, and its under side exposed to the air. The soil is left by the plough in ridges, and therefore a much larger extent of surface is exposed than if it were flat on the top. This you may realize by considering how much farther a mouse would have to travel in running **across** the furrows and ridges than if the ground were quite flat.

Plough Pans. But by continually ploughing the land in this manner and to this depth, the horses and men walking along the bottom of the furrows, and the "sole" of the plough

[1] See also Part IV., pp. 164–166.

sliding on and pressing down the soil every time just beneath the top layer, the soil below is often squeezed and hardened into a dense layer, through which the roots of the plants find great difficulty in passing, and upon which the water stagnates. This hard layer is called a **plough pan.** To break up this pan and stir the subsoil to make a way out for the water and to enable the roots to penetrate, another kind of plough can be used after the ordinary one, called a subsoil plough (Fig. 6), which breaks and stirs up the subsoil without bringing it to

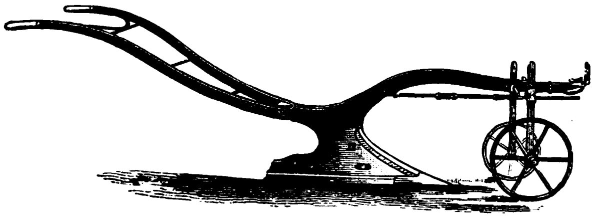


Fig. 6.

the top. Sometimes, however, a plough is used which is of the ordinary shape, but is stronger, and goes deeper, and brings up some of the subsoil to the surface. But so much force is necessary in very deep ploughing, except on the lightest soils, that it is seldom done unless steam power can be obtained to drive the plough.

Other Pans. Pans may be due to other causes besides constant surface ploughing. In some districts, especially where the soil is of a moory or peaty character, it contains a large quantity of iron oxide. As this gets washed into the subsoil by the rain it forms a kind of cement, binding the materials together into a hard cake, which is called an **iron pan** or **moor pan.** The cementing power of iron rust may be seen in the case of iron chains and other articles which have been buried in the ground or sunk in water for a long time, and which, when taken up, are found to be partly rusted away and stuck together into a solid mass. Another kind of pan, called a **vegetable pan,** is also often formed under a peaty or boggy soil, the vegetable matter acting in such a way upon the mineral substances as to form a firm cement, binding together the particles of the under soil. In other soils where much lime abounds, or where lime has been put on the land too plentifully, it has sunk into the soil and formed a hardened cake called a **lime pan** or **calcareous pan.** You will remember that lime and sand are the principal materials used in making mortar and cement, and can therefore understand how they may harden in this manner in the soil.

In all these cases the subsoil plough may be used with advantage to break up the pan and loosen the subsoil. But

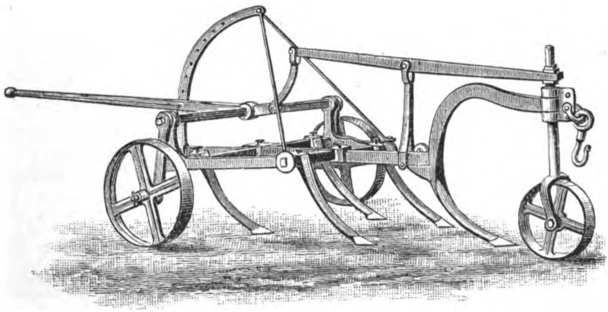


Fig. 7.

in all soils, whether liable to form a pan or not, the occasional use of the subsoil plough, or of some means of stirring the subsoil, so as to admit the water and air and to allow the deep roots to penetrate, and thus render fresh supplies of plant food available, is a great advantage to agriculture. In a certain field which was subsoiled to a depth of fifteen inches, instead of being ploughed in the ordinary manner to about eight inches, it was found that the turnip crop was increased by more than six tons, the barley crop by seven bushels of grain, and the potato crop by fifteen cwts. of potatoes, per acre.

Other Implements. In addition to the plough the chief implements used in tillage operations are the **grubber,** the **horse-hoe,** the **harrow,** and the **roller.** These are used for clearing the ground of weeds, for compressing it, and for preparing the surface for the reception of the seed. The **grubber** or "cultivator" (Fig. 7) consists of several tines slanting downward and forward. These, when dragged through the soil, help to break up clods and draw out weeds such as the troublesome couch-grass. This plant has long creeping underground stems, and is very difficult to destroy.

Various kinds of hoes and harrows are used for turning

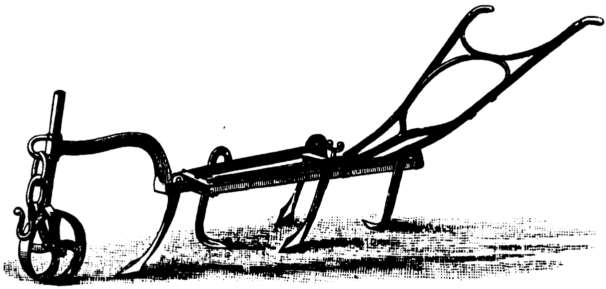


Fig. 8.

over the clods, drawing out weeds, and covering seeds that have been sown. The **horse-hoe** is chiefly used for clearing the land of weeds, and for stirring and loosening the soil about the roots of the plants. It consists of a number of tines or points fixed regularly in a frame at a proper distance apart. The hoe (Fig. 8) is drawn between the rows of plants, by one or two horses, and the tines are of various forms, and can be attached so that they cover all the space between wider or narrower rows. They are most largely used in the cultivation of root crops.

Harrows are made of various sizes and patterns. Heavy harrows or drags are employed on rough land and bare fallows to break down large lumps and hard clods. Lighter harrows (Fig. 9) are used for making the surface still finer, for collecting weeds, and for covering seeds. A special kind of harrow made of chain-work, though also used for covering seeds, is specially employed for gathering weeds into heaps, which can be carted away. The **roller** is principally used for pressing the soil around the seeds or very young plants so as to keep them moist, and enable the tiny roots to take hold of the

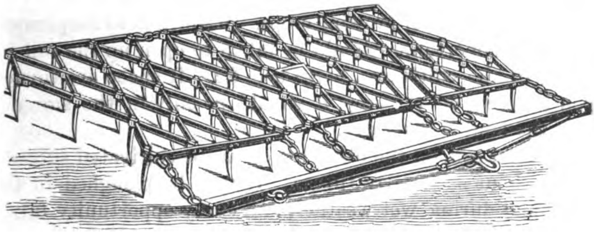


Fig. 9.

soil. A rough kind of roller with projecting points and notches called a **clod crusher** (Fig. 10) is sometimes used to break up the hard lumps of soil, so as to expose a greater surface to the atmosphere.

Cultivation of Heavy and Light Soils. The principles of cultivation which we have been considering require to be modified and varied according to the nature of the soil

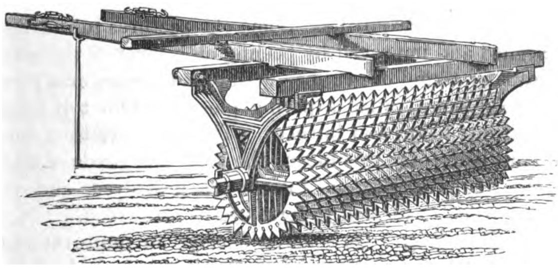


Fig. 10.

and of the crop grown upon it. A heavy clay soil is more suitable for wheat and beans, a light sandy one for turnips and barley. The heavy soil requires to be well drained, with the drains not too far apart. It should be ploughed in autumn during dry weather. If ploughed when very wet, the clay has a tendency to run together again and become as close as before, whereas, if ploughed dry, the clay is torn and broken instead of being cut, and then after being acted upon by the atmosphere it becomes more friable, and remains in a suitable condition for growing crops. In addition to the ploughing, every opportunity should be taken to open up the soil by the use of the cultivator, horse-hoe, &c. If sheep are turned upon it to eat off the crop, it should be only in the summer when the land is quite dry.

The light soil, on the other hand, can be cultivated successfully without such early tillage. It may be ploughed in the spring and during wet weather, and every opportunity taken by rolling and pressing to consolidate it before and after the seed is sown. Sheep may be turned upon it in the winter to eat the crop of turnips, and to consolidate the land still more by their trampling upon it.

These are the two extreme cases of strong clays and loose sands. Soils which are between these in their nature, such as loams, require an intermediate treatment; but in most cases, except when the subsoil is of very poor quality, or contains injurious ingredients, deep tillage will be found useful, and will increase the yield of the crops.

Paring and Burning. Some old pastures full of weeds are cleaned and improved by peeling off a layer of the surface by means of a kind of grubber with broad blades, or a plough with broad share, called a paring plough. This top layer is gathered into heaps and burned. The ashes are then spread upon the land. By this means the roots and seeds of weeds, and the grubs of noxious insects are destroyed, and their ashes returned to the soil to form useful plant food.

Clay Burning. On some stiff clays an improvement is made by digging up clay and burning it slowly in heaps at a low heat. The clay becomes more friable, that is, it crumbles down easily into powder, and the dormant plant food it contains becomes active and soluble. It is also more porous than before burning, so that it is more able to absorb gases from the air, such as ammonia and nitric acid, which form such a valuable portion of the food of the crops.

Formation of a Seed-bed. One great object of the farmer in his winter and spring operations is the preparation of the land to form a suitable "seed-bed," in which the seeds will have the best chance of finding the moisture, warmth, and air which are so necessary for their growth. The preparation of the seed-bed will vary with the nature of the soil, and with the size and character of the seed. But there are some points which must always be carefully attended to. In the first place, it is necessary to secure plenty of room for the roots of the plants to reach downwards into the soil. By deep ploughing and cultivation of well-drained land the soil is loosened to a good depth to allow the roots to penetrate in search of their food. The roots of clover often reach to a depth of three or four feet, and the roots of winter wheat have been traced to a depth of seven feet in a loose subsoil, forty-seven days after the seed had been sown.

In the next place, it is important that the seed should be **clean**, in order that the moisture may penetrate its skin in all directions. If the minute pores of the seed are clogged with clay or dirt, the young plant will be sickly and weak.

The next point to be attended to, is the **depth** at which the seed should be sown. This depends upon the kind of seed and upon the supply of air and moisture. If the seed lies too near the surface, it gets alternately wet and dry with the rain and sun. This prevents its steady growth, and injures the health of the plant. If, however, the seed is buried too deeply in the soil, it will, it is true, be kept always moist, but will not obtain enough air to supply it with the oxygen it requires. The farmer has to judge by the kind of seed and by the nature of the soil and the climate between these two extremes. Then, again, it is necessary for the support of the young seedlings that the soil should lie close around them, yet without shutting out the air from their roots. In some soils it is useful to sow the seed immediately after ploughing, while the freshly turned-up soil is still damp, and to roll it at once to press the earth close to the seeds. Wheat requires a firm support around its young roots, and yet the soil must not be too hard and close, or the roots will not be able to penetrate freely in search of food. The best preparation for a seed-bed for wheat is to grow a crop of clover upon the land just before the wheat is sown. The clover roots go a long way down into the soil and bring up nourishment from below, which becomes chiefly stored in the thicker parts of the roots and stem. The clover roots also open out the particles of a clay soil and make it lighter; yet in a sandy soil they tend to bind the particles together and give the firmness so useful to the young roots of the wheat. So that, when the clover roots are lightly ploughed in and the wheat sown among them, a seed-bed is formed which is very suitable for the wheat. At the same time the clover roots, as they decay, supply the wheat with valuable plant food, especially with the important element nitrogen, which they contain in large quantity.

Broadcast, and Drill Sowing. There are three methods of sowing seed in common use. The first is to **broadcast** by scattering the seed over the ground by hand. The second is to scatter the seed in the same manner by means of one of the machines of which a number are made for the purpose of sowing broadcast. The third method is to sow the seed in parallel rows across the field with a **drill**. This implement contains several points called coulters, which make little trenches in the ground as the machine is drawn across the field to be sown. Just behind each coulter comes a tube, down which the seed gradually falls from a box or barrel above into the trenches. The advantages of drilling over broadcast sowing are these:—1. A saving of seed. 2. The seed is sown regularly all over the field, so that the plants braird and ripen all at the same time. 3. The seed is all put in at the same depth and covered over. This is especially of importance in those districts where the climate makes it necessary to have the seed at a certain depth. 4. The land can be more easily kept free from weeds, as the horse-hoe and cultivator can be drawn backward and forward between the rows, without any danger of injuring the plants. On the other hand broadcasting has some advantages over drilling:—1. The sowing can be done more cheaply. 2. The seed can be sown much more quickly. This is a great advantage in a fickle and uncertain climate.

SUMMARY.

The following short summary of the chief principles taught in this part will be useful to the learner, especially if he should try to give a reason or enlargement in his own words of each of the statements made:—

1. **The Plant** consists of root, stem, leaves, flowers, fruit, and seeds.

2. It is composed of the **organic** substances—cellulose, starch, sugar, oil, protoplasm, chlorophyll, &c. (all of which consist of carbon, oxygen, hydrogen, and the two last of nitrogen as well); and of the **inorganic or mineral** matters—potash, soda, lime, magnesia, silica, iron, chlorine, sulphur, and phosphorus.

3. Its food therefore consists of carbonic acid, oxygen, hydrogen, ammonia, nitric acid, phosphoric acid, sulphuric acid, silica, chlorine, potash, soda, magnesia, lime, and iron oxide.

4. These must reach the plant as gases in the air or completely dissolved in water in the soil.

5. **From the air** the plant derives its oxygen, carbon, and some ammonia and nitric acid. **From the water** it derives oxygen and hydrogen. **From the soil** it derives all the mineral or inorganic substances.

6. **The Soil** has been formed from hard rocks by the action of the sea, rain, rivers, glaciers, the oxygen and carbonic acid of the air, frost, and the growth of plants.

7. Soils may be local or transported, heavy or light, sandy, loamy, clay, peaty, marly or calcareous, rich or poor.

8. A fertile soil contains all the mineral matters required by plants, and **alumina** in addition.

9. The constituents of the soil may be **active** and soluble, or **dormant** and insoluble; the latter do not feed the crops until made soluble by the action of the atmosphere, or by plant roots.

10. **Cultivation** is assisted by rain, frost, oxygen, carbonic acid, &c.

11. Drainage is necessary in most soils: (*a*) To get rid of excess of water. (*b*) To make room for the air to enter the soil. (*c*) To allow the soil to get warmed by the sun. (*d*) To wash out sour and poisonous matters.

12. Pans or hardened subsoils: Plough pan, iron pan, calcareous or lime pan, and peat or vegetable pan.

13. Agricultural implements: Plough, subsoil plough, steam plough, cultivator or grubber, horse-hoe, harrow, and roller.

QUESTIONS.

1. What are the principal objects of agriculture?
2. Name the principal parts of a fully grown wheat plant.
3. What are the chief root crops, forage crops, and corn crops?
4. Describe the root of a turnip and of wheat.
5. What are the "eyes" of a potato?
6. What is the use of the ribs or veins of leaves? How do leaves take in air?
7. What happens to a turnip when left in the ground for two years?
8. What are the parts of a seed, and what do they become when the seed grows?
9. What things are necessary to enable a seed to germinate or begin to grow, and why?
10. What do you understand by a substance being soluble in water? Name a few very soluble substances.
11. What do you understand by the food of plants? How do plants feed?
12. What are the principal substances which form the food of plants?
13. Show why water is so necessary to plants.
14. What causes water to rise up through the plants?
15. What do you understand by **organic** substances? Name some found in plants.
16. Of what three elements are cellulose, starch, sugar, and oil composed?
17. What additional element is found in protoplasm and chlorophyll?
18. If a large stone is laid for a few days upon a grass plot, the grass under it will turn yellow and then nearly white. Explain this.
19. What becomes of the soft parts of a plant when it is burnt up?
20. Name the chief substances found in the ashes of plants. Why are they called **inorganic** substances?
21. What food do plants derive from the air?
22. Explain how they obtain carbon from the carbonic acid of the air.
23. What elements does a plant obtain from pure water?
24. What is the principal use of water to the plant?
25. What part of its food does a plant obtain from the soil?
26. How have most soils been formed?
27. How does such a hard rock as granite get crumbled down into soil?

28. What three minerals compose granite, and of what are they themselves composed?

29. Explain the action of heat and cold, and of frost and thaw upon hard rocks.

30. How does the growth of plants help to break up rocks and soil?

31. How does the crumbled rock get spread out into a flat bed or layer?

32. What is a transported soil? What is a local or sedentary soil?

33. How do you distinguish between the soil and the subsoil?

34. How could you separate the sand and clay in a particular sample of soil?

35. What is sand, and whence was it derived?

36. What substance occurs in clay which is not found in plants?

37. Of what is chalk composed, and how can it be converted into lime?

38. What happens when quicklime is exposed to the atmosphere?

39. Why are some soils of a dark colour?

40. What is a **loam** or loamy soil? How do loamy soils differ from each other?

41. What is a **marl**, and how do marls differ?

42. What do you understand by **poor** soils and **rich** soils?

43. What is meant by heavy and light soils? Which is really heavier, a bushel of clay or a bushel of sand?

44. What is capillary attraction, and how does it act upon moisture in the soil?

45. Which soils absorb and hold the greatest amount of water?

46. Give a list of the substances found in the soil.

47. How many of these are necessary to plants, and what happens if some of them are absent?

48. What do you understand by **active and dormant** constituents of soils?

49. How can the dormant or insoluble substances be converted into active ones?

50. How does the farmer endeavour to bring about this change?

51. Why is land sometimes allowed to rest or remain **fallow?**

52. What hurtful substances are sometimes found in soils, and how can they be got rid of?

53. Describe the action of rain, snow, and frost upon the soil.

54. What gases exist in the air and how do they act upon the soil?

55. In what two ways does carbonic acid act in the soil?

56. What acid is formed in the air during a thunderstorm?

57. Show the chief advantages of the cultivation of the land in the autumn.

58. What soils stand most in need of drainage?

59. What harm does standing water do in the soil?

60. How does drainage act upon the air immediately above the soil?

61. What is the great object of drainage?

62. How do most soils resist the danger which might arise from draining them too much?

63. What is the use of digging and ploughing?

64. What is a plough pan, and how is it produced?

65. What other "pans" give trouble to the farmer?

66. What is a subsoil plough, and what is the use of it?

67. Explain the use of the grubber, the horse-hoe, the harrow, and the roller.

68. What are the essential differences in the manner of cultivation of heavy and light soils?

69. What are the chief points to be attended to in forming a seed-bed?

70. What are the three things necessary to cause a seed to begin to grow?

71. Why is clover often grown just before wheat?

72. Why is it necessary to consider how deep the seed should be sown in the soil?

PRINCIPLES OF AGRICULTURE.

PART II.

THE PRINCIPLES REGULATING THE MORE OR LESS PERFECT SUPPLY OF PLANT FOOD; MANURES AS SUPPLEMENTAL SOURCES OF FOOD.

I.—AGRICULTURAL CHEMISTRY.

BEFORE going on in this second book to speak of the exhaustion of the soil by the growth of crops, and the means of avoiding or repairing this exhaustion by the use of various kinds of manures, it is needful that we should have a little more exact and definite knowledge of the Chemistry of the subject, though it will not be at all necessary to go into the more difficult parts of that study. You must bear in mind, however, that chemical knowledge is of little use if it is not *exact* as far as it goes; and therefore you should pay strict attention to the following facts, and get each one clear in your mind before going on to the next.

Chemical Elements. It has been found that the whole world and everything in it, at least as far as is known at present, is built up of about sixty-three simple substances, some of which exist in great abundance, while others have only been found in very minute quantities.

Again, some of these simple substances, or *elements*, as they are usually called, exist in a free state, so that we can easily see them and handle them by themselves, while others are only found disguised by being joined together in twos and threes, thus forming substances called compounds, which are quite different in appearance and properties from the elements of which they are made up.

Of the sixty-three known elements, forty-eight are metals, such as gold, silver, copper, iron, lead, tin, and many very rare and almost unknown metals. The other fifteen elements are not metals, but play a more active part than the metals in building up the earth and its inhabitants, though neither of the two classes, metals and non-metals, would do much without the other. The following is a list of the fourteen elements which are of importance in agriculture, and with which we should do well to become acquainted. They are placed in two columns as non-metals and metals.

Non-Metals.	Metals.
Oxygen.	Potassium.
Hydrogen.	Sodium.
Carbon.	Calcium.
Nitrogen.	Magnesium.
Sulphur.	Aluminium.
Phosphorus.	Iron.
Silicon.	
Chlorine.	

Non-metallic Elements. The first four on the list of non-metals are often called **organic elements**, because by far the greater part of organized beings, plants and animals, is made up of special compounds of these elements, and can be made up in no other way. But these same elements also make up a large part of the inorganic world (*in* = not) of earths and stones, so that the term organic elements is rather misleading. The **inorganic** elements constitute a small part of the whole structure of plants and animals, whereas they form a much greater proportion of the solid substance of the earth.

Of the organic elements **carbon** is the one which forms the chief bulk of plants. When plants are burned in a vessel closed so that little or no oxygen can enter, carbon appears in the form of the black solid substance known as *charcoal*. When freely supplied with oxygen the carbon combines with it to form *carbonic acid* gas. **Oxygen** in its free state is an invisible gas, which forms one-fifth of the bulk of the atmosphere, and, in a combined state, forms eight-ninths of the weight of water, and nearly half the substance of the whole solid earth. It combines with almost all the other elements to form *oxides*, as we shall see presently. **Nitrogen** when free is also an invisible gas, forming four-fifths of the bulk of the atmosphere, but its most important service to agriculture is rendered in combination with hydrogen, in **ammonia**, and with other elements in the form of *nitrates*. **Hydrogen**, when free, is the lightest of all gases. It combines with oxygen to form water, of which it constitutes one-ninth part by weight, and with nitrogen to form ammonia. **Phosphorus**, the light-producing substance with which common lucifer matches are tipped, and **sulphur** are more concerned than any other of the inorganic elements in the building up of the bodies of animals and plants, as they enter into the composition of albuminous substances, a very important class of organic bodies. They also enter into the composition of many inorganic substances in the form of sulphates and phosphates.

Of the remaining non-metallic elements **silicon** combines with oxygen to form *silica*, the most abundant constituent of soils. Fine white sand is almost pure silica, so likewise are flint and quartz; and it enters largely into the composition of most rocks and stones. **Chlorine**, when free, is a greenish, choking gas; but we chiefly meet with it combined with the metal sodium, in which case it forms chloride of sodium; that is, *common salt*, the substance which is so plentiful in sea water, and which occurs so freely in plants and soils.

Metallic Elements. In the list of elements given above you will see only one well-known metal, namely **iron**. Copper, zinc, and other metals have been found in plants, but seem to have been only accidentally present, and may therefore be omitted by us here. The other metals mentioned in the list are commonly known to us only in combination. **Potassium** is the metal contained in potash, **sodium** in soda and common salt, **calcium** in lime, **magnesium** in magnesia and Epsom salts, and **aluminium** in alum and in clay.

It may seem to you almost impossible that a bright shining metal can exist in the crystals of salt or soda, or in white powdery chalk, or in earthy clay, and yet such is certainly the case. You may perhaps realize this clearly in the following manner. You can buy at the chemist's a small piece of magnesium wire (sold at about 3*d.* per foot), which you will see is a dull whitish metal. It is quite bright when newly made, but easily attracts oxygen from damp air, and becomes *tarnished* or coated with a layer of oxide which dulls its surface. Now, take one end of this with a pair of pliers, and hold the other end in the hot flame of a lamp or gas-burner. The metallic wire takes fire and burns with a splendid brilliant light. The metal magnesium is now combining with the non-metallic gas oxygen, and forming the compound magnesia, which falls down from the dazzling flame in the form of a white powder—the very same powder which is used for medicine under the name of *calcined magnesia*, and which must therefore contain the metal magnesium disguised in this curious manner.

Exactly in the same way the white powdery substance *lime* contains a yellowish metal, *calcium*, and the dirty-looking substance *clay* (which, however, when pure is clean and white, as may be seen in the pure clays used in making "china") contains the lustrous metal *aluminium*, used very much now in making pencil-cases, cheap watches, and mathematical instruments. So again *soda* and *potash* contain the metals *sodium* and *potassium*. These two metals have such a strong liking for oxygen that they cannot easily be kept in the metallic state. A small piece of potassium thrown upon water immediately seizes oxygen from the water, forming potash, and sets the hydrogen free, which even takes fire upon the water with the great heat caused by the union of the metal with oxygen.

Chemical Compounds. You will now understand from what has been said that some of the elements readily combine together to form compounds. Those elements which are most *unlike* each other combine most easily, and the compounds are quite unlike either of the elements of which they are formed. Of the fourteen elements given above, oxygen combines directly with all except chlorine to form oxides. The following compounds of *two elements* are very important in agriculture. They are divided into two groups—**acids** or sharp compounds, as we may say; and **bases,** or flat compounds. The members of one group are unlike those of the other, and therefore, they have more tendency to combine together to form double compounds called **salts**, in which the sharpness of one member neutralizes the flatness of the other. Water lies between the two groups, and may be called an *indifferent* oxide, as it is neither an acid nor a base, but in certain circumstances can act the part either of the one or of the other.

	Common Name.	Formed from
Acids,	Carbonic acid	Carbon and oxygen.
	Sulphuric acid	Sulphur and oxygen.
	Phosphoric acid	Phosphorus and oxygen.
	Nitric acid	Nitrogen and oxygen.
	Silica	Silicon and oxygen.
	Water	Hydrogen and oxygen.
Bases,	Ammonia	Nitrogen and hydrogen.
	Potash	Potassium and oxygen.
	Soda	Sodium and oxygen.
	Lime	Calcium and oxygen.
	Magnesia	Magnesium and oxygen.
	Alumina	Aluminium and oxygen.
	Iron oxide	Iron and oxygen.

Salts. We have just seen that the action of an acid upon a base forms a salt. Thus, for instance, carbonic acid combines with the base lime to form the salt *carbonate of lime*, that is, chalk; so nitric acid combines with potash to form *nitrate of potash*, commonly called saltpetre or nitre; and so on. We will now mention the most important salts with regard to agriculture; and after what has been said you will probably have little difficulty in understanding their composition and their uses to the farmer in his endeavour to supply food to his crops.

Potash Salts. The chief of these are the *carbonate of potash*, forming a great part of the ashes of wood when burnt; the *muriate* or *chloride of potash* and the *sulphate of potash*, which are also contained in the manure called *kainit*, and *nitrate of potash*, called *nitre* or *saltpetre*.

Soda Salts. *Carbonate of soda* occurs in the ashes of many plants, and *nitrate of soda*, or "Chili saltpetre," is a valuable manure. The commonest soda salt is *chloride of sodium* or common salt, which is formed by the direct union of two elements, *chlorine* and *sodium*.

Lime Salts. These are very important. *Carbonate of lime* or chalk is much used for manure. When the carbonate is heated in a kiln the carbonic acid is driven off, and lime only is left, which in this state is called *quicklime*. If water is poured upon this a chemical action takes place; the water combines with the lime, causing great heat, and forming hydrate of lime or *slaked lime*. If this is left exposed to the atmosphere for some time it gradually collects carbonic acid from the air, and is thus again converted into carbonate of lime.

Let us look a little at the exact chemical changes that occur in lime when treated in this manner. The *carbonate of lime*, which is limestone or chalk, is a salt, and consists of carbonic acid (CO_2) united with the base lime, or oxide of calcium (CaO). It is represented by the chemical symbol CaO,CO_2. When the carbonate of lime is burned in a kiln, the carbonic acid (CO_2) is driven off, and the remaining *quicklime* is the oxide of calcium (CaO). When water (H_2O) is poured on the quicklime, the water acts as an acid, and unites with the base, quicklime, to form the salt, *slaked lime* or hydrate of lime (CaO, H_2O). If the slaked lime be exposed to the air, the water (H_2O) is gradually displaced by carbonic acid (CO_2), and there is a return to the original compound, the carbonate of lime (CaO, CO_2).

Another useful salt of lime is *gypsum*, which is a sulphate of lime. But the most important of the lime salts for our purpose is the **phosphate of lime**, which forms the chief part of the mineral matter of bones. If you put a bone in a clear fire and allow the animal matter to burn out of it, the bone will keep its shape, but will be quite brittle, and can easily be broken down into a white powder. This white powder is almost all phosphate of lime. You will see further on how it is made use of for manure.

Composition of the Air. The atmosphere plays such an important part in the growth of crops, that it is very necessary we should have a clear idea of its nature and composition.

The main bulk of the air is made up of the two gases **oxygen** and **nitrogen**, in the proportion of one-fifth of the former to four-fifths of the latter, mixed together, not chemically united. Of these two gases the oxygen only is active, entering plants by their leaves, and especially combining with many other substances in the air and in the soil—where, you will remember, it should be freely admitted by means of drainage —and thus neutralizing hurtful matters, and forming valuable food for the use of the crops. The nitrogen in the air acts merely as a moderator to the oxygen, preventing its too fierce and rapid action. Nitrogen does not directly enter the plants (with the exception of Leguminous plants, see pp. 179 and 180), and therefore, as nitrogen is one of the necessary organic elements, plants must obtain it in some other way.

Besides the oxygen and nitrogen, the atmosphere constantly contains four other substances very useful to the farmer. These are *carbonic acid gas*, *ammonia*, *nitric acid*, and *watery vapour*. The first three exist, it is true, in comparatively small quantities; but when we remember the vast extent of the atmosphere, and the manner in which it is constantly being moved from place to place in the form of wind, we shall see that there is really a large supply of these substances. The **carbonic acid** is the great source of the supply of *carbon* to plants. They take in the carbonic acid by their leaves, and separate it into its elements carbon and oxygen. Most of the oxygen is given out again to the air, while the carbon is made use of by the plant in building up its parts—the cells and their contents—starch, sugar, oil, gum, &c., all of which contain a large proportion of carbon.

The **ammonia** and **nitric acid** of the air are washed down into the soil by the rain, as they are very soluble in water. There they are retained more or less firmly, enriching the soil with a quantity of *nitrogen*, which you will remember they both contain. Bear in mind that the ammonia and nitric acid of the air are two important natural sources of the supply of nitrogen to plants. It has been calculated that from these two sources each acre of soil has washed into it every year about eight or nine pounds of nitrogen.

The other great component of the atmosphere is **watery vapour**, that is simply water in the form of an invisible steam or gas. This is principally of use to the crops when it falls in the form of rain, and soaks its way down to the plant roots. Very little is taken in by the leaves of plants; on the contrary they are continually adding to this vapour by drawing up water from the soil by means of their roots, whence it passes into their leaves, and is there transpired or exhaled into the air. In this way an acre of green crop may pour out into the air several tons of water-vapour every day.

Decay of Plants and Animals. When a plant or an animal dies it soon begins to decay; that is, the complicated organic substances making up its softer parts begin to break up into simpler chemical forms. This decay or putrefaction (*L. putri-* = rotten, *fac-* = to make) is caused by the growth of minute organisms (Fig. 11), the *germs* of which are floating in

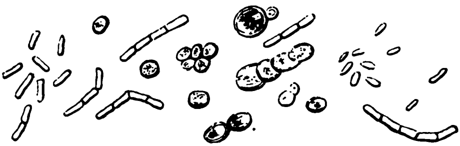


Fig. 11.

the air, and which break up the organic substances (consisting, you will remember, of oxygen, hydrogen, carbon, and nitrogen built up in a very complicated manner) into much simpler substances, such as water, carbonic acid, and ammonia, each of which contains only two elements. If you do not remember what these are, turn back to the list on p. 53, and get them quite clear before going on farther. Now, if the animal or plant decays in the air these gases escape, causing a disagreeable smell; and are lost to agriculture, at any rate for the present. But if the dead matter be placed under the surface of the ground to decay, the soil has the power of **absorbing** these gases. This power of absorption is possessed principally by the humus or organic matter of the soil and by the clay, especially by that small portion of the clay which has taken the form of the **double silicates**, silicate of alumina and soda, silicate of alumina and lime, &c. On this account wounds which would otherwise become corrupt are sometimes dressed with clay soil, which absorbs the corrupting matter and makes them sweet and clean. Thus we see then how the dead plant or animal turns into the simple gases, and is then completely absorbed by the soil, or held in combination with it until required by the growing plants. The mineral or inorganic substances of the decayed plant or animal also crumble gradually in the soil, where they remain as carbonates, phosphates, sulphates, or silicates, either in a solid form or dissolved clearly in water, and ready to supply inorganic food to a new generation of plants. There is thus a ceaseless round of chemical change going on in the air, in the soil, in plants, and in animals, which the wise farmer will carefully study, and of which he will take advantage wherever he can.

Life in the Soil. Every part of the soil where any organic matter is present, is full of life. Worms swallow portions of the soil to get at the organic matter which it contains. Grubs of insects also attack the roots of growing crops, and are sometimes very hurtful to the farmer. They, however, do some good, for they also feed on decaying roots and organic matter in the soil. The food of the grubs and worms, like that of other animals, is changed ultimately into water, carbonic acid, ammonia, and mineral matter. Till these changes are completed decaying organic matter in the soil is only of indirect use to plants. Green plants cannot feed upon decayed matter directly; it must be changed for them into the chemical compounds named. These are retained very firmly in the soil till plants require them, but when the nitrogen of the organic matter is converted into the form of nitrates it is liable to be lost by drainage, especially from light soils. This loss may be prevented if crops be grown which can make use of the nitrates, and transform them into fresh vegetable matter. But there is a set of plants called **fungi**—to which class mushrooms and "toadstools" belong—which have the power of feeding like animals upon vegetable matter directly. These exist in the soil, and help in the work of preparing food for the higher plants. An interesting sign of this action exists in the so-called "fairy rings," which have long been a puzzle to naturalists. These are often found in pastures, and are due to the growth of fungi. The fungi, growing in any spot, feed freely on the organic matter in the soil, and in their decay leave it rich in food in a condition in which it is readily available for the use of the higher plants. The grass in that spot grows luxuriantly in a dark green tuft. The fungi extend their growth in a constantly widening circle, and are followed by a ring of grass which is noticeably greener than the rest.

But, besides these larger animals and fungi, the soil swarms with minute forms of life only to be seen with the microscope. Some of these are shown very much magnified in Fig. 11. Some very minute microscopic ferments or plants, which occur in all fertile soils, do a very important work for the farmer. It has recently been discovered that they help to prepare food for crops by converting the nitrogen in the soil from other forms into that of a **nitrate**. It is now believed that plants take up most of their nitrogen in the form of nitrates. The process of change by which the nitrates are prepared is called **nitrification**, and it cannot be brought about without the aid of these little plants in the soil.

Conditions Necessary to Nitrification. For the proper progress of these changes in the organic matter of the soil, and to make them useful to the farmer, four conditions are necessary. 1. The presence of **oxygen**. Here we see a further reason for the good cultivation of the soil and thorough drainage, by which the air with its oxygen may be admitted. 2. **Moisture** in moderate quantity must be present, such as may be got in well-drained soils, and in a moist climate; stagnant water will not do. 3. **Warmth**: the nitrification goes on more rapidly in the summer time than in winter. 4. The presence of some **base** in the soil capable of uniting with the nitrogen to form nitrates. The most convenient substance for this purpose is carbonate of lime; the base, lime, unites with the nitrogen to form nitrate of lime, which is quite a useful form of nitrate for the crops. These conditions are favoured by good tillage. Warington has estimated that during the fallowing of an ordinary soil at Rothamstead about 64 lbs. of nitrogen are converted into nitrates on every acre in a year, and are then ready to be used by the crops. This nitrogen is principally derived from the organic matter left in the soil by former crops in the form of roots, and by unused manure.

II.—EXHAUSTION OF THE SOIL.

In the first book of this course we have studied, 1st. The structure and composition of **plants**, and the manner in which they take their food; 2d. The mode of formation, and the mechanical and chemical composition of the **soil** from which much of that food is derived; and 3d. The best methods of **tilling that soil**, so as to get the food ready for the use of the plants, and fit to support them during their growth.

We have now to consider more especially the circumstances under which some soils have an abundant and perfect supply of plant food, while others are wanting in some necessary substances; together with the manner in which the substances wanting in any particular soil may be supplied by the farmer so as to make that soil fertile.

Active and Dormant Constituents. The whole of the soil is never in a fit state to form the food of plants. Only that proportion of its constituents is useful which can be dissolved so completely in water, with the help of plant roots or of organic acids, that it can enter the tiny rootlets and root-hairs of the plants. This soluble or **active** matter forms a very small proportion of the soil; the rest consists of the same substances, but locked up in reserve, as it were, or sleeping, and they are therefore said to be in a **dormant** state, from which they can only be awakened by the action of such agents as oxygen and carbonic acid. This is why the soil is turned over frequently, and as long as may be before the crops require their food, that the air may have time to act upon the dormant substances, and render them active and useful as food. Should it happen that this time and opportunity are not allowed, then one crop may use up all the active food of one or more particular kinds, so that the next crop cannot get enough of those materials and suffers accordingly. The soil is then said to be **exhausted**. This exhaustion shows itself in the weak and sickly appearance of the crop, and more especially in the small amount of produce which it yields compared with what it should yield in an unexhausted soil. You see that an exhausted soil may be a perfectly good one if it only has time to recover itself, and to have its dormant stores of plant food awakened by the action of the agencies in the air and in the soil itself. On the other hand, some soils are so poor and deficient in some of the necessary elements of plant food, that even if all the dormant substances in such a soil could be converted into an active state they would be used up by the crops in a few years, and the soil would then be thoroughly exhausted, and could only be rendered fertile by the artificial addition to it of the materials it had lost.

Instances of Exhaustion. In some of the older slave states of America the soil has been so long cultivated with one or two kinds of crops—as much as possible being taken out of it, and little or nothing put in—that large tracts of soil have become exhausted, and have therefore been abandoned and left waste. So, also, in the more northern states which have been long settled, immense crops of wheat and maize were grown, year after year, until it was found that the land would no longer produce those crops in abundance; the settlers therefore moved farther westward, cultivating new soil, which in time became exhausted, and was abandoned in its turn. But this is a very wasteful mode of cultivation, and will not answer in countries containing large numbers of people. Here it is necessary by some means to restore fertility to the exhausted soil, and to make it able to go on producing crops for hundreds of years. Before we go on to consider how this can be done, we must inquire more particularly what substances, and how much of each, are taken from the soil by the various crops grown upon it.

Sources of Plant Food. You will remember that the food of plants consists of the following substances:—

PLANT FOOD.

A. *Organic Matters.*—Forming the softer parts, which may be burned away into gas and smoke.

Carbon.	Hydrogen.	{ Sulphur. }
Oxygen.	Nitrogen.	

B. *Inorganic Matters.*—Forming the ashes left behind when the plants are burnt.

Potash.	Phosphoric acid.
Soda.	Sulphuric acid.
Lime.	Carbonic acid.
Magnesia.	Silica.
Iron.	Chlorine.

Of these you will also remember that the organic elements, carbon, oxygen, and hydrogen, can be obtained by the plants from the air and water, and much of the nitrogen can be got from the ammonia and nitric acid washed out of the air by the rain. The carbonic acid, too, of the inorganic matters can be derived in the same way from the air; but all the rest of the substances forming the ashes of plants can only be obtained from the soil. It has been found by careful experiment that three of the above-mentioned inorganic substances, namely, soda, silica, and chlorine, are not absolutely necessary for all plants; but, as they are always found in plants grown in a natural manner, it is most probable that they are beneficial to their healthy growth.

Exhaustion by Continuous Growth. In a natural forest or prairie there is no exhaustion, for, as the plants and trees decay, their leaves and branches return to the soil, and supply to it the very same substances taken from it by their growth, as well as the carbon and ammonia which they have derived from the atmosphere. The long roots also bring up nourishment from the subsoil, which they leave in the form of decaying vegetable matter or humus in the surface soil, which thus becomes richer instead of poorer by their growth. And even if a large portion of the produce is eaten by wild animals, it is merely laid up for a time in their bodies, to be returned to the earth when they die.

But the case is very different when we grow large quantities of corn upon a piece of ground and then cut it and carry it away, using the grain for human food and the straw for fodder or for manufactures. In this case the mineral matters are carried quite away from the soil, with no chance of return. And even should it be a grass field, in which cattle and sheep are turned to graze, although it is true they return part of the mineral matters to the soil in their excrement, yet their bodies, which have been built up out of the grass they have eaten, are at last carried away to be consumed elsewhere.

Thus we see that if crops are constantly grown upon the same soil, and carried away to be used by men and animals, the materials of plant food will be carried away little by little, until some of them which were not very abundant at first, or which have been more especially wanted by the crops, will be quite used up, and the soil will become exhausted.

This exhaustion of the soil may be prevented to a great extent by good cultivation. For, as it is only the soluble or active portions of the soil which have been carried away, there is still a reserve of dormant matter to work upon. By turning the soil over in autumn, and exposing it to the frosts of winter, we encourage the oxygen and carbonic acid of the air to act upon it. By deep ploughing and thorough drainage we admit these friendly agents to all parts of the soil, and thus cause the dormant supplies of plant food to become soluble and active, so that new portions can be brought into use by the plants year after year.

Exhaustion may also be delayed by returning to the soil as much as can be spared of the plants grown upon it. This is well illustrated by the practice of the wood-cutters of Heidelberg, in Germany, who lop off the smaller branches and twigs and burn them, and then strew the ashes over the ground upon which the trees grew. In this way much of the plant food which has been taken from the soil by the plants may be returned to it again. But sooner or later the supply of some article of plant food will run short, and in that particular the soil will be exhausted.

Principle of Least Supply. You must carefully bear in mind that the fertility of the soil depends upon that substance of plant food which it contains in least abundance. Suppose you were putting together a particular pattern with variously-coloured tiles, say *red*, *blue*, *yellow*, and *green*. You have a large mixed heap of the tiles to use from; but after working for some time you find you have used up all the *red* tiles. You will then be unable to go on with your pattern, although you may have plenty of blue, yellow, and green tiles. But if, before your red tiles were exhausted, you saw you had a short supply, and therefore determined to change your pattern for one which did not require so many red, you would then be able to go on with the new pattern until perhaps some other colour ran short. So it is with the crops. They require eight or ten different kinds of food; and if any one of these runs short the crop cannot get on, although all the other food-stuffs may be abundant in the soil. This is a point which cannot be too often insisted on—that each kind of plant food is necessary, and that the absence of one kind cannot be made up by a plentiful supply of another. The roots of the plants must obtain from the soil all the substances they require; and if they do not find a supply of *every* substance, they either die or they grow in a stunted and sickly fashion.

Substances taken from the Soil by various Crops. The substances removed from the soil in this way are not exactly the same for each crop, or rather are not taken in the same proportion. One crop takes more *potash*, as turnips; another more *lime*, as clover; a third more *silica*, as wheat; and so on. Each crop has its own *pattern*, as it were, which requires a special set of substances to build it up. The following table shows the number of pounds weight of the most important mineral substances of plant food removed from an acre of land by moderate crops of various kinds. Of course larger crops would take larger quantities of food, but the *proportion* between the substances taken by each crop would remain about the same.

LBS. PER ACRE.	TURNIPS.	BARLEY.	CLOVER.	WHEAT.
Potash, ...	*149	31	87	28
Soda, ...	*25	5	4	3
Lime, ...	74	10	*86	10
Magnesia, ...	10	7	*31	8
Phosphoric acid, ...	*33	21	25	23
Sulphur, ...	*21	6	9	8
Silica, ...	8	64	7	*100
Iron oxide, ...	2	2	1	1
Chlorine, ...	*22	4	9	3
Totals, ...	344	150	259	186

These numbers are not given for you to learn, for they would not be the same for all crops even of the same kind. Some kinds of wheat, for instance, contain more potash than others. Barley grown on one soil contains more or less of some mineral substances than the same kind of barley when grown on another soil, and so on. Then, again, a favourable season may make a crop twice as heavy as it would be in a bad season, and it will then, of course, draw from the soil twice the quantity of all the mineral matters it feeds upon.

But looking carefully through the numbers in the table as it stands, and taking it to represent a fair average set of crops, we may see plainly that these crops differ very much in the amount of mineral matter which they draw from the soil. Looking first at the *totals*, we see that a fair crop of *turnips* requires much more inorganic food than one of clover, while clover requires more than wheat or barley. Turnips and clover are therefore more exhausting crops in this respect than wheat or barley. But looking again at the table—and noticing especially the numbers pointed out by asterisks—we see that the various substances are taken in very different proportions. Turnips take more *potash* than the other crops, more *soda*, more *phosphoric acid*, more *sulphuric acid*, and more *chlorine;* but clover takes the most *lime* and *magnesia*, and wheat and barley take by far the most *silica*. All the crops take a fair amount of *phosphoric acid*, and all agree in requiring very little *iron*.

You will notice that barley and wheat are very much alike in the above table, and all other *cereals* or corn crops, such as oats, rye, and maize, resemble them in requiring somewhat similar quantities of mineral food; so also do the true grasses, which belong to the same order of plants as the cereals. Clover, though often classed by farmers with grasses, belongs to the order of *leguminous* or pod-bearing plants, to which also belong peas, beans, sainfoin, and vetches, and these resemble clover in their mineral composition, requiring relatively large quantities of lime and magnesia. Turnips may be taken to represent the "*root crops*," including mangels and carrots, which, however, belong to different orders of plants, and vary among themselves in the mineral matters which they draw from the soil.

It has been found by careful experiment that the mineral substances already named are necessary for the successful growth of crops. Many interesting observations upon the growth and food of plants have been made by growing plants in water without any soil at all, and adding to the water the food that was thought necessary for their growth. In this process of **water culture** a cylinder or bottle is used with a wide mouth fitted with a cork in which a notch is cut to hold the young plant (Fig. 12). Seeds of maize or other plants are caused to sprout by keeping them in moist cotton or sand, and then the strongest plant is selected and fixed in the notch of the cork by packing the stem round with cotton. The bottle is then filled with pure water nearly up to the seed, and the plant will continue to grow and thrive until nearly all the store of food in the seed is

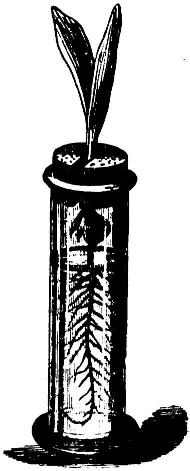


Fig. 12.

exhausted. Then the pure water is taken out, and water containing plant food in solution is introduced, to try the effect of different kinds of food and manures upon the plant's growth. In this manner, and by removing the plants to larger vessels as they grew, Professor Wolff produced a maize plant nearly six feet high, and four oat plants yielding 1535 well-developed seeds. It is interesting and important to notice that in a quart of water one drop of chloride of iron was sufficient to keep the plant in health, while the absence of that drop caused the plant to become yellow and weak, and cease to grow. Plants have also been grown in artificial soil from which one substance of plant food was carefully shut out, and although all the other matters were present in abundance the plants drooped and died. Other plants, grown in the same way and beginning to droop, were brought into good health again by adding to the soil a little of the particular substance which had been left out. Even the small quantity of iron which is found in all plants, is, as we have seen, absolutely necessary for their growth, and is found to be active in connection with the formation of the green colouring matter existing in the leaves of all plants.

It is true that plants do often take up more of some mineral matters than they require, especially of *silica* and *soda*, for they have been grown artificially with much less of these substances than they usually take up. It is thought possible that the plants find it more convenient in the open ground to take in a larger supply of soda and silica than they require, as by that means they are able to get a more perfect supply of the more necessary substances, nitrogen, potash, or phosphoric acid.

We may therefore safely say that *all the nine mineral substances* included in the table we have been considering, together with a supply of *nitrogen*, are required for the perfect growth of all crops.

Exhaustion of Nitrogen. We have seen that various crops require to take various mineral matters from the soil, so that if the same kind of crop is grown year after year in the same soil, it soon exhausts it of some of its soluble inorganic substances. But, besides the mineral matters, the crops also depend upon the soil for a large part of their *nitrogen.* Much of this important organic element is carried down by the rain in the form of ammonia and nitric acid; but a store of nitrogen exists in all fertile soils in the dead roots of plants, and in the decaying vegetable matter or *humus,* which gives the dark colour to many soils. The nitrogenous matters of the humus, like the mineral matters of the rest of the soil, are liable to become exhausted by the continuous growth of crops on the same soil.

Remedies for Exhaustion. There are three ways in which this exhaustion of the soil can be prevented or remedied. These are: 1. By giving the land **rest**; 2. By **change of crops**; and 3. By the use of **manures.**

Rest and Fallow. Suppose a field to be exhausted of all its soluble potash by the continual growth of crops upon it requiring large supplies of that substance. By ploughing up the land and leaving it for a year without crop, the atmosphere would have time to act upon it; the rain and snow and the frosts of winter would break up and crumble the hard particles of soil, and allow the *oxygen* and *carbonic acid,* the farmer's friends in the air, to act upon the dormant or insoluble matters, and bring them into an active and soluble state, and thus a new supply of potash would be got ready for the crop when the time of rest should be over. During this time the land is said to be lying **fallow** (an old word meaning pale or reddish yellow, that is, not green with crops). It is generally ploughed four or five times during the year and stirred with the cultivator, to open the soil to the air, and to prevent the growth of weeds, which would spring up from seed carried by the wind or lying dormant in the soil. These weeds, if allowed to grow, would do a great deal of harm to the fields by producing large quantities of seed, which would mostly fall into the ground and give the farmer much trouble for a long time after.

Land that is left for a time without a crop, and often also land laid down to pasture, are said to be left *to rest.* This resting of the land may be compared to the resting of our bodies in sleep. While we sleep at night the heart keeps beating, and sending the blood to all parts of the body; building up any parts that have been much used and worn away during the day, and getting the body ready to begin work again in the morning. So with the land during a fallow: the air circulates among the particles of soil, causing chemical changes to take place in them, and setting free the dormant matters, both mineral and nitrogenous, ready to supply soluble plant food to the next year's crop. You will remember the action of living ferments in the soil upon organic matter. During a fallow they are at work increasing the supply of nitrates and enriching the land for the next crop. Warington, in one of his experiments, found that after a crop of beans which had been fully manured, the land contained 19½ lbs. of nitrogen per acre; but after the same field had been left fallow the next year it contained 48½ lbs. per acre. Another field which was sown with wheat without manure, contained when the wheat had been removed only 2½ lbs. of nitrogen per acre, yet after a year's bare fallow this same field yielded 33½ lbs. The great danger of a bare fallow, especially on light soils, is that the nitrates and other soluble plant food should be washed out by the rain, and it is partly to meet this difficulty that fallow crops are grown which take up this soluble food and make it into green fodder or roots.

The custom of giving the land rest is a very old one. You will probably remember that Moses ordered the Jews to leave the land fallow every seventh year, showing that the need of rest for the soil was felt in very early times.

Fallow Crops. If nothing at all is grown on the land it is called a **bare fallow.** But there are some crops which can be grown in rows wide apart so as to allow the drill grubber, the horse-hoe, and even special ploughs to be used between the rows, and thus the land can be stirred and cultivated, cleared of weeds and exposed to the atmosphere, almost as well as if no crops were growing upon it, and at the same time the soil is being turned to a profitable use by the growth of a supply of cattle food. The roots of the crop also bring up plant food from the subsoil into the surface soil, and thus the soil is enriched with matter which is left in the ground for the next crop. The principal crops grown in this way, and called *fallow crops*, are turnips, mangel-wurzels, both commonly known as "roots," and also cabbages, kohl-rabi, potatoes, and in some soils carrots and parsnips.

Change or Rotation of Crops. Land is never allowed by farmers to remain more than one year in bare fallow, and it is not customary to grow any crop, with the exception of the pasture grasses, more than one year in succession on the same land. The common practice is to grow a few crops one after another, changing the crop every year for several years, after which a return is made to the first. This makes a set of changes which is called a **rotation**, that is, a *round* of crops. I daresay you have found that you can keep on working for a much longer time without rest if you change your work every now and then, than if you keep on all day at the same thing. This is chiefly because you use different parts of the body for the different kinds of work, so that one part can rest while another is working. So it is with the land; different crops require different materials and use different parts of the soil; and just as you might say, "I am sick of this work, I should like a change;" so a farmer may say, "My field is not giving me good crops of potatoes; it is sick of potatoes, and I must give it a change." This failure is due to the exhaustion of some special materials of plant food. Now, if a different crop be grown upon the land, it may not require so much of one particular kind of plant food as the first crop did, but may use a different set of substances, and thus give time for the former to become soluble, and to accumulate in the soil, until the first crop comes round again, when it will find a perfect supply of food. A farmer, therefore, prevents his land from becoming sick of a crop by growing a regular round or succession, or *rotation* of his crops. Thus, a very common rotation is the following, called the Norfolk course:—

First year, ...	Turnips.
Second ,, ...	Barley.
Third ,, ...	Clover.
Fourth ,, ...	Wheat.

Let us try and understand this by the help of the table on page 64. The **turnips** take out of the soil large quantities of *potash*, *soda*, *phosphoric acid*, *sulphuric acid*, and *chlorine*. Another crop of turnips the second year would want, of course, the same kind of food, so that there would be a danger of some of these substances running short. Therefore the second year **barley** is sown, which takes up much less potash, soda, sulphuric acid, &c., but more *silica*. The third year comes the **clover**, requiring a moderate amount of potash and phosphoric acid, very little silica and soda, but a large supply of *lime* and *magnesia*. This is followed in the fourth year by **wheat**, taking up, like barley, a large amount of *silica* and a small share of more important and less plentiful substances.

By this time the soil has been able to recover itself, and the potash and other substances required by the turnips have been rendered soluble by the oxygen and carbonic acid of the atmosphere. There are many other systems of rotation followed in various parts of the country, and extending over five, six, or more years according to the quality of the soil and character of the climate. Some soils are so fertile that the same kind of crop can be grown upon them year after year for a time without any sign of exhaustion, especially if they are well cultivated, so as to bring their dormant constituents into an active condition. Others again are so poor that they can only be made to grow certain crops, which require very little of the substances in which these soils are deficient.

Mechanical Value of Rotation. Another great use of the rotation of crops is the opportunity which it gives of clearing and cultivating the land, getting rid of the weeds, and bringing the soil into a fit mechanical state for the successful growth of the most valuable crops. Thus, to take the Norfolk course again as an example:—(1) Turnips; (2) Barley; (3) Clover; (4) Wheat. To prepare for the turnips the land is ploughed deeply in autumn, and the weeds are drawn out and gathered into heaps by the grubber and harrow, and burned or laid aside to rot. The seed is sown in rows far enough apart for the cultivation to go on while the turnips are growing. The barley and clover are generally sown together the second year. The barley is not very deep rooted, and it draws its food from near the surface; the clover has long roots, which penetrate to the subsoil and bring up nourishment from below. After the barley is cut the clover continues to grow among the stubble, and during the third year provides excellent fodder for cattle and sheep, and at the same time prepares the soil for the wheat by laying up in its numerous branching roots a supply of nitrogenous plant food, which it has brought up from the subsoil. So that, when the clover has been cut or eaten off by sheep, and the roots ploughed in, an excellent and nourishing seed-bed is prepared for the wheat in the fourth year. The clover-roots as they decay supply nitrogenous plant food to the wheat, and also improve the mechanical texture of the soil, binding it together if too loose, but opening it if too stiff and clayey, and thus assisting the entrance of air and improving the drainage.

III.—USE OF MANURES.

The great remedy for the exhaustion of the land, brought about as we have seen by the continual growth of crops upon it, is the use of manures.

You have no doubt seen manures used upon land and in gardens, and you knew that in some way or other they made the plants grow better than they would without it; but without having any very clear idea of *how* this could be. But I hope now you will be able to realize more exactly what the manure does to the land and to the crops, and also what it does not do. For many mistakes are made in this matter, and many hundreds of pounds have been wasted in buying manures which could not possibly do what they were expected to.

Action of Manures. There are three principal modes in which manures act upon the soil so as to help it to produce more and better plants.

1°. They **supply deficiencies** in the plant food of the soil. To do this they must, of course, contain the substances which are wanting in the soil.

2°. Some manures **act mechanically** on the soil by their mere bulk and substance, making clay soils, for instance, lighter and more porous, or binding sands together and making them closer and more compact.

3°. Some manures **act as a stimulus** (L. *stimulus* = a goad or spur) in such a way as to cause the soil to give up for the immediate use of the crop some of its reserve stores of plant food, instead of keeping them back for future use. They act in fact like *whips* or *spurs*, driving the soil to do more work in a given time.

Some kinds of manure serve all three of these purposes, others two out of the three, and others only one.

The various manures used by farmers may be considered as belonging to the following classes:[1]—

1. *Green manures* (ploughed in).
2. *Farmyard manure.*
3. *Lime, chalk, and marl* (calcareous or natural).
4. *Artificial manures.*

I. Green Manures. We have already seen that the roots of the clover crop ploughed into the land supply valuable food for the wheat crop which follows. The long roots of the clover have brought up much plant food from the subsoil, and the broad green leaves have absorbed abundance of it from the atmosphere. After the crop has been cut much of this nutritious matter remains behind in the parts of the stems and the clover roots, and when these are ploughed into the land they die and rot in the soil, yielding up to the following crop the substances they had gathered from the soil and from the atmosphere.

Green Crops ploughed in. But sometimes the whole of the green crop is ploughed into the soil, and, in fact, is grown for that purpose only. Valuable crops such as clover, grass, and wheat, are never ploughed in as manures. But such crops when cut or grazed always leave a large quantity of stubble, debris, and roots, which when ploughed in act as green manures. But some quick-growing crops are specially cultivated for this purpose. The seeds of turnips, rape, rye,

[1] See also Part IV., pp. 167–178.

white mustard, &c., are sown thickly; and when the young plants are strong and green, the whole crop is ploughed in to enrich the soil. The best time to do this is just at flowering time, because then the plant contains the greatest amount of organic matter in the fittest condition to decay rapidly in the soil. Green manuring is a very perfect way of restoring fertility to the soil, for the plants have collected the greater part of their organic matter from the atmosphere, and by the decay of this organic matter in the soil, ammonia and carbonic acid are produced, while the mineral matters, which the plants collected from various parts of the soil and subsoil, are returned to the surface soil in a form suitable for use by other crops. The green vegetable matter also benefits the soil mechanically, breaking up stiff sticky clays and making them looser and more porous; or, on the other hand, enriching dry poor sands, adding to them organic matter, and giving them more power to hold moisture and soluble manures.

The principal reason why green manuring is not so much practised as we might expect, is, that cattle and sheep fetch such a high price, that farmers rightly think it more economical as a rule to feed them upon the green crops first, and use their dung as manure, adding to it by buying artificial manures to supply to the soil those substances which the animals keep and carry off in their own bodies.

Feeding off with Sheep. In such cases, instead of the crop of white mustard, or turnips, or rape being gathered and carried away, sheep are turned upon it, and allowed to eat it upon the land. In this way not only are the deep roots left in the ground; but the sheep return to the surface in their droppings all those constituents of the crop which are not used in their bodies in building up their bones and flesh, or cast out into the atmosphere in their breath and perspiration. The substances of most importance to the farmer returned to the soil in this way are phosphoric acid, potash, and nitrogen; so that, when the roots and droppings are all ploughed in, the soil is enriched with a large quantity of plant food suitable for the next crop.

Sea-weed and Fern, and some other cheap vegetable substances, are often used in a fresh state as manures, and act exactly in the same way as crops grown for the purpose; except that, as they obtained their materials from other soils, or from the sea-water, they may contain substances in which the soil to which they are applied is deficient, and, therefore, may in some cases be even better for the purpose than crops grown on the spot.

II. Farmyard Manure. This has long been the most important manure used upon the land; and, when carefully prepared and protected, it is found to be of the greatest value as a supply of plant food. It consists of straw and litter which has been trampled upon by the cattle and horses in the stables and farmyard, mixed with their excrements (Latin *ex* = out, *cretum* = separated), that is, their urine and dung. Now, the bodies of animals are built up of the same materials as plants; and, as the farmyard animals feed upon the plants which have grown in the soil, their dung contains all those constituents of the plants which have not been stored up in the animals' bodies from their food, or given out by them to the air in the form of gas. Carbon is being constantly breathed out by all animals as *carbonic acid*, and *watery vapour* is expired at the same time. All the mineral matters of their food and most of the nitrogen, except what are required to build up their bones and flesh, are returned into the solid and liquid manure.

Variations in Quality. The manure produced by different animals is not of the same quality. A full-grown working horse, for instance, does not store up in its body any of the materials of its food. The food is burned up in the body to maintain heat, and to repair waste, and the same quantity of ingredients is given out in breathing and in the manure as have been taken in by the food. Carbon is given out by the breath, and the manure is enriched by a quantity of nitrogen and minerals equal to that contained in the food. But in the case of young animals—lambs, calves, and fattening pigs—much of the food goes to build up the bones and flesh and fat, and thus manure from such animals is poorer than that from full-grown animals. So with a cow giving milk. The milk contains nitrogenous matter and mineral substances, which, of course, have been derived from the food, and the manure from the cow is poorer in those substances, in proportion to the quality and yield of milk.

The different kinds of food given to the animals also lead to differences in the manure they yield. Thus, animals fed upon oil-cakes, which contain a large amount of nitrogen, phosphoric acid, and potash, will produce much better manure than those fed upon straw alone or upon grass and hay. In buying oil-cakes to feed their cattle, farmers consider that their manure will be made richer in nitrogen, and that it will be more valuable to the land.

Composition of Farmyard Manure. A ton (2240 lbs.) of farmyard manure may contain about 1600 lbs. of water and 640 lbs. of solid matter, of which perhaps 100 lbs. may be soluble fertilizing substances, viz. *ammonia*, *silica*, *phosphate of lime*, *lime*, *magnesia*, *potash*, *soda*, *common salt*, *sulphuric acid*, and *carbonic acid*. Here all the substances required by the crops are contained in the farmyard manure, including a supply of *ammonia*, always a valuable substance in manure, because it contains nitrogen in a form that becomes readily available to plants. Nitrogen is not more necessary to the plant than oxygen, or hydrogen, or carbon, but all these the plant can get directly from the air and water, while nitrogen, though existing in great quantities free in the air, cannot in that state be directly taken in by plants (with exception of Leguminous plants; see pp. 55, 179 and 180), but must be supplied to them combined with some other element or elements into compounds such as nitrate of soda, or nitrate of lime.

You will notice the large quantity of water in the farmyard manure, and also the insoluble solid matters. This makes the manure very cumbersome, as about 15 cwts. of useless water has to be carted about to supply 5 cwts. of solid matter, of which the greater part consists of substances of low fertilizing value. Yet the manure contains such a variety of substances, and these in such a suitable condition, that farmyard manure is found to be still the most useful manure of all that can be used. Its very bulk is useful to most soils, for it acts mechanically upon the light soils by binding the loose particles together, and upon heavy soils by separating them and leaving channels for air and water to penetrate. Its great value as a fertilizer consists in the fact that it returns to the soil the very substances which were drawn out of it by the plants, and in much the same condition, and therefore it repays part of the loan which we may say the farmer has borrowed from the soil. It is true that these same substances could be added to the soil by other manures, as we shall see presently, and sometimes it is necessary to use artificial manures to supply plant food in addition to farmyard manure, but it would be wrong for a farmer to depend too much upon artificial substances, and neglect this invaluable manure, which is generally close at hand, and which is suitable for all crops.

Fermentation. When farmyard manure is placed in a heap for a time it rots and ferments. This fermentation, like all others, as for instance that of beer and wine, is caused by the growth of immense numbers of minute living organisms or ferments. The tiny germs of these ferments are always floating about in the air, and, when they fall into any solution of animal or vegetable matter, they find there the food they require and begin to grow and multiply with great rapidity. As they feed upon the organic matter of the farmyard manure, they break it up from complex into simpler compounds, such as water, ammonia, carbonic acid, and certain other organic acids. During this process a great deal of heat is developed, as is always the case where oxidation is going on, as for instance in our own bodies. Now, if the manure is kept moist and does not get too hot, organic acids contained in it combine with the ammonia and hold it in a solid form. But if the heap gets too dry and hot, then carbonic acid is formed more rapidly and combines with the ammonia, forming the strong-smelling carbonate of ammonia, which is very **volatile** (L. *volare* = to fly), and flies off into the air in the form of a gas.

On the other hand, if the heap get too wet, the water soaks through and runs away into the drains, carrying away with it organic acids and soluble matters, and forming the black streams which you may have seen running out from under a manure heap. If the manure is obliged to be exposed to the rain, and these black streams run from it, some way should be found of making use of the liquid, either by collecting it and pouring it upon the heap again, or by allowing it to run upon land which requires manure.

A good farmer, then, will try to prevent these two signs of waste in his manure heap—1. *A strong pungent smell* like smelling salts, giving proof of waste of ammonia in the air; and 2. *Black streams* from under the heap, showing waste of organic acids and ammonia in the wayside and in the drains. In the first case he will moisten the heap, using any drainage from it for this purpose. In the second case he will try and keep it drier by having a shelter for it from the rain, or if this be impossible, he will have a tank to collect the valuable liquid and use it upon his land.

If the manure is required to ferment quickly, it should be turned over frequently and exposed to the air. The oxygen then gets at all parts of it and acts upon it more rapidly, assisting the various matters to decay, on somewhat the same principle as poking a fire causes it to burn more brightly, by admitting more air containing oxygen to the inner parts of the fire. If, however, it is required to check the fermentation, the heap should be pressed and trodden down closely, so as to shut out the air as much as possible.

Application to Light and Heavy Soils. On light sandy soils the manure should be well rotted, and applied just before it is wanted by the crop, because, these soils having large pores, the soluble matters are apt to be washed out of them by the rain before the plants are ready to take them up. The long straw in fresh farmyard manure tends to open soils, but in treating light soils the farmer wants to make them firmer and closer in texture. The short straw of well-rotted manure is therefore more suitable for them. In heavy clay soils, on the contrary, the manure may be applied in a fresh state, and long before it is needed by the crops. The particles in a clay soil are so small and close together that there is less fear of the soluble parts of the manure being washed through, and as the crops grow the manure gradually decays in the soil, supplying the crop regularly with plant food during the season of its growth. In these soils, too, which are too heavy and close, the long straw of the half-rotted manure assists in loosening the soil and thus improving the drainage, and in making passages for the air to enter and perform its important office in setting free the dormant supplies of plant food. The decay of the manure in the soil is also found to act upon the mineral and organic constituents of the soil itself, and promotes their change from a dormant to an active condition, as in another way rotten apples placed among sound ones tend to cause these to become rotten like themselves.

Compost Heap. A very useful manure may be made out of the waste animal and vegetable matters of the farm—stubble, ferns, ditch scourings, road scrapings, weeds (collected as much as possible before they produce their seed), and dead animals or parts of animals. If these are formed into a heap, and watered now and then with liquid manure from the farmyard, or ammonia water from the gas-works, a series of chemical changes takes place, putrefaction and fermentation set in, which are hastened and assisted by turning the heap over at intervals to allow the air with its oxygen and carbonic acid to penetrate, and thus a manure is formed which contains much useful plant food. When lime is mixed with the compost heap the changes proceed in such a manner upon the nitrogenous matters and the potash as to produce the valuable substance, nitrate of potash.

Animal Manures. Quantities of **fish** and other sea animals are used as manures on parts of the coast where they are plentiful, as *sprats* in Norfolk, refuse of the *herring* and *pilchard* fisheries in Scotland and in Cornwall, *shell-fish* in the Solway, *star-fishes* in Kent, and so on. The waste matters from various factories also form manures—**blood** from slaughter-houses, **skin** and **hoof** cuttings from tanneries and glue works, **shoddy** or waste from the cloth mills, **woollen rags** collected for the purpose, and **horn** refuse from comb factories. These are all principally valuable for the nitrogen they contain, which they gradually yield up in the soil in the form of ammonia. The common ammonia of the chemists' shops was formerly made from horns of deer, &c., whence its common name of "hartshorn."

Some of these animal matters, if used as manures without any preparation, decay very slowly in the soil, and so form a lasting supply of plant food; but the manure manufacturer can treat them so as to make them more quickly available.

III. Natural or Calcareous Manures.[1] Lime, chalk, marl, shells, and gypsum, all containing lime, may be called natural or calcareous manures (L. *calx* = lime). They act in several important ways: 1. They supply plant food themselves. 2. They set free other substances in the soil as plant food. 3. They act mechanically upon the soil. Many soils known as marly or calcareous soils contain a considerable quantity of lime. These, of course, would not be benefited by the addition of more lime. But others, and especially stiff clays, and soils containing a good supply of organic matter or humus, are much improved by occasional dressings of lime.

Chemical Changes. The form in which lime occurs most largely in nature is that of the **carbonate**; chalk, limestone, and oyster shells are chiefly composed of carbonate of lime. But when any one of these is placed in a limekiln and exposed to heat, the carbonic acid is driven off in the form of gas, and only oxide of calcium is left. In this state it is called **burnt-lime** or **quicklime**, because of its lively active nature, or **caustic** lime (L. *causticus* = burning) on account of its hot burning properties. When water is poured upon a lump of quicklime it becomes hot, the water boils and hisses into steam, and the lime swells and breaks to pieces, and forms at last a fine powder, which takes up about three times as much room as the original quicklime. This white powder is called **slaked** lime (the verb *slake* being connected with *slack*). It consists of 76 parts of lime to 24 parts of water, or 40 lbs. of quicklime absorbs 13 lbs. of water, still remaining apparently dry, and forming 53 lbs. of slaked lime. If quicklime is exposed to the air it absorbs moisture from it even in dry weather, and slakes much more slowly than when water is poured on it, and without showing such violent signs of heat, but the

[1] See also Part IV., pp. 174-178.

result is the same. If the slaked lime is still left exposed to the air, it absorbs carbonic acid, which converts it again into carbonate of lime, as at first. But it is now in a very different mechanical condition, for whereas in the first case it consisted of hard lumps of chalk or limestone, or of whole shells, it now forms a fine powder which can be thoroughly mixed with the soil.

Lime as Plant Food. All plants require a supply of lime in their food, but turnips and clover need a specially large quantity. A crop of 17 tons of turnips carries off about 74 lbs. of lime, and a crop of 2 tons of clover carries off 86 lbs. of lime, as shown on page 64. Liming the land has a very beneficial effect on both these crops. The lime may be applied as quicklime, when it rapidly becomes changed in the soil into the carbonate. Or it may be applied in chalk, or marl, or shells, in all of which it exists already in the form of carbonate.

Chemical Action of Lime. But the great use of lime in the soil is to act upon the other ingredients in such a way as to set free food more useful to the crops than lime itself. In the first place, lime, either in the state of quicklime or more slowly in the state of chalk or other carbonate, acts upon the decaying *organic matter* in the soil, assisting its decomposition. In this process various acid matters are formed which are injurious to plants, but the lime forming a base, as explained in our lesson in chemistry, p. 53, combines with these acids and renders them harmless and even useful as plant food. The result upon the crops is that they become more healthy and sweet. In the case of meadow land it is found that the better and sweeter kinds of grass will not grow where these acid matters are present, but when lime has been put on the land the harsh bitter grasses die away, and sweeter and more nourishing kinds spring up plentifully in their place. By the decay of the vegetable matter, too, the inorganic substances which formed part of the dead plants will be set free in such a state that they can be very readily taken up by a new crop. You will easily understand, however, that by this action of the lime upon the organic matter of the soil, that matter will be used up more rapidly than it would be without the lime, and therefore farmyard manure or some other organic substances should be added to the soil after the lime, or before it. An old proverb says—

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

But while this is generally true, you must not suppose that it is always necessary to add manure to soils in order to restore the organic matter that has been broken up and destroyed by the action of the lime. Some soils to which lime is commonly applied with great benefit contain such an excessive amount of organic matter that they cannot be the better of any addition to the quantity. Peats and mosses are so largely composed of organic matter that ordinary liming cannot possibly reduce its proportion to a very low point. And old pastures, especially those that have lain for many years undrained, when they are first broken up for cropping are often so rich in organic matter that its exhaustion by a first liming is not to be feared. But applications repeated regularly at short intervals of years may ultimately produce such an exhaustion. On all the medium and lighter classes of soils, also, organic matter forms an extremely important constituent, and if the action of lime reduce it in any great measure the fertility of the soils might be seriously impaired, and they would yield smaller crops for many years. Care must be taken on these soils to keep up the stock of organic matter.

Action on Dormant Matter. Lime also acts upon the dormant mineral matters of the soil, uniting with the clay in such a manner as to liberate some of the potash, &c., in the soil, and thus makes those substances ready to supply food to the plants. These combine with acids in the soil into nitrates, carbonates, &c., which are soluble in water, and thus enter the rootlets and root-hairs of the plants.

Action in forming Nitre. This is another useful chemical change, which occurs in compost heaps and also in the soil. The lime combining with the nitric acid produced by the decay of animal or vegetable matter forms **nitrate of lime,** and this meeting with potash in the soil, an exchange takes place, and

nitrate of potash, that is, nitre or saltpetre, is formed. Thus a manure, so costly that the farmer seldom buys it, is produced naturally in the soil with the help of lime.

Mechanical Action of Lime. Upon heavy clay soils lime in any of its states acts very beneficially, by lightening them and making them more easily worked and drained, and thus admitting air and rain more freely into them.

Application of Lime. Lime is applied in large quantities to soils in many parts of the country. It is carted from the kiln after burning, and is usually set out in small heaps on the field and allowed gradually to slake by exposure to the atmosphere. But when lime is required in its caustic state it should not be left exposed to the atmosphere, or much of it will change into carbonate of lime before it can be got into the land. It may be placed in heaps, and water poured upon it to slake it, and the heaps may then be covered with soil for a few days, after which the lime should be spread on the land and quickly harrowed in to begin its action on the soil. The practice of leaving the lime in heaps on the field for a long time in order that it may be slaked by atmospheric moisture is not a good one if caustic lime be needed. While the lime is absorbing moisture from the air, it is also exposed to the action of carbonic acid, and a part becomes changed into the carbonate. In this form it does not act so energetically in the soil as quicklime does before it combines with carbonic acid. It is usually better to harrow lime into the soil rather than to plough it in, because lime has a great tendency to **sink** year by year further down through the soil.

From its action upon organic matter lime is very useful upon peaty soils, which contain large quantities of vegetable matter, and in which injurious organic acids are very apt to form.

Other Natural Manures. **Marl** is a soil containing such large quantities of carbonate of lime that it is often carted on to the land as a lime manure. **Shell sand** from the sea-shore is used in the same way. Both of these substances generally contain small quantities of phosphate of lime, magnesia, &c., and they therefore provide various kinds of plant food as well as lime. **Gypsum** is a sulphate of lime, often found mixed with the carbonate in marls and chalks. It supplies both sulphur and lime to crops, but it has not the value of the carbonate in causing chemical changes in the soil.

IV. Artificial Manures. We have now to consider a number of substances which are used to supply particular kinds of plant food in which the soil may be deficient, or which the plants may require in a special manner or at a particular stage of their growth. They are called **Artificial Manures,** because they require the *art* of the importer or manufacturer to bring them from the countries where they are found, or to prepare them from the materials of which they are composed. One of the most important of these is

Guano. This consists of the dried dung of fish-eating sea birds, and is brought principally from the rocky coast and islands of Peru, and other parts of South America. As in these countries rain seldom falls, the dung of the sea-birds accumulates to such an extent that in some places the deposits are 200 feet thick, and one bed, discovered in 1874, was estimated to contain five million tons. Guano consists principally of organic matters capable of yielding **ammonia,** and of **phosphates** of lime, &c., and may therefore be considered as mixed ammoniacal and phosphatic manures. Some guanos contain more nitrogen than others; these form more powerful manures, acting rapidly on corn crops, grass, and potatoes, but their use is limited by the high price at which they are sold. Those guanos which contain more phosphates and little nitrogen are usually treated as phosphatic manures, and are frequently dissolved in sulphuric acid, in the manner presently to be described in the case of bones. These phosphatic guanos are most suitable for root crops.

Phosphatic Manures. We have seen that of the organic substances required by plants nitrogen is the one which must be added in the manure, as it cannot be obtained in sufficient quantity by the plants from the air or the soil. We shall now see that of the **inorganic** substances which are required by plants, the one which is most likely to run short, and therefore requires to be added in the form of manure, is the **phos-**

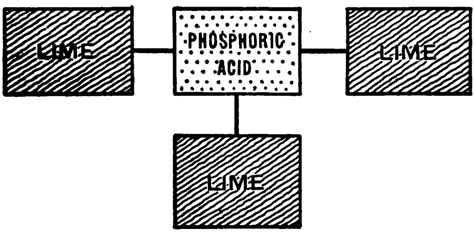
phoric acid. This is partly because it forms only a small proportion of the soil to begin with, and partly because much of it is carried off from the farm in the produce, without any return being made to the land. The grain of wheat and barley contains a large proportion of phosphoric acid, and this is carried away and used for human food, while the straw, containing the silica and potash, is usually returned to the land in the farmyard manure. So also the grain of beans and peas and the tubers of potatoes contain large supplies of this mineral. The milk of the cow, again, carries off phosphoric acid which is not returned; and finally, the calves and other young live stock, while returning a great part of the other mineral matters of their food to the soil in their manure, keep much of the phosphoric acid and use it in building up their bones, which are largely composed of phosphate of lime. The following is the composition of 100 lbs. of the bones of the ox, and all other animals' bones are much like it:—

Animal matter (gelatine and fat), ...	33 lbs.
Phosphate of lime, ...	58 ,,
Carbonate of lime, ...	4 ,,
Phosphate of magnesia, ...	2 ,,
Soda and common salt, &c., ...	3 ,,

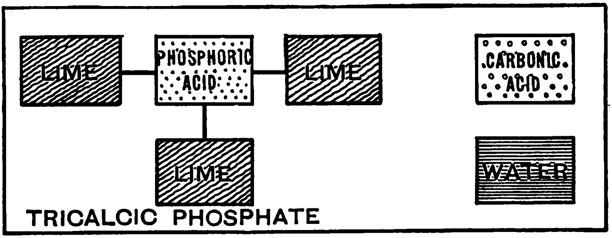
Bones as Manure. All these substances have of course been derived from the animal's food, and therefore from the soil, and it is not surprising that when bones are returned in a fit state for plant food to a soil which has been long grazed by cattle, they should restore its fertility. It was first discovered in Cheshire that a dressing of crushed bones doubled the value of pastures which had been considered worn-out and exhausted, and since then the use of bones as manure has been extended to nearly all soils and crops. The bones were at first simply broken into large pieces with a hammer, and spread on the surface of the soil, and for pastures they are still often used in the same state, only crushed much smaller by means of machinery. In this state their action is slow, and they gradually decay and supply phosphoric acid to the soil for many years. But bones in very large pieces are now seldom used for manure. The bones are usually broken and ground down by powerful machinery into what is known as **bone meal.** In this manure much of the bone is reduced to a coarse powder, and the remainder is in fragments not much larger than in coarse saw-dust. The effect of this fine grinding is to make the manure act more quickly on the crops. Its effects do not continue for so many years, but it gives a return much sooner, because the smaller pieces of bone are better exposed to the action of the solvent agencies in the soil, and they yield a supply of plant food much more readily. It was Baron Liebig who discovered that by dissolving the bones in *sulphuric acid* (oil of vitriol) the phosphate of lime became in a short time completely soluble in water; and thus a process, which under the ordinary influences of the air and the soil takes years to complete, and which even when assisted by fermentation requires months, can be accomplished in a day.

Chemical Changes in Bone Phosphate. To understand these changes it is necessary to know that the phosphate of lime in bone exists under a special form called **tricalcic phosphate** (*tri-* = three, *calc-* = lime) or three-lime phosphate, that is, phosphoric acid combined with three portions of the base calcic oxide or lime.

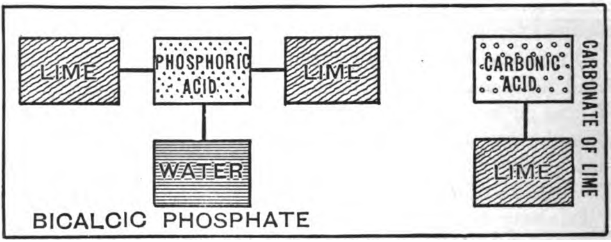
This may be represented in the following way:—



This tricalcic phosphate is quite insoluble in water, and therefore, before it can become food for plants, it must be changed into a soluble form. This is done in the soil and more rapidly in the fermenting heaps probably by carbonic acid and water. The acid draws out one portion of lime from the three-lime phosphate, and water takes its place, forming a **bicalcic phosphate** (*bi-* = two) or two-lime phosphate, which is slowly soluble in water. This action may be shown thus:—



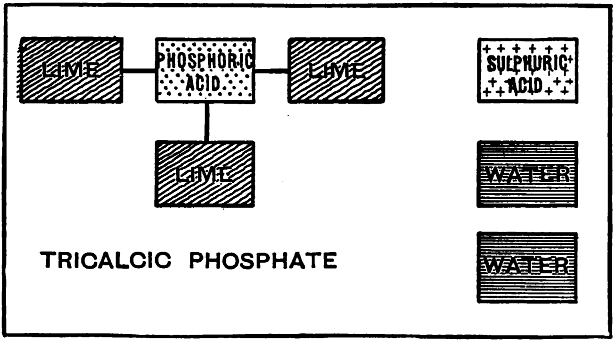
BEFORE THE CHANGE.



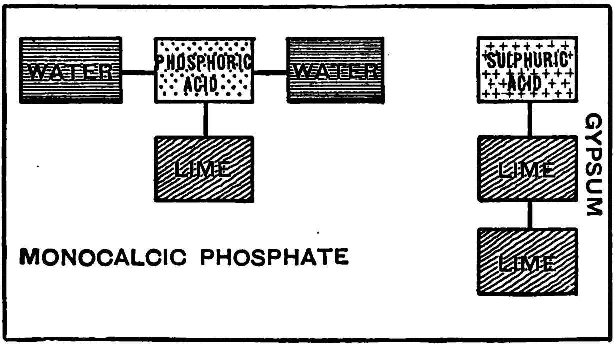
AFTER THE CHANGE.

Here, after the change, one portion of lime has combined with the carbonic acid to form carbonate of lime, and water has taken its place in the phosphate. Or translating the diagrams into words we may say, **Tricalcic phosphate of lime and carbonic acid and water : make : bicalcic phosphate of lime and carbonate of lime.**

But when, instead of waiting for the slow action of the carbonic acid (which is a weak acid and occurs in small quantities), strong sulphuric acid is used, then *two* portions of lime are extracted from the tricalcic phosphate, leaving the very soluble **monocalcic** or one-lime phosphate (*mono-* = one). The two portions of lime unite with the sulphuric acid to form **sulphate of lime** or gypsum, which is itself a useful manure, supplying sulphur as well as lime to the plants. This change is shown in the following diagram:—



BEFORE THE CHANGE.



AFTER THE CHANGE.

That is, **Tricalcic phosphate of lime and sulphuric acid and water : make : monocalcic phosphate of lime and gypsum.** This product is known among farmers and manure manufacturers by the name of **Dissolved Bones** or **Bone Superphosphate,** because in proportion to the lime the phosphoric acid in each unit of the monocalcic phosphate is increased *beyond* or above that in the other phosphates.

Reduced Superphosphates. In some circumstances a certain proportion of the monocalcic or "soluble" phosphate, as it is usually termed by farmers, of the superphosphate, returns to the bicalcic form. It is then called **reduced** or **reverted** phosphate. This reversion of the monocalcic, "one-lime," or "soluble" phosphate in superphosphate may occur from several causes. It may be brought about by the farmer by mixing superphosphate with a manure like bone ash, which contains "insoluble" tricalcic, or "three-lime" phosphate. In course of time some of the "one-lime" and the "three-lime" phosphates being in contact react upon each other, and form the middle, "two-lime," or bicalcic phosphate. This bicalcic or reverted phosphate is more soluble in the soil than the tricalcic form, but less soluble than the monocalcic. The monocalcic phosphate has this great advantage that it can be readily dissolved by rain and washed into the soil, and distributed completely through its particles in a very fine state of subdivision. The bicalcic phosphate, though less soluble, is nevertheless quite capable of being dissolved with some readiness by the carbonic acid water in soils, and is therefore in a condition in which it is available for plant food.

Mineral Phosphates. But the demand for phosphatic manures is so great that the supply of bones is not sufficient for the purpose, and therefore other supplies of phosphate of lime have been sought out. It was discovered about 1855 that certain stones and rocks, largely composed of phosphate of lime, could be used instead of bones to supply phosphates to the soil. In Cambridgeshire are large beds of stones called **coprolites** which can be used for this purpose. Other mineral phosphates are brought from Canada and South Carolina, from Estremadura in Spain, and from Bordeaux in France. But as these rocks are often very hard, and contain their phosphoric acid as insoluble tricalcic phosphate, they are usually dissolved by sulphuric acid, and are then known as **mineral superphosphates.** These rocks can also be ground down into a fine powder and applied to the soil in that condition.

Bone Ash and Phosphatic Guanos. In South America large numbers of cattle are slaughtered principally for their hides, horns, and tallow. For many years the bones of these animals have been used there for fuel to melt the tallow, and the ashes of their bones have accumulated in heaps like the refuse from our iron furnaces. Now, however, these ashes are exported to England and other countries and used for manure. When pure they contain about 80 lbs. in the 100 of phosphate of lime, but in some parts they have become mixed with sand, which lessens their value. Those guanos, also, which contain more phosphate of lime than ammonia are often treated as phosphatic manures, dissolved in sulphuric acid, and sold as **Dissolved Guanos.**

Application of Phosphatic Manures. If a soil contains little carbonate of lime the tricalcic phosphate in a finely ground form, either as bone or mineral, may prove an effective manure, because the carbonic acid in the air and soil will soon change it into the slowly soluble bicalcic state, and form at the same time a supply of carbonate of lime. If, however, there is already much carbonate of lime in the soil the carbonic acid will attack that instead of the tricalcic phosphate, and therefore it will be better to use the superphosphate, which will act rapidly in spite of the carbonate of lime. Superphosphate is an excellent manure for turnips and for other rapidly growing crops, and acts not only as a food but as a stimulant. It is also suitable for potatoes, clover, barley, oats, and all crops that are benefited by applications of phosphates. It is the quickest acting and most certain of the phosphatic manures, and is adapted to all soils. Many artificial manures are sold as turnip manure, potato manure, &c. These are mainly superphosphate with various proportions of other matters added, such as shoddy, dried blood, &c., but it is much better for the farmer to know exactly what kind of substance he is using, so that he may be able to judge whether it be what his particular soil requires.

Special Nitrogenous Manures. There are several substances that are commonly used as manures to add nitrogen to the soil when it is specially deficient, or when the crops would be better for an extra supply of it. **Sulphate of ammonia** is one of these. Most of it is made from the liquor which is formed in the manufacture of gas, and which was formerly thrown away as useless. It consists of white crystals containing 20 per cent of nitrogen, and forms a powerful manure for corn crops. Another manure of a similar kind is **nitrate of soda** or Chili saltpetre, which is a white salt found in large quantities lying like snow upon the ground in Peru. It is purified there and sent to this country. It contains about one-fifth less nitrogen than sulphate of ammonia, but is a somewhat quicker acting manure, and shows its effect on such crops as grass by producing a darker green colour in a very few days after it has been applied. Both of these manures are generally applied as *top dressings*, that is, they are spread upon the surface among the young plants, so that as the manure dissolves with the rain and sinks into the ground, the young roots may feed upon it without loss of time, before it gets washed too low into the soil. They are capital manures to apply to grass and to all kinds of cereal crops, and they cause a great increase in the produce of hay, of straw, and of grain. **Soot** is another manure which contains some salts of ammonia, and it may be used in much the same way.

Potash Manures. The three substances of greatest importance to be added specially to the soil are **nitrogen, phosphoric acid,** and **potash;** the others are generally in sufficiently large quantities in the soil, or are added without special arrangement in the general manures. We have seen how *nitrogen* can be specially applied in Peruvian guano and special salts, and phosphoric acid in guano, bones, and mineral phosphates. *Potash,* though generally less needed than nitrogen and phosphoric acid, is sometimes deficient, and may be supplied in several ways. Where wood is plentiful *wood ashes* may be used, especially those from young twigs and cuttings which contain a great deal of potash. *Sea-weed* and the *ashes* *of sea-weed* answer the same purpose. Another useful potash manure is a mixed salt brought from Stassfurt and Leopoldshall in Prussia and known as **kainit.** It consists of a mixture of sulphates and chlorides of potassium, magnesium, and sodium. Ordinary commercial kainit contains about 12 per cent of potash, which corresponds to about 24 to 25 per cent of sulphate of potash. It may be used either as a manure by itself, or it may be mixed with farmyard manure, or with a compost. You remember that lime in the compost heap and in the soil combines with the nitric acid from the decaying vegetable matter to form nitrate of lime, which easily changes into nitrate of potash if a supply of potash be present, and that is just what is given by the kainit. *Nitrate of potash* (nitre or saltpetre) is not much used as a manure in this country, as it is very expensive, being wanted for the manufacture of gunpowder, which is made of sulphur, charcoal, and saltpetre. A variable and sometimes very slight quantity has been found in farmyard manure. *Sulphate of potash* and *muriate of potash* contain much more potash than kainit, and are both commonly employed as manures.

Common Salt is often used as manure on account of its action in producing chemical changes in the soil, and setting free other ingredients of plant food. The cultivated mangel-wurzel and the beet-root are descended from a plant which grows wild on the sea-shore, and they still keep the taste for salt which they received from their ancestor. An acre of mangels will carry off a large quantity of salt from the soil. Cabbages and turnips also require a good deal. But most soils contain a considerable quantity of this mineral, especially those near the sea. Even 50 or 60 miles from the sea the wind sometimes tastes of the salt which is carried inland from the spray of the sea. But much salt applied directly to plants will kill them, and when applied as manure it may have a retarding influence on the growth of the crop, especially at first, and this is sometimes useful on cereals in holding the plants back from making too much leaf or straw, and in turning their energies towards the production of grain.

Application of Manures. You should carefully bear in mind that manures are only a supplemental supply of plant food. The natural source of plant food is the soil itself, and it is bad policy for the farmer to neglect this source of supply, and then pay large sums of money for expensive manures. By good and deep cultivation, and by a suitable rotation of crops, the land should be encouraged to yield up its plant food; and by this and good drainage the friends of the farmer, the oxygen and carbonic acid of the air, should be admitted into the soil; and then manures should be used to make up any deficiency which may be found in the soil, and to restore to the soil that which has been carried away by the crops or lost in the drainage water. And some of them not only restore useful substances to the soil, but they assist in liberating some of its treasures that are held in unavailable forms, and they also give the soil greater power to retain the valuable ingredients that are intrusted to its care.

SUMMARY.

In this short summary the salient points taught in this stage are brought before the pupil, who should be encouraged to enlarge or illustrate each statement in his own words.

1. **Agricultural Chemistry** deals with **fourteen elements**, namely, **four organic**—oxygen, hydrogen, carbon, nitrogen; **ten inorganic**—sulphur and phosphorus; silicon, chlorine, potassium, sodium, calcium, magnesium, aluminium, and iron. The *last six* are metals. The others are non-metallic elements.

2. The chief **binary compounds** are—carbonic acid, sulphuric acid, phosphoric acid, nitric acid, silica, water, ammonia, potash, soda, lime, magnesia, alumina, and iron.

3. The chief **salts** are potash salts, soda salts, lime salts, and silicates.

4. The **air** contains oxygen, nitrogen, carbonic acid, ammonia, nitric acid, and watery vapour.

5. The **decay** of plants and animals produces water, carbonic acid, ammonia, and mineral matters.

6. **The exhaustion of the soil** is caused by the continual growth of plants for food.

7. Nine inorganic substances and nitrogen are necessary in different quantities for all crops.

8. Fertility depends on that necessary substance which the soil contains in **least** abundance.

9. The remedies for exhaustion are (*a*) fallows, (*b*) rotations, (*c*) manures.

10. **Manures** (*a*) supply deficiencies, (*b*) improve the soil mechanically, or (*c*) stimulate plant growth.

11. **Green manures** are ploughed in.

12. **Farmyard manure** contains water and all the substances required by plants.

13. **Fermentation** should be regulated. If too hot and dry, ammonia lost in the air; if too wet, ammonia lost in the drains.

14. Other general manures are fish, blood, skin, hoof and horn refuse, shoddy, and woollen rags.

15. **Calcareous manures**—lime, chalk, marl, gypsum, oyster shells, shell sand. Lime may be quicklime, slaked, or carbonate.

16. **Artificial or special manures** are :—

Ammoniacal and phosphatic—guano.

Phosphatic—bones, ground bones, mineral phosphates, superphosphates, reduced superphosphates, bone ash, and phosphatic guanos.

{ Tricalcic phosphate (3-lime) is insoluble in water.
Bicalcic phosphate (2-lime) is slowly soluble in water.
Monocalcic phosphate (1-lime) is very soluble in water.

Nitrogenous manures—sulphate of ammonia and nitrate of soda and soot.

Potash manures—ashes of wood and of sea-weed, kainit, nitrate of potash (saltpetre), muriate of potash, and sulphate of potash.

Common salt acts as plant food and "check."

17. Manures are **supplemental** supplies of plant food to assist good cultivation.

QUESTIONS.

1. What chemical elements are most important in the study of agriculture?
2. Explain organic and inorganic elements.
3. What is charcoal? What gas is formed when charcoal is burnt?
4. Of what elements is ammonia composed?
5. What element exists in sand, flint, and quartz?
6. What common metal occurs in plants?
7. What metals are in potash, soda, lime, and clay?
8. What is a salt? Name a few of the most common salts useful to agriculture.
9. What is the general composition of the air?
10. In what three states does nitrogen exist in the air?
11. Whence do plants obtain their carbon?
12. What substances do plants give out to the air?
13. Name the chief products of the decay of a plant or an animal. What becomes of these when the plant or animal is buried?
14. What causes a soil to become exhausted?
15. Where would you look for signs of exhaustion of the soil?
16. Name the chief articles of plant food, and state which are not derived from the soil.
17. What happens if a plant is deprived of any one article of food?
18. Which article of plant food decides the fertility of a soil?
19. Name the substances required in the greatest quantity by turnips, clover, and wheat respectively.

20. How can plants be grown without soil, and what use has been made of this?
21. What is the special use of iron to plants?
22. Whence do plants get their nitrogen? What is humus?
23. What are the remedies for the exhaustion of the soil?
24. Why are fallow crops better than a bare fallow? Name the chief fallow crops.
25. What do you understand by rotation of crops, and why is it necessary?
26. What is the meaning of clover sickness?
27. Describe the Norfolk course of cropping, and show the benefits derived from it.
28. Why is it good to grow clover before wheat?
29. What are manures, and why are they used?
30. What are green manures, and in what different ways are they used?
31. What crops are specially grown to be ploughed into the land?
32. What limits the use of green manuring?
33. How is farmyard manure made?
34. What parts of the food of animals goes out into the air?
35. What part remains in their bodies?
36. What causes farmyard manure to vary in quality?
37. Name the substances existing in rotted farmyard manure.
38. Why does a manure heap get hot, and how can the heat be checked?
39. What is the black liquid which sometimes runs from under manure heaps?
40. What causes the strong smell from some manure heaps?
41. Of what are these things signs, and how can they be prevented?
42. Why should the manure heap be sheltered if possible?
43. When, and in what state, should farmyard manure be applied to light and heavy soils respectively?
44. What is a compost heap, and how can it be made most useful?
45. Name any refuse matters forming good general manures.
46. Give the composition of hartshorn, chalk, nitre, and gypsum.
47. What are calcareous manures? Give a list of those most often used.
48. How can chalk be turned into quicklime, and back again into chalk?
49. What plants require lime in their food?
50. Describe the action of lime on the organic matter in the soil.
51. Why should lime not be used without any other manure?
52. To what soils is this rule not wholly applicable, and why?
53. How does lime act on the dormant matters in the soil? And what changes does it effect?

54. What is nitrate of potash, and what has lime to do with its formation?

55. Why should lime be spread upon the land and not ploughed in?

56. Point out the error in a common method of applying lime.

57. What are the chief artificial manures, and why are they used?

58. From what countries is guano obtained, and of what does it chiefly consist?

59. Which inorganic substance is it most needful to add to the soil, and why?

60. What are bones composed of, and why are they used for manure?

61. In what different states are bones used as manure? What is dissolved bone?

62. What are the three forms of bone-phosphate?

63. How is the bicalcic phosphate formed in the soil?

64. What is superphosphate, and how is it made?

65. What do you understand by "reduced superphosphates?"

66. From what countries are mineral phosphates derived? How do they differ from bone?

67. What is bone-ash, and where is it obtained?

68. For what soils and crops is superphosphate most suitable?

69. What manure is obtained from gasworks?

70. What other manure is there of the same class? Where is it found?

71. What is "top-dressing," and what manures are applied in that way?

72. Name the principal sources of potash as a manure for crops.

73. What is kainit, and why is it useful with farmyard manure and lime?

74. How does common salt act when applied in large quantity to plants, and when applied in smaller quantity as manure?

75. What crop makes use of a large supply of salt?

76. Why should a farmer be careful in buying manures?

77. Upon what should good farming principally depend?

78. Write out the substance of what you have learned about the use of manures.

PRINCIPLES OF AGRICULTURE.

PART III.

"THE PRINCIPLES REGULATING THE GROWTH OF CROPS, AND THE VARIATIONS IN THEIR YIELD AND QUALITY."

I.—HOW CROPS GROW.

Introduction. In the first book of this course of agriculture we had a general description of a plant as the principal object of all cultivation, and we learnt how plants feed upon the carbonic acid and oxygen of the air, and upon the organic and mineral substances existing in the soil itself, or washed down into it from the air by the rain. We saw that these substances, to be of use to the plant, must reach it either in the form of a gas, when it enters into it through the leaves—or it must be completely and clearly dissolved in water, in which state it is absorbed by the delicate fibres of the roots, or the still more delicate hairs with which the roots are covered. We also saw that the whole plant was built up of millions of tiny cells, which might be compared to little paper boxes packed closely together, and these cells are filled with a fluid called *sap*. This sap consists at first chiefly of the water with its dissolved plant food taken in by the roots; it passes from cell to cell through the walls until it reaches the leaves, where the pure water is evaporated into the atmosphere, and the food is manufactured into plant substance under the influence of sunlight upon the green matter in the cells of the leaves. We have now to enter a little more deeply into the subject of the growth of plants, especially with regard to those plants which are grown in large quantities by the farmer as *crops*. We will commence with the seed and follow the crops from their **birth**, through their active **life** in the soil, to their **death** for the benefit of men.

The Seeds used for agricultural purposes should be fully *ripe*, otherwise the young plant within will not be properly formed, and the seed may not germinate. They should also be *new* seeds, that is, taken from the last year's crop. This is most important in the case of seeds with a delicate outer skin, such as those of wheat, for these lose their moisture very quickly, and in a few years are quite useless for seed. Turnip seed is sometimes all the better for being two years old, as it is then found to produce larger roots and less leaf, but as a rule new seed is the best. Every perfect seed contains a **germ** or **embryo,** which in some kinds, as in the bean, pea, and turnip, fills the whole seed; but in others, as in wheat, oat, and other grains, occupies only a small part of the seed, the rest being taken up with the store of food provided for the germ.

Germination of Seed. Take a few peas or beans, and a few grains of wheat or maize. Lay them between the folds of a piece of flannel moistened with water, and keep the whole in a warm place. Or if it should be summer time, sow a handful of each kind of seed in a warm and moist corner of the garden, and dig up one or two of each kind every day to see the changes taking place in them. The seeds will now find the three conditions necessary for germination, namely, **air, warmth,** and **moisture.** The moisture will find its way through the coats of the seed, causing it to swell up and become much larger than before, the oxygen of the air will enter at the same time, and chemical changes will take place which soon lead to the growth of the germ or embryo into a perfect plant. By the swelling of the seed the outer skin bursts, and the radicle or young root appears, pointing downward into the soil; then the plumule or young stem makes its way out, pointing in an upward direction, and soon appears above the ground. And here we shall see a great difference between the peas and the wheat. Fig. 13 shows the process of germination in a **grain of wheat.** At *a* down in a corner of the seed is the embryo, consisting of seed-leaf, plumule, and radicle. The rest of the seed is filled with the white floury substance which is to serve as the first food of the young plant. As soon as the seed begins to germinate, this flour, which consists chiefly of starch, becomes changed into a milky sweet fluid by the action of ferments already referred to. Starch is insoluble in water, and therefore cannot pass through the cells of the seed to reach the embyro; but when it has been changed into sugar, as it is during this process of germination, it easily dissolves in the water which has soaked into the seed, and then, with the other food-substances which have been acted upon in the same way, it passes from cell to cell till it reaches the young plant and supplies it with perfect nourishment. The plant being thus fed grows rapidly, as shown at *b*, the tiny rootlet passes down into the soil, and the young bud reaches up towards the air. At *c*, which is a back view of the grain of wheat further advanced, we see three root fibres breaking out from the blunt end of the root, and at *d* the fibres have increased in number and length, and have become covered with root-hairs, while the plumule has lengthened upwards into a green shoot, and the plant is now ready to begin life on its own account, by absorbing nourishment from the soil and passing it upwards to the leaves.

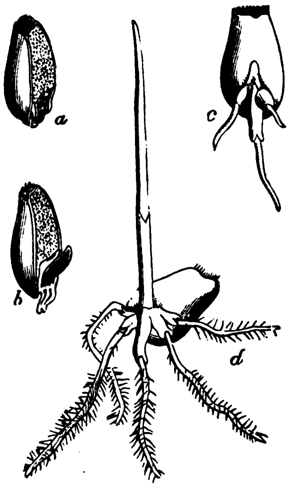


Fig. 13.

In the pea, as shown in Fig. 14, the arrangement is different. Here there is no separate store of nourishment, as in the wheat; but there are two thick fleshy seed-leaves filling up the whole of the skin, and forming the hemispherical pieces which come apart in dried "split peas." Between these two seed-leaves lie the plumule and radicle. When the pea germinates and the seed-leaves swell up with the moisture and oxygen which they absorb, the starch and other matters which they contain become sweet and soluble and so pass through the cells to the plumule and radicle. These then begin to grow in length, the radicle downwards and the plumule upwards, until the root-hairs are formed and the first green leaves spread out to the air. The young plant is now able to obtain nourishment for itself, and has no further use for the seed-leaves, which are allowed to die away.

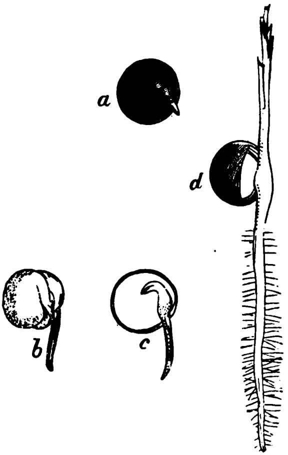


Fig. 14.

In the **turnip** again there is another difference. The embryo, like that of the pea, has two seed-leaves, but these are small, and therefore hold but a small supply of food, but they soon push up into the air, throw off their black seed-skin, spread themselves out and become green, and the young plant quickly draws in food from the soil and the air to make up for the short supply it had at first. These are the two smooth green leaves which are first seen in a young turnip plant, and which you may have often noticed in the young mustard plant used as a salad. The store of plant food in the turnip seed consists largely of oil instead of starch; but you know that both these substances consist of the three elements, carbon, oxygen, and hydrogen, and both can be changed during germination into sugar. In the germinating wheat the radicle gives out several fibres from a sort of sheath or blunt end, forming a **fibrous root**, while in the pea and turnip the radicle itself elongates and passes down into the soil, forming a **tap-root**. These are the principal modes of germination among all ordinary plants.

Of the farm crops, all the grain plants—barley, oats, &c., and all the grasses germinate like wheat; beans, clover, and others, like the pea; and swedes, cabbage, and rape, like the turnip.

Nutrition. The Root. The food of plants, as we have seen, consists of various mineral matters thoroughly dissolved in water in the soil; and of certain gases, especially that known as **carbonic acid gas**, existing in the air. The water carrying the soil food in solution passes through the delicate membranes of the roots and root-hairs into the cells of the plant on its way towards the leaves. The root stretches downward into the soil by the growth of new cells near the tips of the rootlets. A plant does not push its roots down into the soil as you would force a stick into the ground. The tip of the root grows into the little spaces it finds between the particles of soil; and then the cells just above the tip multiply very fast, usually by each cell dividing into two or more cells, each of which soon becomes large enough to divide again. As this goes on in hundreds of cells at once, and these all become swollen with moisture absorbed from the soil, the rootlet grows rapidly in length and thickness, creeping into the spaces lower and lower in the soil, and making these spaces wider by pushing away the particles on all sides. If the subsoil is very close and hard the root fibres find no spaces to grow into and so either cease to grow or spread out sideways among their fellows, where, of course, they are more crowded, and cannot find so much food. One of the benefits of deep cultivation is the loosening which it causes in the subsoil, thus allowing the tips of the roots to penetrate and find plant food.

The roots of some plants have a habit of going down very deep into the subsoil in search of plant food. The roots of lucerne, a kind of clover, have been found as much as thirty feet long. Wheat and red clover get much of their food from the subsoil, while barley and most grasses spread out their roots nearer the surface.

The thick fleshy roots of turnip and mangel-wurzel have another kind of work to do in assisting the nutrition of the plant. They not only receive plant food from the soil and pass it up towards the leaves, but they also receive *from* the leaves starch, sugar, and other useful organic matters, which have been formed in the leaves from the food and sent down into the root to be there *stored up* until the second year, when they will be used up in feeding the plant while it is producing its flowers and fruit. Roots of this kind thus storing up nourishment for a second year's life are called **biennial** roots (L. *bi* = two, *annus* = year).

Nutrition. The Stem. The stem grows from the tiny plumule or bud of the seed upwards into the air. Its great use to the plant is to lift up the leaves and expose them to air and light, and to allow the passage upwards and downwards of the foods taken in by the roots and leaves. The stems of wheat and other grains and grasses are hollow and unbranched, those of potatoes are solid and branched, while turnips and mangels have during their first year very short stems, the leaves seeming to grow out from the top of the root; but all agree in being built up of minute cells, some short and rounded in shape, others comparatively long and narrow, through which the food passes on to the leaves.

In kohl-rabi, a kind of thick-stemmed cabbage much cultivated in some districts for cattle food, the stem answers the same purpose as the fleshy root of the turnip, a store of nourishment being laid up in it for the future use of the plant.

Assimilation. The Leaves. The leaves are the principal organs by which the food obtained through the roots and leaves is **assimilated** (L. *as* for *ad* = to, *similis* = like) or *made like to* the substance of the plant itself. That is to say, out of the simple substances water, carbonic acid, ammonia, potash, &c., are built up the complicated substances starch, gum, cellulose, woody fibre, &c., of which the plant is composed. The leaf is the workshop in which this manufacture goes on, and a plant deprived of its leaves soon withers and dies. The exact chemical processes which go on in the leaves are so wonderful as to be beyond the reach of our present knowledge, but the general process can be made out pretty clearly.

A leaf consists of layers of soft green **cells** strengthened with branching ribs of long hard cells and vessels. These ribs are sometimes called **veins**, but they are not hollow like the veins of animals, and serve partly to support and strengthen the tender leaves, and partly to bring sap from the stem. Each surface of the leaf is covered with a thin transparent **skin** having an immense number of minute openings or pores, through which carbonic acid and other gases are taken in from the air, and water-vapour and oxygen given out in exchange.

Fig. 15 represents a small piece of a leaf cut across and very much magnified, so that from *a* to *d* represents the thickness of the leaf: *a* is the skin of the upper surface made of close-fitting cells, *d* is that of the lower surface, having the minute openings *s s* leading into irregular air spaces between the green cells. Each little mouth is guarded by two cells different

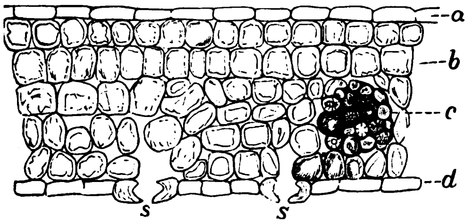


Fig. 15.

from the rest which open and close in various states of the light and air. At *b* are the green cells, and *c* represents a rib cut across. The green cells contain the two important nitrogenous substances, **protoplasm** (Gr. *proto-* = first, *plasma* = a thing spread out), the life substance of the plant, which in many plants can be seen with the microscope like a little bit of living jelly, moving round and round inside the cell; and **chlorophyll** (Gr. *chloro-* = green, *phyllon* = a leaf), which appears as little green grains packed inside the cells, and generally enveloped in the protoplasm.

The leaves being spread out to the light and air, carbonic acid gas is absorbed by them, and a large quantity of water is exhaled or given out. This water has come up from the roots, bringing various plant foods from the soil, and as the water escapes into the air these matters remain behind in the cells of the leaf, and are in some wonderful way built up by help of the protoplasm and chlorophyll into organic substances, such as starch, which, as you may remember, consists of carbon, oxygen, and hydrogen; and other substances required to build up the plant. From this starch, **sugar, oil,** and other matters are formed, and especially **cellulose** and **woody matter,** of which the walls of cells are composed. All these contain much *carbon*, which is chiefly derived from the carbonic acid entering the leaf-pores from the atmosphere. In the presence of *light* and *chlorophyll* the carbonic acid is split up into its two parts, carbon and oxygen; the carbon joins with the other materials in the cells to form starch, &c., and the oxygen is sent out into the air again. Thus the growth of plants purifies the air of its carbonic acid, so hurtful to men and animals, and restores to it the oxygen which is so useful to them, and which they had consumed in the process of breathing.

It is in part by what goes on in the leaves that the force is developed which brings up the water from the soil through the plant. For as the water in the leaves evaporates it leaves the fluid in the cells thicker than before, and therefore thicker than that in the cells behind, which have not been so much exposed to the air. But we have learnt (see p. 10, Part I.) that a thicker fluid tends to draw water through a membrane; and therefore the thickened sap in the outer cells of the leaves draws the thinner sap from the inner cells, these from cells farther back, and so the action passes backward until the cells of the root draw in the water from the soil around them containing the substances which the plant requires for its food. But it would be a mistake to suppose that the introduction of plant food through the roots is chiefly dependent on this evaporation from the leaves and upward movement of water. Other forces assist in bringing mineral substances into the plant, and growth may be rapid, as in a moist tropical forest, or in a greenhouse, when evaporation of moisture from the leaves is necessarily small.

Movements of Assimilated Materials. The materials of the food of the plant having been thus made into the inorganic substances starch, oil, &c., by the action of the leaves, these substances pass back from the leaves into the stem, and are either used up at once where growth is going on, or are stored up in the root or stem for future use. For this purpose many wonderful chemical changes take place. In a potato plant, for instance, the starch formed in the leaves is insoluble in water, and therefore cannot pass through the walls of the cells. It therefore changes into a kind of sugar, which *is* soluble, and which passes down the stem of the plant to side branches below the ground, where it changes back again into starch, and forms the thickened masses or "tubers" for which the plant is cultivated. These tubers are really short thick branches filled with starch, and the "eyes" upon them are buds; and if the potatoes were left in the ground the buds would next year produce new roots and stems from the store of nourishment thus laid up. In a turnip again the same thing takes place, but the reserve matters are deposited in the *root*, which thus becomes thick and fleshy. In the beet-root plant the starch formed in the leaves is changed into a soluble form and thus passes back down the leaf-stalks and then into the root, where it changes still farther into cane-sugar. In other plants, especially those which live only one year (annuals), as wheat, the materials assimilated in the leaves pass on to the upper part of the stem, and so at once to the ear for the formation of fruit and seed.

Reproduction. The Flower. All plants grown as crops by the farmer have **flowers**, either bright-coloured and large, as in the pea, bean, potato, and turnip, or small, green, and easily overlooked, as in wheat and other grains, in grasses, and in mangels and beet. Whether large or small, however, the flowers are all formed on the same principle, and serve the same purpose, namely, the production of seed, and therefore the **reproduction** and multiplication of the plants.

Take some common flowers and see how they are fitted for this purpose. Try to do this for yourselves, and make out the general construction of every flower you can meet with.

Take first a single flower of turnip, cabbage, mustard, or rape, for these are almost exactly alike. If you cannot meet with either of these take a single wallflower, which is much like them. Pull off first the four outside green leaves of the flower, and then the four yellow leaves, which you may notice are arranged in the form of a cross (Fig. 16), so that the whole of these plants, and many others of similar construction, are classed by botanists in the order **Cruciferæ** (L. *cruci-* = a cross, *ferre* = to bear). The parts you have pulled off serve chiefly to protect the inner organs, which are the important parts of the flower. You will see now six upright stalks (Fig. 17), two rather shorter than the rest, all bearing knobs at the top, which you may make out to be hollow and filled with a yellow

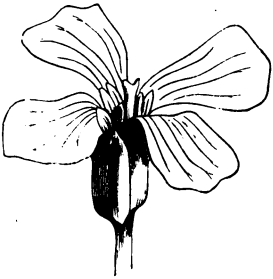


Fig. 16.

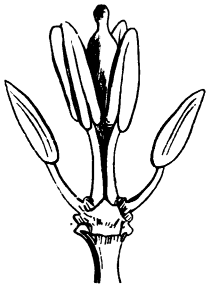


Fig. 17.

powder. These are called the **stamens** (L. *stamen* = an upright thread). In the centre of the flower, surrounded by the stamens, is the **pistil** (L. *pistillum* = a small pestle), which would in time become the fruit. It contains two rows of minute bodies called **ovules** (L. = little eggs), which would grow into the seeds. But before this can happen it is necessary that some of the yellow powder or **pollen** from the stamens should fall upon the top of the pistil, when it would penetrate to the ovules and cause them to begin to grow and ripen into seed. This action of the pollen on the pistil is called **fertilization**, because it causes the plant to become fertile, and bear fruit and seeds.

Now take the flower of a pea, bean, or vetch, and try to make out the same parts. Fig. 18 shows a pea flower cut through the middle. The coloured part in these flowers is of a peculiar winged shape, something like a butterfly, so that plants of this family are called **Papilionaceous** (L. *papilio* = a butterfly), but they form part of a very large order, all the plants of which bear pods like the pea, and the order is therefore called **Leguminosæ** (Fr. *légume* = a pod), or leguminous plants. Here you will find ten stamens, nine of them being joined into a tube around the pistil. The pistil consists of one cell containing several ovules, and will afterwards enlarge into the pea pod with its peas. In clover and lucerne a large number of flowers like those of the pea, each having its stamens and pistil, are crowded together into a head forming a sort of compound flower.

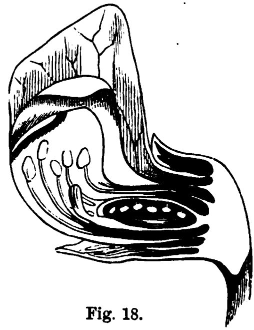


Fig. 18.

Next take a flower of wheat, barley, oat, or grass. To find this you must look when the ears are quite green, and you will see many little yellow bodies hanging out of each ear: these are the stamens. An ear of wheat consists of several rows of small flowers arranged upon a central stalk. Try and get out one of these flowers separately, and you will find it to be something like Fig. 19. Here, instead of the coloured leaves seen in the turnip and in the pea, the flower is inclosed in chaffy scales. Inside these are three stamens with weak stalks and hanging heads, surrounding the pistil, which contains only one ovule or young seed. At the top of the pistil are two feathery styles, which catch the pollen from the stamens, and pass it down into the pistil.

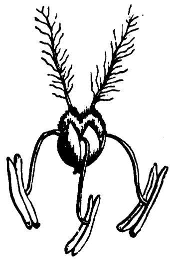


Fig. 19.

Fertilization by Insects. If you watch a field of beans or peas when in flower you will probably see numbers of bees and other insects flying about from flower to flower in search of the honey which they find at the bottom of each. In entering to reach this honey the bees brush against the stamens, and get covered with the pollen. This they carry away with them to the next flower they visit, where they rub some of it off against the top of the pistil, thus ensuring the fertilization of the flower. It has been found that most flowers produce more and better seed when they are fertilized with the pollen from another flower of the same kind, than if each flower has to depend upon its own pollen; and therefore bees and other honey-gathering insects are of great use to the farmer by ensuring the cross-fertilization of the flowers of such plants as require it. The bees benefit the flowers just as much as the flowers, by supplying them with honey, benefit the bees. And this is believed to be the reason why so many plants have brightly coloured flowers, with a sweet smell and a store of honey—that they may attract bees and other insects to visit them. The wheat and other plants with obscure flowers do not require the visits of insects; for they are as a rule sufficiently fertilized by their own pollen. The wind also blowing over them sometimes scatters and mixes the pollen among neighbouring plants.

Fig. 20.

Reproduction. The Fruit. When a flower has been fertilized the outer coloured parts and the stamens drop off, while the pistil enlarges and becomes the fruit. The fruit of the turnip and other plants of the same family is a kind of double pod (Fig. 20), which opens on each side from below, and bears two rows of seeds. The fruit of the pea, bean, and other leguminous plants is the well-known single pod or legume, bearing one row of seeds. In lucerne the pod is twisted round in a peculiar manner like a snail shell (Fig. 21); and in sainfoin it is something like a little boat, holding a single seed (Fig. 22). In wheat, barley, and grass, the fruit is commonly called the *seed*, because the covering fits the seed closely, and cannot be removed from it without tearing to pieces. This covering or husk forms the *bran* which splits off in little flakes when wheat is ground in the mill. The fruit of the potato is the green "potato apple," a fleshy fruit containing the seeds; but as the potato can be multiplied by planting the tubers, which, as we have seen, are short underground branches, the fruit and seeds are of little importance to the farmer.

Fig. 21.

Reproduction. The Seed. The end and aim of the whole life of a plant is to produce seed, in order to carry on its kind through future generations. We have already spoken of the seed in describing the process of germination, and we have now come round to it again. All plant life runs in a circle, and the farmer breaks into the circle to suit his requirements. If he wants the green leaves and stems, as he does in the grasses and clovers, he encourages green growth by proper manures, and cuts the crop when leaf and stem yield the greatest amount of green food. If he wants the reserve stores which the plant lays up for its own future use, as he does in the turnip and mangel-wurzel, he manures accordingly, and gathers the crop at the end of the first year, when these stores are just completed. If, however, it is the seed that he requires, as in the grain crops, he discourages the growth of too much foliage, and then lets the plant run the full round of its life, and cuts it just when it has perfected its seed. The seed in all cases contains a store of nourishment suitable for the next year's young plant while germinating, but which also in many cases forms excellent food for human beings and for the animals of the farm.

Fig. 22.

Selection of Seed. Seed, then, is grown by the farmer for two purposes—for food, and for sowing again. It is possible to improve the crops considerably by selecting the very best seed from any crop and sowing it in rich soil, then selecting the best from that crop, and so on for several years. Also by selecting those seeds which grow best in certain soils, or which answer best for certain purposes, various sorts or varieties are formed from which the farmer can choose those which are likely to suit him best. Seeds improved in this way are sometimes called **pedigree** seeds, and the improvement is only the careful following out of the method by which all our cultivated plants have been derived and improved from wild plants. In this way wheat, barley, oats, &c., have been derived from various species of grass; cabbage, kohl-rabi, turnips, and swedes, from plants that can still be found growing wild; and mangel-wurzel and beet-root from the straggling sea-beet found plentifully on most sea-shores.

II.—CROPS OF THE FARM.[1]

We have seen how the plants forming the crops live and grow in the soil, how they germinate from the seed, how they gather their food from the soil and from the air and use it to build up their various parts, and how they produce flowers, and fruit, and seed, and thus reproduce their kind. We have now to study these plants grown *as crops* in such a manner as to produce the greatest amount of food for man or beast with the least expense to the farmer.

Classes of Crops. The farmer generally classes his crops according to the product for which they are grown; as **grain** or **cereal** crops, grown chiefly for the grain or seed; **fodder** crops, grown for the stems and leaves, which are intended to supply fresh green or dried food for stock; and **fallow, root, or green** crops, grown chiefly to provide stock with a supply of juicy roots in the winter, when no other green food is available. But as some so-called roots are really stems, and some crops may be used for various purposes, it seems better to classify them according to their natural relationship. By that means we shall the better understand some peculiarities which would otherwise be very puzzling. The following table shows both methods of classification, and will be useful for reference while

[1] See also Part IV., p. 179.

reading the descriptions of the different crops. The first column gives the name of the natural order to which the plants belong; that is, the plants in each order are naturally related to each other, just as the various members of one family are related. It is not necessary to remember these names, but it will be useful to notice what plants are related.

NATURAL ORDER.	GRAIN CROPS.	FODDER CROPS.	FALLOW CROPS OR "ROOT" CROPS.
Gramineæ. Grass Family.	Wheat. Barley. Oats. Rye. Maize.	Grasses (many species). Rye (*green*). Winter Barley (*green*).	
Leguminosæ. Pod-bearing Family.	Beans. Peas.	Vetches. Clovers. Sainfoin. Lucerne.	
Cruciferæ. Cross-flower Family.		Rape. Mustard. Cabbage. Thousand-headed [Kale.	Turnips.[1] Swedes. Kohl-rabi (stem).
Chenopodeæ. Spinach Family.			Mangel-wurzel. Beet-root.
Umbelliferæ. Umbel-flower Family.			Carrot. Parsnip.
Solaneæ. Nightshade Family.			Potato (tuber).

It is interesting to note that out of nearly a hundred natural orders of plants, representatives of which are found wild in this country, six orders contain all the common cultivated crops; and by far the greater number of these are comprised in the three great families of the **grasses**, the **legumes**, and the **cross-bearers**. This shows that plants related to one another by nature are, as we might expect, related also in their useful properties.

[1] In Scotland the term Turnips is commonly used to include Swedes as well as Yellow and White Turnips, but it is otherwise in England.

The Cereals. The grass family (Gramineæ, from L. *gramen*=grass) contains about 4500 species of plants, of which more than a hundred are natives of this country, while others have been introduced and cultivated for centuries. Some of these are cultivated for their *seeds*, forming the grain crops or *cereals* (from *Ceres*, the Roman goddess of agriculture); others for their *foliage*, forming the true grasses of the meadows and pastures. The cereals cultivated in this country are **wheat, barley, oats,** and **rye.**

Wheat. This is the most valuable of all the cereals, especially in England, but it is much influenced by temperature and climate, and it cannot be grown with the same general success in the north of England or in Scotland. It is probably a native of the south-west of Asia, and has been cultivated for thousands of years. There are many varieties of wheat, which have been formed by careful selection of seed and growth in different soils and climates, as *red* and *white wheats*, *smooth* and *bearded*, *autumn* and *spring wheats*, and so on; and the farmer will choose the kind that he finds best suited to his soil and climate. The red wheats are coarser and rougher than the white, but are for this very reason better suited for poor soils and severe climates, where the finer and more delicate white wheats would not succeed at all. But it would not pay to grow coarse red wheat upon a fertile soil, where the white would produce a good crop of greater value. It is often necessary or convenient to sow spring wheat, but as a rule autumn-sown wheat is the best. It has more time to send its roots deep down into the soil in search of food, and it generally gives the larger crop. The best soil for wheat is a rich clay loam; but it will grow with fair success upon any fertile soil, in a mild climate, especially if the soil is well prepared by thorough cultivation. It is the habit of wheat to penetrate deeply into the soil, and therefore it may be grown after barley, which has shallow roots, although, as you will remember, it requires almost exactly the same minerals for food. The barley gathers its food from the surface-soil, the wheat more largely from the subsoil. In Scotland the usual order of the wheat in the rotation is after fallow or roots. In England it very commonly follows clover. The clover is ploughed down in the autumn, and the wheat sown amongst its upturned roots, which have brought up nourishment from the subsoil and give just the firmness which wheat requires in its seed-bed, without letting the soil become too close and hard.

When the seed has germinated, as shown in Fig. 13, p. 99, little buds appear around the young plant, and several stalks are sent up instead of one. This is called "tillering," and as many as fifty stems have been known to shoot up from one seed in good soil and with plenty of room. The frosts of winter often loosen the soil very much around the young wheat plants, and they are even liable to be pushed out of the ground in this way. It is, therefore, common to roll the crop in the spring to consolidate the soil about the roots. Sheep are also sometimes turned in to eat the plants close down to the ground so that they shall start afresh and grow up evenly. The wheat is all the better for this rather rough usage, and requires no more attention till harvest time. Wheat should be cut as soon as the milky juice in the seed sets firm so as not to run out when squeezed between the fingers. It is better, except for seed purposes, to cut a fortnight before the grain is dead ripe, for if the cutting be left until the fruit is hard and ripe it will be liable to fall out of the ear during harvest. In the two or three weeks before complete ripeness the plant takes little or no nourishment from the soil; the growth of the seed is then due to the movement of the starch and other matters formed in the leaves, up the stem, and into the ear, and these movements can go on after the corn is cut. In manuring for wheat, manures containing *nitrogen* are found most useful. If the young corn is not sufficiently vigorous in spring a top-dressing of a stimulating manure, such as nitrate of soda or sulphate of ammonia is applied. This encourages the grassy growth for a time, after which the energies of the plant should be devoted to filling and ripening the seed.

The average yield of wheat on fair soil is from 26 to 30 bushels per acre, but crops of 70 and even 80 bushels have been grown under specially favourable conditions. The largest crops are usually, but not always, the most valuable, as the quality of the grain and the amount of bran thrown off in the grinding have to be taken into account.

Barley. This crop is grown for two quite different purposes:—1st, For the **feeding** of stock (horses, cattle, &c.), and to a small extent for human food, as when made into "pot-barley" and "pearl barley;" and 2d, For making into **malt**, which again is chiefly used for brewing beer. For these two purposes two different constituents of the grain have to be considered, namely, the **starch**—which you will remember contains no nitrogen—and the **gluten**, a sticky substance, rich in nitrogen, which can be separated from the starch by washing the ground grain in water. Now the gluten is the more valuable of these for feeding purposes, as it supplies nitrogen to the animal body, but the starch is the part chiefly required for malting. To make malt the barley is soaked in water and thrown into heaps, which soon causes it to germinate. When the radicles have sprouted out to about the length of the grain the germination is stopped by drying the grain in a kiln. During the germination the starch is partly changed into a soluble form, and when the malt has been powdered and stirred in warm water for some time the whole of the starch becomes changed into sugar. Now if this be allowed to stand for a time it begins to **ferment**, and some of the sugar is changed still farther into alcohol. This fermentation depends upon some of the nitrogenous matters of the barley, and if these are in too great quantity, or in an unripe state, the fermentation does not proceed properly. For malting purposes, therefore, the barley should be fully ripe, and should have a thin skin, a large amount of starch, and a small supply of gluten.

Good barley for feeding can be grown on strong clay land, but for the finest qualities of malting barley light rich soils are the best, and it is also necessary that the climate should be dry. The usual place for it in the rotation is after turnips which have been eaten on the land by sheep. The species commonly cultivated is the *two-rowed barley*, of which there are several varieties suitable for different soils. There is also a four-rowed barley called *bere*, which is grown on poor lands. The barley is sown in March or April, and, as it is ripe early, it stands but a short time in the ground, and can therefore be grown more northward, where the summer is short, than wheat can. Great care must be taken to form a good seed-bed for barley, fine and powdery, and not too wet, though it need not be so firm as for wheat, the roots of barley spreading about near the surface of the soil. For malting barley the crop must be dead ripe before being reaped, even though some loss may occur from the grains falling out or the ears breaking off.

A change of seed is very useful in the case of barley as in all the cereal crops; that is, seed obtained from a crop grown in a different district will often succeed better than that taken from a previous crop on the same farm.

The average yield of barley is from 35 to 40 bushels per acre, but may reach 60 or 70 bushels in a favourable soil. The straw is shorter than that of wheat, and is not very valuable fodder for cattle.

Oats. This is the hardiest of the three chief cereal crops of Great Britain. It can be grown successfully in a severe climate and on lands lying high above the sea, and is therefore well suited for the upland farms of Scotland, in which country the oat crops cover three times as much land as the wheat and barley together. It is also much grown in the north of England and in Ireland. The oat thrives better than any of the other cereals on old turf, as its roots penetrate readily through the tough surface slices in search of food. It can get nourishment from the coarse decaying vegetable matter in which turf abounds, and its roots seem to have the power of assisting the decay of such matter in the soil. It is therefore generally sown upon land which has been in grass for some years, and is always sown wherever old moorlands or pastures are to be brought under cultivation for the first time. It is a hardy plant, and will produce a crop upon very poor land, though, of course, better land will produce larger and better crops, and the oat crop will reward the farmer for careful cultivation and deep drainage as well as any crop that is grown.

Oatmeal forms an important part of the bread food of Scotland, though wheat-flour is used there much more than formerly. Oatmeal contains more fat and more nitrogenous matters than wheat, and is proved to be, for children and for persons accustomed to outdoor exercise in a cold climate, the best staple food which can be used. It cannot, however, be made into light porous bread, and it is therefore generally made into oatcakes or porridge.

The oat differs from wheat and barley in having its flowers and grains hanging from little stalks which branch out from the main stem. In the common oat (Fig. 23) these little stalks spread themselves out all round the stem, but in a variety called the *Tartarian oat* they all hang towards one side (Fig. 24).

Oats may be sown more thickly than wheat or barley, as the plant does not "tiller" so much or throw up so large a number of stems from one grain. The straw of oats forms a much better fodder for cattle than either wheat or barley straw, being sometimes almost as nutritive as hay, especially if cut before the grain is quite ripe. The grain itself, except when intended for seed, is all the better for being cut early, as it does not then get scattered during harvest.

The average crop of oats is about 45 bushels per acre, but crops of 90 and 100 bushels have been reaped in a favourable soil and climate, and with first-rate cultivation.

Rye is a hardier crop than even oats, and may be grown upon poor sandy soils which will produce scarcely any other crop. It is not now used in this country for human food, though rye bread was once very common in England, and is still the chief food of the peasantry in Germany and other parts of the Continent. It is therefore not much grown here for its seed, of which it produces 30 or 40 bushels per acre. It is, however, often grown for its herbage as a green crop, for which purpose it is sown thickly in autumn and produces a good supply of green food early in the spring, before most green crops are ready.

Maize or Indian corn is a cereal which is hardly grown at all in this country, the climate not being warm enough or the summers long enough to ripen the seeds. In the warmer parts of America it ripens its grain and forms the principal corn crop grown for human food.

The Grasses. We have seen that the cereal crops are merely grasses, improved and cultivated for their *seeds.* We now come to the grass crops grown entirely for their **foliage,** and more generally known as **grass.** About a hundred different kinds of grass are found wild in this country, showing a great variety of form and quality. Some have smooth and

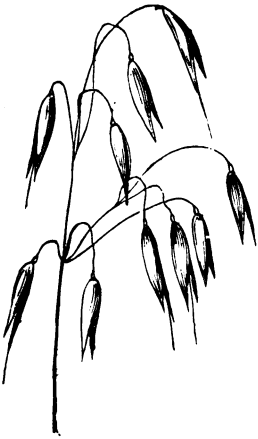


Fig. 23.

Fig. 24.

delicate leaves and juicy stems; others are coarse and bristly, having sharp spines along the leaves which may inflict slight wounds when drawn across the fingers: others again are covered with soft woolly hairs. But the main distinction to the sight is in the arrangement of their flowers; and no more interesting amusement for a boy or girl can be found than the collection and examination of the various species of grass, when in flower during the summer months, or in fruit during the autumn. They can be easily dried by being pressed in a large book, or between sheets of old newspaper, and when mounted on cartridge-paper with a little gum, and made up into a book, form a beautiful album at a very small cost. Of these flowers some are spiked like wheat, some bearded with long "awns" or bristles like barley, others spread and branched like oats, while many have beautiful forms of their own.

Useful Grasses. Of all the varieties of grass, however, less than a dozen are commonly employed for agricultural purposes. These have smooth-skinned leaves, and sweet juicy stems, and form nutritious food for sheep and cattle. These useful grasses are found mixed together in varying proportions in most good natural pastures, along with a number of inferior species which give less produce, and are not liked by stock. Unlike the other crops of the farm, the grasses are allowed to a certain extent to have their own way, and to struggle with each other for the best places and food. The chief difference between a good pasture and a bad one is that in a good pasture the nutritive grasses are in greater quantity and overpower the bad ones. If the soil is good and well cultivated, the better grasses can get a good supply of food, and so win the battle, and drive most of the bad ones from the field. If, however, the soil is poor, or badly drained, or neglected in any way, the better grasses do not thrive, and the sour, rough grasses, which can make use of coarser food, get the upper hand, and drive them out. The following are some of the most valuable grasses, with figures of their heads of flowers by which they are chiefly to be distinguished. Most of them are **perennial,**

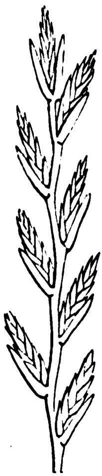


Fig. 25.

Fig. 26.

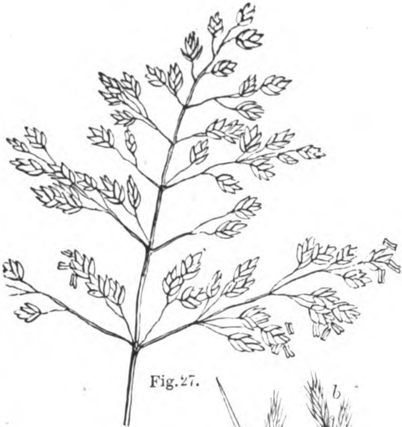


Fig. 27.

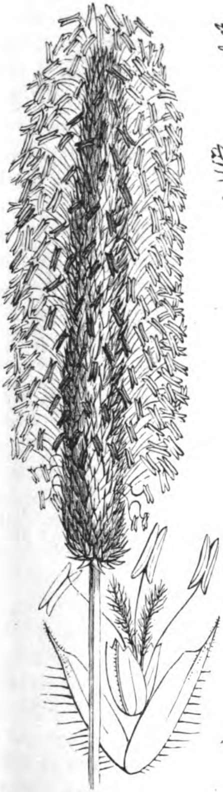


Fig. 29.

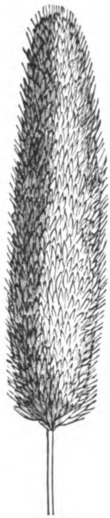


Fig. 28.

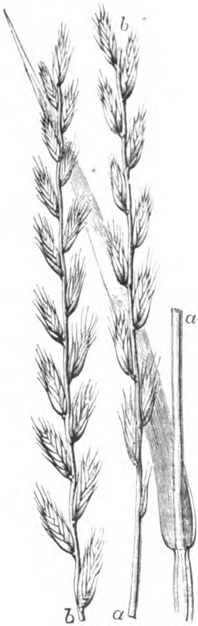


Fig. 30.

that is, their roots live on from year to year and send up fresh stems and flowers:—

1. *Italian Rye Grass.*
2. *Perennial Rye Grass* (Fig. 25).
3. *Meadow Fescue* (Fig. 26).
4. *Meadow Foxtail* (Fig. 28).
5. *Catstail or Timothy* (Fig. 29).
6. *Cocksfoot* (Fig. 31).
7. *Meadow Grass* (Fig. 27).
8. *Crested Dogstail* (Fig. 32).

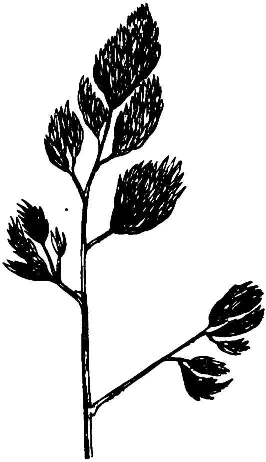


Fig. 31.

Fig. 32.

Rye Grass. Of these useful grasses the only ones grown as independent crops are Timothy and the Rye Grasses. The variety called Italian Rye Grass grows very rapidly, and gives a large produce. When used as green forage, it should be mown just as it comes into ear, as the leaves and stem then contain the greatest amount of nourishment. Like all the grasses it requires a large supply of nitrogenous food and is specially suitable for sewage farms, where it is flooded at intervals with sewage water from a town, and produces several crops of nutritious food in a year. In this way every acre may be made to produce as much as 50 or 60 tons of fodder during the year.

Temporary Pastures. A mixture of various grass and clover seeds is often sown in rotation with the other crops of the farm, forming a temporary pasture which is either mown for hay or eaten off with sheep or cattle. The "seeds" (by which a farmer means mixed grass and clover seeds) are sown with the grain crop, or just after the grain (preferably barley) appears above ground. The crop is allowed to remain down for one, two, or three years, and sometimes longer. It is mown or eaten off each year, and is at last ploughed up for the next crop. Thus a very common six-year course in the North of England is—1 Oats, 2 Turnips, 3 Barley, 4 Seeds, 5 Seeds, 6 Seeds.

Permanent Pasture. More than two-thirds of the arable land of the United Kingdom is lying under grass, and the area is steadily increasing, as farmers find that grass at present pays better than corn upon all except the better class of soils. Many pastures have been under grass for hundreds of years, but lands hitherto cultivated are in many places being converted into pasture by being sown with a mixture of various good grasses, which, with care, establish themselves in a few years, shutting out the wild coarser kinds and forming a permanent pasture. The grass on some pastures, as on the mountain districts and chalk downs, is short and scanty, though sweet and suitable for small hardy breeds of sheep. That in many valleys and river meadows gives valuable crops of grass and hay year after year.

When a pasture has been grazed for many years the soil becomes partly exhausted of plant food, and is often much improved by a top-dressing of bones, to supply the phosphate of lime necessary to replace that carried off in the milk and bones of the animals fed upon the grass. Superphosphate and nitrate of soda also form valuable manures for grass, supplying phosphates and nitrogen. Any drainage from the manure heap and farm buildings may be used on the meadows with advantage.

Haymaking. The proper time to cut the grass for hay is shortly after the time of flowering, and when the seeds are still soft and milky. After flowering the soluble nitrogenous and starchy matters in the leaf and stem are partly converted into indigestible woody matter, and partly pass on into the seeds, and these if ripe drop out during the haymaking and much nutritious food is lost. The great point in making hay is to get the grass thoroughly dried as quickly as possible without exposure to rain, which washes out much of the nutriment. If stacked before being quite dry it is likely to *ferment* in the stack, the fermentation being accompanied by the oxidation of the warm and moist organic matter. This oxidation gives rise to so much heat that haystacks sometimes take fire from this cause, or become so blackened with the heat as to be spoiled for fodder.

Ensilage. A method of preserving grass and other green crops without drying has lately been introduced into this country, and promises to be very useful, as it enables the farmer to be quite independent of the weather. The green fodder, which may be quite wet with rain, is placed in an air-tight pit or building called a **silo,** and trodden down tightly as it is put in. It is then covered with boards, and heavy weights are placed on the top. The great point is to shut out the air with its oxygen so that fermentation cannot take place. When opened after several months the fodder is found to be palatable and good, and is readily eaten by the live stock. Silage can also be made in stacks by applying enough pressure. This mode of treating grass and other fodder crops is called **ensilage.**

The Leguminous Crops. The pod-bearing family furnishes a large number of very important crops, which, like the grasses, may be divided into two groups—those grown for their **seeds,** and therefore often spoken of with the grain crops; and those grown for their **foliage,** and forming fodder or green crops. To the first of these groups belong only two crops, **beans** and **peas**; to the second group belong **vetches** or **tares, sainfoin, lucerne,** and various kinds of **clover.** These are all distinguished by having coloured flowers of the same general form as that of the pea (Fig. 18), though in some these are very small and crowded into a head. They have also broad leaves divided into three, or five, or more rounded leaflets. They all contain a large amount of *nitrogen*—about twice as much as the grasses—and also much potash and lime. Yet nitrogenous manures such as nitrate of soda and sulphate of ammonia, which produce such striking effect upon the cereals and grasses, have very little influence upon these crops. Potash and lime are useful to them as manures, but the nitrogen they seem to be able to collect for themselves, plants of this class having a special power of collecting the nitrogen of their food which renders them independent of nitrogenous manures.

Leguminous crops are very liable to exhaust the soil of some particular part of their food if grown repeatedly on the same land. This is probably one of the causes of "bean sickness" and "clover sickness," and the only remedy known is to cease growing these crops until the soil has had time to recover itself.

Beans. This crop is generally grown after a grain crop. In clay land, which suits them best, especially if lime is present, beans take the place of a fallow crop, being sown in rows wide apart so as to allow of the cultivation of the soil between, during the time they are upon the land. The field bean is really the same species as the garden bean, but is a rather smaller and hardier variety. Beans are usually sown early in spring. They are allowed to ripen and are then cut down like corn, dried and stacked, and when threshed out will produce about 30 bushels per acre. They are, however, a very uncertain crop, as they are liable to be seriously injured by bad weather, and to be attacked by several kinds of insects, so that sometimes the crop is quite a failure. The seeds make very nutritious food for cattle and horses, containing much nitrogenous matter, suitable for the formation of flesh; and the straw, though containing much woody fibre, forms a very nutritious fodder, and makes a rich manure when trodden down in the farmyard.

Peas. These are grown as a field crop, either to be picked when green for human food or to be reaped and threshed like corn when ripe. They are sometimes grown mixed with beans, reaped and threshed together, and separated afterwards by sifting. They grow best, however, on a lighter soil than beans, but their manuring, management, and yield are about the same as for that crop. Like beans too they suffer much from the attacks of insects. They form very nutritious food, and the straw makes much better fodder than that of beans, being very nutritive and much liked by all animals.

Vetches, Fitches, or Tares. We now come to those leguminous plants which are grown only for their foliage, and of these the one which comes nearest to the pea and bean is the **vetch**, with its long trailing stem, its leaves made up of five or six pairs of leaflets, and its red or purple flowers. There are winter and spring vetches, and they may be sown at different times during the year so as to give a succession of green food for many months. Like all foliage plants they should be cut as soon as they are in full bloom, or woody fibre will be formed in the stem, and the lower leaves will begin to decay. They may be either eaten on the land by sheep, or cut and carried to the farmyard, where they furnish excellent food for all kinds of stock. They succeed best on a clay loam containing lime. They are very often grown as a "*catch crop;*" that is, they are grown quickly between two crops when the land would otherwise be lying idle. For instance, they may be sown as soon as the corn is reaped, and will supply early food in the spring; they will then be eaten off, and the land sown with turnips to be gathered the same year. Vetches are often sown with rye or oats, the stiff stems of which keep the vetches from trailing so much on the ground. If fed off with sheep they leave the land in rich condition for the turnips which follow.

Sainfoin. This is a very useful fodder crop, and grows well on calcareous soils. The leaves are something like those of vetches but with fewer leaflets. The flowers are rosy red, smaller than those of tares, and growing in egg-shaped bunches; each pod has only one seed. (See Fig. 22.) It grows best upon dry, light, chalky, or marly soils, and strikes its roots deep into the subsoil, so that it can thrive in dry seasons when other crops fail. It is generally sown in spring with the barley or directly after. It is a hardy perennial crop, and may be kept down for eight or ten years, and eaten off or made into hay every year. It is apt to get foul with weeds after five or six years, and is then often pared off and burned (see p. 42, Part I.) to destroy the roots of weeds and the grubs of insects which would otherwise injure the following corn crop.

Lucerne or Purple Medick. This is a crop cultivated very much like sainfoin, but confined chiefly to the south of England. The plant has leaves with only three leaflets, and bears a head of blue or purple flowers, and the seeds are contained in a peculiar pod twisted like a snail shell (Fig. 21). It grows best on deep light soils. It is not so hardy as sainfoin, but on suitable soils produces a larger quantity of excellent fodder, which is especially valuable for dairy cows. It can be kept down five or six years, but must be kept clear of weeds by hoeing as much as possible.

A species of medick with yellow flowers and black pods is known as **yellow clover** or **hop trefoil**, and is often grown with the clovers.

Clover. This is the most important of the leguminous fodder plants. Several kinds are grown, the principal being the common **red clover**, the white or **Dutch clover**, and the **Swedish** or **Alsike.** Other useful sorts are the **Italian** or **crimson**, and a stout strong variety of red clover which flowers rather later, and is called **cow-grass** or **perennial red clover.** All the clovers and miscellaneous plants sown in pastures are known to farmers as "*artificial grasses*," to distinguish them from the real or *natural grasses*, which they resemble in their mode of cultivation. A mixture of grasses and clovers is often grown for temporary or permanent pasture, to be eaten off by sheep, or made into hay. Clover forms an important part of the rotation of crops, being the very best crop that can be grown as a preparation for wheat. The common red clover is generally used for this purpose. Its roots go deep into the subsoil and bring up valuable plant food. Its broad three-lobed leaves spread out to the air and absorb large supplies of carbon. Then when it has been cut for hay or consumed by stock, its richly nitrogenous roots remain in the ground, and being ploughed in they gradually decay, and yield up abundance of nitrogen and other matters to nourish the wheat during its growth. The roots of the clover also have an excellent effect upon the mechanical texture of the soil, binding its particles together if too loose and separating them if too close, thus giving the firmness without hardness so necessary for the roots of the wheat.

The white or Dutch clover is the kind most used for sheep-walks, and is found growing naturally in most good old pastures. For haymaking red clover is even more valuable than grass. The hay is made in a similar manner, but care is taken not to shake it too much, as the leaves are brittle and apt to break off, and much good fodder may be lost.

We have seen that nitrogenous manures have little effect upon leguminous crops. If a meadow be constantly manured with these the clovers will gradually disappear, being overcome by the grasses; but the clovers may be brought back by manuring with potash and lime.

The Cruciferous Crops. The cross-flower family (see p. 106) contains a large number of plants useful for various purposes. Of those most cultivated as crops there are two classes, namely, those cultivated for their **leaves**, including **rape, mustard,** and **cabbage**; and those cultivated for their **stem** and **root**, comprising **kohl-rabi, turnip,** and **swede.** These are all biennials except mustard, and the object of the farmer is to encourage them to lay up a store of nourishment during their first year's growth, which he makes use of for his own purposes.

Rape. There are two kinds of rape grown, the rough-leaved winter rape or **cole-seed**; and the smooth-leaved summer rape or **colza,** from the seeds of which colza-oil is expressed. Rape grows best on soils containing much vegetable matter and is therefore much grown on the peaty soil of the fens, but it will also succeed on clays. The summer variety sown in May or June gives early autumn sheep food before the turnips are ready. It is generally taken between two grain crops, and often as a stolen or catch crop, and comes in usefully to fill the place of a turnip crop which may have failed.

Mustard is a quick-growing annual, and therefore very suitable for catch crops and for green manuring. For the latter purpose it is sown thickly, and when in full growth is ploughed into the ground, and, slowly decaying, supplies to the next crop the plant food which it has gathered from the soil, and which might otherwise have been washed out by the rains before that crop could use it. Two species of mustard are grown as crops. The species grown for forage is the **White Mustard.** The **Black Mustard** has a darker seed skin, and is grown for its seeds, which, when ground, supply the well-known yellow condiment. Another species, known as field mustard or **Charlock,** is a troublesome weed in many soils.

The Cabbage forms a very useful forage crop on strong clay soil, as it furnishes a large quantity of good food for sheep and cattle. There are many kinds, the most important being the **Drum-head** or common cattle cabbage, with close leaves forming a "heart;" and the **Thousand-headed Kale,** which grows three feet high, with a large number of side shoots and open leaves. The cabbage requires deep cultivation, and much manure, especially farmyard and nitrogenous manures. The seeds are generally sown in autumn in a seed-bed, and the young plants taken up and planted singly in the spring two to three feet apart, so that they may have room to grow, and that the horse-hoe may be taken between the rows to keep the weeds down. The ground can be tilled till the plants become pretty large. The average produce is about 30 tons per acre. The drum-head can be stored for the winter if kept well ventilated, and both kinds can be preserved by ensilage. The cabbage is liable to be attacked by various insects, but as a rule suffers no serious injury.

Kohl-rabi. This is a German name, meaning cole-rape, that is *cabbage-turnip*, and is very suitable for this plant, which is a kind of cabbage with a stem swollen into the shape of a turnip (Fig. 33). The leaves growing out from the swollen part show that it is a stem and not a root, though the farmer generally classes it with the root-crops, and cultivates and uses it in much the same way as turnips and other roots. It forms a good substitute for the turnip crop on lands which have become "turnip sick." It is very hardy and resists both

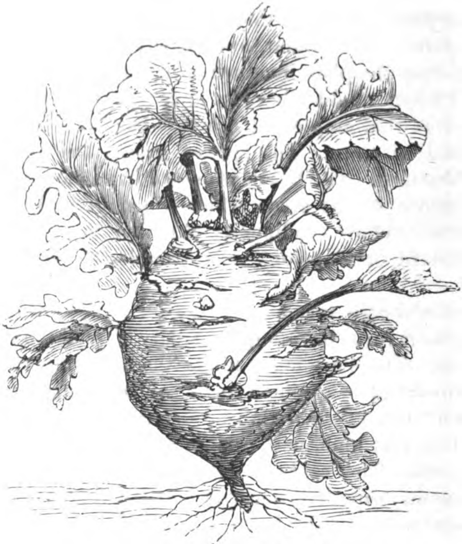


Fig. 33.

drought and frost. It is more nourishing than turnips, and when given to dairy cows does not cause a disagreeable flavour in the milk, as turnips often do. Like all the cabbage tribe kohl-rabi is a gross feeder, growing best on strong rich soils with plenty of manure. It is sown early in April, and either transplanted into rows like cabbage, or sown in drills and thinned out by hoeing up most of the young plants, leaving one and one at a distance of about a foot from each other. It forms a good fallow crop, allowing of thorough cultivation of the land between the rows during the whole period of its growth, admitting air to the soil, by which the dormant matters are rendered soluble, and plant food is prepared for a future crop. A good crop of kohl-rabi may yield about 20 or 25 tons per acre of nourishing food for sheep or cattle.

Turnips and Swedes. These are two varieties or species of the same kind of plant as rape, but cultivated specially for their **roots.** They have long formed, in fact, the principal *root-crops* grown in this country, though in many parts they have now to take their turn with kohl-rabi and mangel-wurzel. Turnips grow best on a rather light loam, but with careful and deep autumn cultivation they can be grown successfully on many clay soils. They require a good supply of farmyard manure, with superphosphate or some other phosphatic manure. It is very important to get a fine light seed-bed, so that the soil shall lie close and moist around the small seeds, yet without shutting out the air from them. You will remember that the turnip-seed when germinating sends up two little smooth green leaves like those of mustard. Between these is a little bud which soon opens out into several rough green leaves, of a different shape from the first two, and these grow into the turnip "top." But before the rough leaves appear the seed-leaves are often attacked by a tiny beetle called the *turnip fly* or *flea,* which sometimes appears in such numbers as to destroy the whole crop. It is, therefore, very important to hasten the early growth of the plant, by keeping the soil moist and using stimulating manure. If, however, the stimulation be carried too far, it causes an unhealthy growth of large soft roots, which contain too much water, and are not so good for food. The great point to be aimed at is to get a steady and constant growth, with time for the cells of the root to become filled with the starch and other matters sent down from the leaves. Remember that turnips are really a **fallow** crop. They are grown in rows wide apart to allow of the horse-hoe and cultivator being often passed between them, and they are singled out in the rows with the hand-hoe till they are ten or twelve inches apart. Turnips are chiefly surface feeders, and are able to take up more nitrogenous matters from the soil than the cereal crops. They contain a large quantity of water, white turnips especially having as much as 92 lbs. of water out of every 100 lbs. of turnips. They should therefore be accompanied with some drier kind of food when given to sheep or cattle. The largest roots are not always the best food; indeed, as a rule, they are the worst, as they contain more water and a less proportion of solid matter. Turnips are better for feeding purposes after they have become properly ripened. Swedes are generally stored by being built up into heaps in the field and covered with a layer of earth. The ordinary yield of the turnip or swede crop is 15 to 25 tons per acre.

Other Fallow Crops. If you turn to the table of crops on page 111 you will see that we have noticed all the crops belonging to the three principal orders, namely, the **grasses,** the **pod-bearers,** and the **cross-flower family;** and we have now a few crops to consider belonging to three other orders, each containing only one or two species of agricultural importance.

Mangel-wurzel and Beet-root. These two plants are merely varieties of the same species, and belong to an order containing spinach and some other "pot-herbs." The wild beet from which the cultivated plants are descended grows on the sea-shores of England and Ireland, and has a small fleshy root and spikes of small green flowers. By continual cultivation and selection of seed from the best plants, this has been improved into the many varieties of mangel and beet—long, round, red, yellow, and others. The word *mangel-wurzel*, or more correctly *mangold-wurzel*, is simply the German for "beet-root." The variety known as **beet** is cultivated in France for its sugar, but in England the several forms of mangel are largely grown for sheep and cattle food. It is liable to fewer diseases than turnips, and produces a larger crop, but cannot be grown so well in Scotland on account of the colder climate. Mangels differ from turnips and swedes in striking their roots deeper into the soil, and in requiring a longer time for their growth. They are generally sown in April or even earlier. Like turnips they require a large amount of plant food, and therefore a plentiful supply of manure, but they are not so dependent upon the manure for their supply of phosphoric acid as turnips are, being able to collect it from the soil. Common salt is a very useful manure for mangels, for the plant requires a large supply, being of sea-side origin, and the salt also attracts moisture and renders other plant food soluble. Nitrate of soda has a powerful effect in increasing the crop, and a large quantity of it may be applied. Deep cultivation in autumn is even more important to the mangel than to turnips, especially upon heavy or sticky soils. The seed is contained in a hard case or shell, so that it is frequently steeped in water for a day or two before sowing, to hasten germination. The young plants are thinned out like turnips until they stand singly in the rows, and the horse-hoe is used repeatedly between the rows to keep the ground loose and open to the atmosphere. The roots must be taken up before frost comes, and stored in pits or covered heaps. They are longer in ripening than swedes, and generally form food for the following spring and early summer. They yield about 25 tons per acre, but may be much more if the soil, season, and cultivation be favourable.

The Carrot and Parsnip belong to an order which contains celery, parsley, and other garden plants, together with many poisonous ones, such as hemlock. The parsnip is not much grown as a field crop, but the carrot is of importance in some districts. It requires a deep loose soil, where its tap-root can pierce straight down. A stone in its way will cause the root to fork or branch out, and become less valuable. The seeds are covered with little spines or hooks, which cause them to cling together. To prevent this they may be mixed with sand before being sown, and kept damp for a few days. This also causes the seeds to germinate quickly and get the start of the weeds. In a favourable soil and season the carrot will produce 20 tons of roots per acre.

Potatoes belong to the same order as the *bittersweet*, a trailing hedge plant with red berries, and the *deadly nightshade.* You may easily see how much the flowers of these plants are like those of the potato. The tobacco plant belongs to the same order, and, like the potato, was introduced to this country from America. The potato is of great importance as a field-crop, especially in Ireland, where it forms the chief food of the peasantry. Potatoes grow best in a sandy loam, but may be grown with success in many soils, the least suited being stiff clays and chalks. Though classed among the root-crops the potato is really a thickened underground branch or *tuber* in which a store of starch, formed in the leaves, has been deposited for the next year's growth. It differs from all the other farm crops in not being grown from seed, some of the tubers being saved and planted to produce the next crop. The tubers thus used are often called "seed" potatoes, because they answer the same purpose as seeds. They are either planted whole or cut into two or three pieces, care being taken to leave at least one "eye" on each piece, these being the buds from which a new stem and root will be developed. There are many varieties of potatoes: *red* and *white*, *round* and *kidney-shaped*, *early* and *late*, suitable for different soils and various uses. Their great use is for human food, of which they produce more per acre than any other crop. They are also used to feed horses, cows, and pigs, and for the manufacture of starch. As they are generally sold off the farm, potatoes form an exhausting crop, and require a plentiful supply of manure. Well rotted farmyard manure and seaweed are often used, and as potatoes respond very readily to applications of potash, manures containing it produce a good effect upon the crop. Six tons per acre is the average yield.

In the year 1846 the potato disease suddenly appeared, and caused almost a total failure of the crop; and although many remedies have been tried, the potato crop still suffers very severely from this cause.

III.—PESTS OF THE FARM.

We have now to consider some of the enemies of the farmer, which injure his crops, and often make a very serious difference in their yield and quality. These enemies belong both to the vegetable and animal kingdom, and the work of the farmer must include a watchful and constant war against them, or they will spoil his labour and eat up all his profits. The vegetable foes to agriculture are **weeds** and **fungi.**

Weeds. A weed is a plant growing in the wrong place. A crop consists of a large number of plants of the kind sown by the farmer, growing so as to produce the greatest amount of food or other useful material in a given space. Now these plants require, as we have seen, light, and air, and plant food. But weeds also require the very same things; and therefore if they grow with the crop they take from it some of these necessaries of plant life. They are *robbers* in fact, and being often stronger or broader-leaved or longer-rooted than the cultivated plants, they are able to overpower them and take the lion's share of the supply, causing the rightful occupants of the soil to grow poor and sickly, or even to die away altogether. Some weeds are poisonous in character, as for instance the seeds of a grass called **darnel,** which yet is closely related to the useful rye-grass. Many of the crops have discreditable relations hanging round the fields in this way taking the room of more useful plants and doing injury to the crops. Thus the troublesome **couch-grass** is a relative of wheat; an **oat-grass** with creeping underground stems is related to the oat; **way-bent** or **barley-grass** to barley, and **charlock** to mustard and turnip. Some weeds are signs of a poor soil, as **daisy** and **cowslip,** others of wet and undrained land, as **rushes** and **sedges;** while **nettle, dock,** and **thistle** are signs of neglected cultivation.

It is necessary to keep up a constant war upon weeds, even upon waste land at the ends of the fields and by the roadside; for, besides taking food from the crops, they form a home for many fungi and insects which will come out from them and fasten upon the crops. The weeds by the roadside, too, especially those with downy seeds, such as thistle, dandelion, and groundsel, scatter their seed by the help of the wind over the fields around, and cause trouble for a long time after. Weeds should never be allowed to form and ripen their seed, for as each plant often produces thousands of seeds, the old proverb is not far from the truth—"One year's seed makes seven years' weed." They should be cut down or rooted up at the first opportunity. The appearance of their flowers should be looked upon as a signal of danger.

The seeds of some plants may lie buried in the ground for a long time, and spring up all at once when some change has been made in the soil, as by draining, or by the use of a different manure, or on the removal of an old layer of turf. After the great fire of London in 1666 a weed, thence called "London Rocket," sprang up in great abundance, covering all the waste places where the fire had been.

The weeds against which the farmer has to fight form a very large army, belonging to many different families; but we can here only consider particularly a few of the most troublesome ones requiring special methods of attack.

Couch-grass, Twitch, or Quitch. These names are

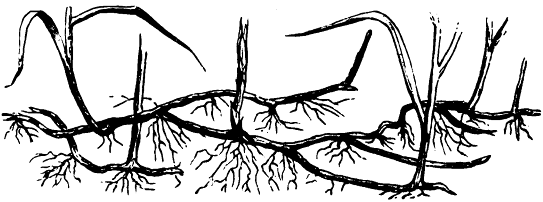


Fig. 34.

all corruptions of the word *quick*, that is *living*, and are very suitable to this grass, for it is almost impossible to kill it. It is, as we have said, related to wheat, but is chiefly distinguished by its underground stem, which creeps about in the soil and gives off new stems and root fibres from each joint (Fig. 34). Even if this white creeping stem is cut in pieces, each piece will go on growing, and will produce a new plant. The only way to get rid of couch is to cultivate the land as often as necessary with grubbers and harrows, to hook out these runners on to the surface, and then gather them into heaps and burn them. The headlands or waste borders of the fields should also be ploughed up and cleared in the same way.

Bindweed or *Wild Convolvulus* is another plant with creeping, underground stems, which must be treated like couch grass. It has a twining stem which winds round the corn plants, and robs them of light, air, and food.

Thistles are deep-rooted plants, and require close attention. There are many different species, but only three need be mentioned:—1. The **stemless thistle**, growing in gravelly and chalky pastures, with spreading leaves and one crimson flower close to the ground. 2. The common **field thistle**, two to four feet high, with many purple flowers and a creeping root-stock. 3. The **corn sow-thistle**, which is not a true thistle, having yellow flowers and milky juice; this has also a creeping root-stock. These all scatter their seeds by floating them on the wind by means of a crown of feathery hairs, so that they may be blown miles away from the parent plant. The two main points to be attended to in dealing with thistles are, getting up the roots, and preventing the ripening of seed. The roots should be pulled up by hand after rain when the ground is soft, or dug up. Cutting the stems either above or even a little below the surface of the soil does not kill the plants, as the roots send up new stems. But all stems should be cut early in the summer to prevent the ripening of the seeds, and usually a second cutting will be required later in the season for the same purpose.

Charlock or *Wild Mustard* is very plentiful on some soils. It has bright yellow flowers. The turnip beetle which does such mischief to the turnip crops often finds shelter on the charlock growing round the fields, until the young turnips come up. The seeds being very oily will often lie for years in the ground, and spring up when the soil is cultivated; and as it is an annual plant, it is a good plan to encourage the germination of the seeds, and then destroy the plants by horse-hoeing.

Dodder is a **parasite**; that is, it feeds directly upon other plants, especially upon clover. The dodder at first grows like other plants from seed in the ground, which seed is too often left among the seeds of clover with which the field is sown. As soon as the dodder seed has sent up its slender red stem, this fastens upon the clover plant by means of suckers. The root of the dodder then dies away and the plant obtains all its nourishment from the juices of the clover, which thus dies of starvation, but not before the dodder has ripened its seed, which may thus get mixed with the clover seed and spoil the next crop. It is thus very important in buying clover seed to make sure that it is free from seeds of dodder.

Fungi.[1] Many of the crops are infested with numbers of very minute fungi, that is, plants of the same order as Mushroom, but so small that they can only be seen separately with the microscope; and yet they may occur in such vast numbers as to make a field of corn look quite black, and cause great loss to the cultivator. Some of the most hurtful of the diseases produced by these fungi are known by the names of **mould, rust, bunt, smut,** and **mildew.** Mould and mildew form white or dark spots, and rust red spots on the plants, and cause them to droop and sicken: bunt and smut fill the ears of corn with a black powder in the place of the grain. The potato disease is also due to a similar fungus, which grows in the leaf, stem, and tuber, and spoils the crop. Fungi are mostly encouraged by damp; and in order to prevent as far as possible all these diseases it is well to have the land **well drained** and **well cultivated,** to use **good** and **clean seed,** and to take all means to encourage the healthy and vigorous growth of the crop. The seed of wheat is generally steeped in some chemical preparation before sowing, so as to destroy any spores of fungi which may remain on them from a previous attack.

Animal Pests. Most of the animal foes of the farmer are **insects.**[2] It is true that some larger animals, such as rabbits and hares, eat portions of all the crops. Birds also help themselves to fruit and seeds. Rooks and pigeons are very troublesome at the time of seed-sowing, and again at harvest, when they are assisted by pheasants and other game in destroying the ripened ears of corn. Pigeons are particularly fond of peas and vetches, and search greedily for them. Crows do much damage by pulling up young turnip plants after they have been singled in order to find insects at their roots. All this, however, is nothing compared with the injury

[1] See also Part IV., pp. 180–192. [2] Ibid. pp. 192–198.

committed by insects. The birds, indeed, do some good as well as harm by devouring the insects which feed upon the crops, and in places where birds have been destroyed it is found that insect pests increase and multiply.

Insect Changes. Nearly all insects, after leaving the egg, appear under three different forms. These are first the **larva,** called maggot, grub or caterpillar, in which state the insect eats voraciously; second, the **pupa** or chrysalis, in which state the insect is generally quiet and inclosed in a horny case; and third, the **perfect insect**—fly, beetle, butterfly or moth. Thus the common white butterfly, which you have no doubt often chased in the summer time, lays its eggs on the under side of a cabbage leaf. These soon hatch into little greenish caterpillars, which feed upon the cabbage until full grown. They then crawl away to some sheltered place, and hanging themselves by their tails shrink up and become covered with a horny skin, forming a chrysalis. Out of this in about a fortnight if it is summer time, or next spring if it is now autumn, comes the well-known white cabbage butterfly.

Injurious Butterflies and Moths. There are three butterflies, the caterpillars of which are very destructive to the cabbage crops, namely, the **large white,** the **small white,** and the **green-veined white.** There are also various other caterpillars of butterflies and moths which injure the cabbage, turnip, pea, and other crops. The best remedies are to encourage insect-eating birds, to destroy the chrysalises in outhouses and amongst lumber, and to destroy all weeds in fields.

Daddy-long-legs or Crane-fly. There are various flies whose grubs are hurtful to the crops. One of the most destructive is the grub of the insect commonly known as the **crane-fly,** or "daddy-long-legs." These grubs, or maggots, generally known by farmers as "*the grub*," have very tough skins, and are about an inch and a half long when full grown, and feed upon the roots of corn, turnips, and other crops. Fig. 35 (*a*) shows the grub or leather jacket. It has no legs, but has strong jaws with which it gnaws through the roots just below the surface of the ground. When full grown it changes to a "pupa" with a horny case which rises out of the ground (*b*) and soon splits down the back setting free the perfect insect or fly (*c*). This lays its small black eggs (*d*) on the ground or on the low grass, in damp places or in neglected ground at the sides of the fields. Therefore all such spots should be cultivated and cleared. A good plan is to push on the young plant in the spring with nitrate of soda to get it past the period when its young roots are just beginning to absorb food from the soil, the supply in the seed being exhausted.

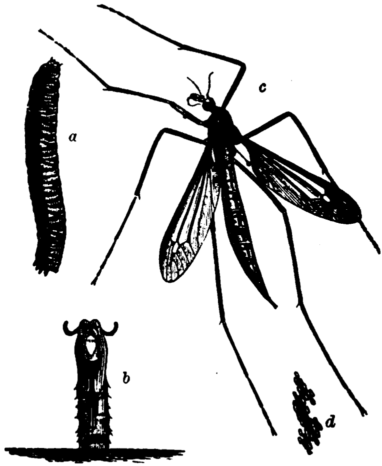


Fig. 35.

Red Maggot or Wheat Midge. This is a very small orange-coloured maggot, about $\frac{1}{12}$ of an inch in length, which feeds upon the ears of corn, injuring the young grains and preventing their growth. The pupæ remain in the ear or in the ground till the next year, when they change into the little midges or flies, and these lay their tiny eggs in the next crop. With these insects again it is found that deep cultivation is the best remedy. The insects are buried too deeply in the soil to find their way out. Weeds which might harbour them should be burned or buried; and the chaff of the wheat which has been affected with them should be got rid of in the same way.

Wireworm. This is one of the most destructive pests to agriculture, as it lives several years in the soil, and destroys the roots of all kinds of crops. The wireworm is the grub of a small species of beetle called "skip-jack" or "click-beetle," from its power of righting itself with a leap and a sharp click when laid upon its back. The grub is long and stiff like a piece of flattened wire, with a hard shiny skin and three pairs of legs near the head (Fig. 36). The six legs distinguish it from other grubs such as the crane-fly grub, and from the "hundred legs" and "thousand legs," which do little harm. The wireworms feed ravenously upon the roots and underground stems of almost all crops for three, four, or five years; after which they go through their changes in the earth, and come out as click-beetles. The remedies for the attacks of wireworm are paring and burning of stubble on infested land to destroy the grubs, good cultivation, and the use of suitable manures to quicken the growth of the crop. By encouraging the growth of the crops when young they are more able to overcome the attack, and to send out new roots when weaker plants would be killed.

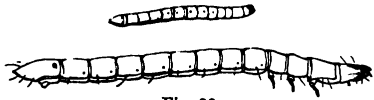


Fig. 36.

The Turnip Fly, or Flea Beetle. This is the most destructive enemy to the turnip crop, which is sometimes quite destroyed by it. There are several kinds of turnip-beetle, but they all seem to attack the crop in the same manner. They are little black shining beetles, about $\frac{1}{8}$ of an inch long, and have strong hind-legs, with which they can spring to a good distance; they are therefore often called *fleas*. They feed upon the young seed-leaves of the turnip, and from the eggs which they lay tiny maggots are produced in large numbers, which gnaw their way into the soft part of the leaf, and burrow among the cells. They go through all their changes in about a month, feeding nearly all the time, and a new brood is then ready to carry on the work of destruction. There are five or six broods in a season. When no turnips are at hand "the fly" feeds upon wild plants of the same family, such as charlock, hedge-mustard, and others; and thus we see still farther proof of the need for cleanliness around the borders of the fields, and the clearance of weeds and refuse matter.

The turnip seed is sometimes sown very thickly, in order that some plants at least may escape the enemy, but this is apt to make the young plants grow thin and sickly from want of room. Thorough cultivation, good manuring, and the preparation of a fine moist seed-bed are advisable, so that the young plants may easily find a good supply of plant food, which will enable them to grow quickly and get out of reach of the turnip-beetle.

In all cases of insect attack you will notice the importance, as a means of preventing loss of crops, that is placed on deep and thorough cultivation of the soil, with good drainage where necessary, and the clearance of all weeds and rubbish. But these things form also the very best preparation for the growth of the crops themselves, so that there is every reason for bearing them constantly in mind. The weeds and waste matters when properly treated may be turned into a supply of plant food and added to the soil. The deep cultivation will make it easy for the roots to penetrate the soil, and will admit the natural agents always at hand—the oxygen and carbonic acid of the atmosphere—and these will act upon the soil itself, and set free the dormant matters in a soluble and useful form. Natural and artificial manures will then come in as a supplemental supply of food for the plants, suitable for special crops and soils and on particular occasions. Lastly, a careful selection of seed—ripe, clean, healthy, and suited to the soil and climate, will give the cultivator every hope of growing crops of good yield and quality.

SUMMARY.

Each point in this summary should be made the base of an exercise, being amplified and illustrated by the pupil in his own words.

1. **The Growth of Plants** includes *germination*, *nutrition*, *assimilation*, and *reproduction*.
2. **Germination** requires **air, warmth,** and **moisture.**
3. **Root** and **stem** are organs of **nutrition.**
4. **Leaves** are organs of **nutrition** and **assimilation.**
5. **Flowers,** leading to **fruit,** containing **seed,** are organs of **reproduction.**

6. **Crops** may be classed as **grain** or **cereal** crops, **fodder** or **forage** crops, and **fallow** or **root** crops, or according to their natural relation to each other.

7. The **cereal** crops are wheat, barley, oats, rye, and maize.

8. **Wheat** is deep-rooted, tillers well, requires *firm* seed-bed, yields 25 to 30 bushels per acre.

9. **Barley** is grown for feeding (gluten) or for malting (starch), is shallow rooted, requires *fine* seed-bed, yields 35 to 40 bushels per acre.

10. **Oats** are hardy, grow on any soil, do not tiller much, yield 45 bushels per acre.

11. **Rye** is very hardy, yields 30 to 40 bushels.

12. The chief **fodder crops** are green rye and maize, the grasses, vetches, sainfoin, lucerne, the clovers, rape, mustard, and cabbage.

13. The most **useful grasses** are the rye-grasses, fescue-grass, meadow foxtail, catstail or timothy, cocksfoot, meadow-grasses, and crested dogstail.

14. **Temporary pastures** are sown with mixed grass and clover seeds to remain for a few years.

15. **Permanent pastures** depend on grass growing in a natural condition for many years.

16. **Hay** should be made shortly after the grasses have flowered. *Ensilage* is a substitute for haymaking.

17. **Beans** and **peas** are leguminous crops grown for their seed.

18. **Clovers** are called "artificial grasses." Kinds:—common or red, Dutch or white, Italian or crimson, Alsike or pink, and "cow-grass."

19. **Rape, mustard,** and **cabbage** are cruciferous fodder crops.

20. The principal **fallow** or **root crops** are:—Kohl-rabi, turnips, swedes, mangel-wurzel, carrots, parsnips, and potatoes.

21. **Turnips** and **swedes** are not very deep rooted and produce 15 to 25 tons per acre.

22. **Mangels** are deeper rooted, produce 25 tons or more.

23. **The Pests of the Farm** are weeds, fungi, and insects.

24. **Weeds** show *poor soil* (daisy and cowslip), *wet soil* (rushes and sedges), or *neglect* (nettle, dock, thistle). Dodder is a parasite on clover.

25. **Fungi** upon crops are mould, rust, bunt, smut, and mildew.

26. **Insects** appear as eggs, larva, pupa, and imago or perfect insect.

27. **Injurious insects** are cabbage butterflies, daddy-long-legs grub or "leather jacket," red maggot or wheat-midge, wireworm, larvæ of click-beetle or skip-jack, and turnip fly or flea beetle.

28. **Remedies** for farm pests—birds, deep cultivation, clearance of weeds, good seed-beds, and judicious use of manure.

QUESTIONS.

1. Why should seeds for sowing be ripe and new?
2. What are the requisites for germination?
3. Describe the germination of a grain of wheat.
4. How does the germination of a pea differ from that of wheat? What are split peas?
5. Describe the seed-leaves of a young turnip or mustard plant.
6. What is a tap-root? What plants have tap-roots?
7. How does plant food get into the roots?
8. How does a root grow in length and thickness?
9. Name some deep-rooted plants, and some shallow-rooted ones.
10. What are biennial roots, and of what use are they to the plant?
11. Describe the stems of wheat and kohl-rabi, and the tuber of the potato.
12. What is assimilation? In what part of the plant is it chiefly carried on?
13. Describe a leaf as seen through a microscope. What are ribs or veins?
14. What are leaf-pores, and how do they act?
15. What do the green cells of leaves contain?
16. How does plant food rise up from the root into the leaves?
17. Whence is the carbon in plants chiefly derived?
18. How do living animals and living plants benefit each other?
19. Show how a potato becomes full of starch.
20. What is the use of flowers to plants?
21. Describe a wallflower. What crops have flowers much like it?
22. What do you understand by fertilization of flowers? How do insects assist in the process?
23. Describe the flower of a pea. What crops have flowers like it?
24. Describe the flower of the wheat plant. What other crops have flowers like it?
25. Why have many plants brightly coloured flowers and a store of honey?
26. How does the pod of the turnip differ from that of the pea?
27 Is a grain of wheat a fruit or a seed, and why?
28. What is the fruit of the potato?
29. Say which part of the plant the farmer requires in the case of grasses, turnips, and wheat respectively.
30. How is it possible to improve the character and quality of any crop?
31. How does a farmer classify his crops?
32. What are the principal grain crops, fodder crops, and root crops?

33. Name any crops which are related to the wild plants of this country.

34. What are the cereals, and why are they so called?

35. What are the chief differences between red and white wheat?

36. Why is it usual to sow wheat in autumn?

37. What crop is usually grown next before wheat, and why?

38. What is the "tillering" of wheat and other cereal crops?

39. Why are sheep sometimes sent in to feed upon young wheat?

40. Why is wheat often cut before it is ripe?

41. For what two different purposes is barley grown?

42. Describe briefly the manufacture of malt.

43. What soils are most suitable for barley?

44. How do the roots and the straw of barley differ from those of wheat?

45. Why are oats suitable for growing on old pasture land?

46. Why is wheat flour generally made into loaves, and oatmeal into flat thin cakes?

47. What different kinds of oats are there? How does the Tartarian oat differ from others?

48. For what is rye cultivated in this country? Where is it grown for human food?

49. How do the ordinary grasses differ from the cereals?

50. Describe generally the wild grasses common in this country.

51. How many useful species of grass are there, and how may they be distinguished from the useless ones?

52. How does the life of the grasses in a pasture differ from that of other crops?

53. What grasses are sown and grown as separate crops? For what are they chiefly valuable?

54. What is a temporary pasture, and what does a farmer understand by "seeds?"

55. What is a permanent pasture, and how can arable land be converted into permanent pasture?

56. How can a natural pasture be improved?

57. When should grass be cut for hay, and why? What is the best weather for haymaking?

58. What causes a haystack sometimes to take fire of itself?

59. How can grass and other green crops be preserved without drying?

60. Name the chief leguminous crops, and say which are grown for grain and which for fodder.

61. Why have nitrogenous manures little effect upon leguminous crops?

62. Name one cause of clover sickness. What is the remedy?

63. Describe vetches or tares. When should they be cut for fodder?

64. What are "catch crops," and what crops are most suitable to be grown in this way?

65. How are sainfoin and lucerne generally grown? In what respects are they alike, and how do they differ?

66. Which is the most important of the leguminous crops, and why?

67. What does a farmer mean by "artificial grasses"?

68. Which clover is mostly grown before wheat, and which on sheep pastures?

69. What effect have nitrogenous and potash manures respectively on a mixed pasture?

70. Name the crops related to cabbage, and say which are fodder crops and which root crops.

71. How are rape and mustard generally grown?

72. What kind of a plant is kohl-rabi, and when does it form a very useful crop?

73. Why is a fine light moist seed-bed of great importance for turnips?

74. What do you understand by a fallow crop? Which are the best fallow crops?

75. How do mangels differ from turnips in depth of root, need of plant food, and time of ripening?

76. What are the principal crops grown for human food in England, Scotland, and Ireland respectively?

77. How do weeds injure the crops?

78. What weeds are signs of poor land, of wet land, and of neglected land respectively?

79. Name a few of the most troublesome weeds, and the best methods of destroying them.

80. What kind of a plant is dodder? How is it often introduced among the crops?

81. What are rust, bunt, smut, mildew, and mould, and how may they best be prevented?

82. What is "the grub" or "leather jacket," and what harm does it do to the crops?

83. What is the wireworm? How is it able to do so much damage?

84. Describe the turnip-beetle. When are its attacks most dangerous to the turnip?

85. State some of the advantages of deep and thorough cultivation of the soil, and destruction of all weeds and rubbish.

PRINCIPLES OF AGRICULTURE.

PART IV.

THE PROCESS OF GERMINATION.[1]

We have seen that three conditions are required in order that a seed should begin to grow, viz. warmth, air, moisture.

Warmth. The degree of warmth necessary to germination is not the same for all seeds. Some are capable of germinating at a very high and some at a very low temperature, but an extreme degree of either heat or cold retards germination, and if it exceed certain limits, altogether prevents it. All seeds, however, will germinate through a pretty wide range of temperature. The seeds of the common farm crops cultivated in Britain germinate readily at temperatures of from 55° to 90° F. Wheat and barley germinate most rapidly when the temperature is about 84° F.

Moisture. Germination without moisture is impossible, as the presence of water in the seed is essential to the solution and movement of the food required to nourish the young plant. Too much wet is, however, injurious to the seeds of our farm crops, as it prevents the free admission to them of air, and it may cause them to rot. A moderate amount of moisture is most favourable. It is very important that the supply of moisture should be constant from the time the seed begins to germinate till the young plant has its roots firmly attached to the soil. It happens occasionally on some dry soils that turnip seeds are sown when there is just enough moisture in the soil to start the process of germination. If a drought should set in after the seeds have partly sprouted, and should continue long enough to dry up completely the soil around them, and to stop entirely the supply of moisture,

[1] See also pp. 7, 8.

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growth will cease, the vitality of the seed will be destroyed, and it will be unable to renew its growth when rain again falls.

The absorption of moisture is the first step in the process of germination. The seed absorbs water to the extent of about from one-fourth to three times its own weight and swells. Some of the food substances stored in the seed, such as sugar, gum, and dextrine, are freely soluble in water, and are capable at once of being transported to all parts of the young plant. But other substances, such as the fats, oil, starch, and the albuminoid material or proteids, are practically insoluble in water. Provision has therefore to be made to bring these substances also into an available condition. In a suitable temperature a series of bodies known as **unorganized ferments,** whose nature is not fully understood, are then formed. These ferments act on the insoluble substances in the seed and change them into forms readily soluble in water. One ferment, well known under the name of **diastase,** acts on the starch and converts it into a kind of sugar. Another acts on cellulose, another on proteid material, another breaks up the fats and oils. While these changes are going on in the seed, oxygen is absorbed, heat is developed by the oxidation, and carbonic acid is given off. The final result of the action of the ferments is to render the whole store of food in the seed soluble and fit to supply the young plant with the food it needs. Water passing through the seed carries the soluble foods into the young plant, at first chiefly into the little rootlets, afterwards into both rootlets and plumule or stem. The radicle and plumule grow rapidly into root and leaf, and the plant then becomes independent of the seed, and is capable of obtaining food from the earth and from the air.

Malting. The phenomena and effects of germination can be clearly observed in the process of malting as it is practised in breweries and distilleries. The barley or other grain is soaked in water till it is thoroughly softened, and is then thrown into heaps. The heaps are occasionally turned over; heat is developed by oxidation, and they gradually dry. In a few days the grains begin to send out sprouts, and the plumule and radicle are allowed to grow till the rootlets have attained to about the length of the grain. The malt is then exposed to a high temperature to destroy the young plant, and the sprouts are removed by screening. The dry grains remaining form what is known as malt. The effect of the malting is to diminish the insoluble and to increase the soluble albuminoids; to convert a considerable proportion of the insoluble starch into soluble compounds such as sugar and dextrine; and to cause the development of the nitrogenous ferment, diastase, by which the whole of the starch is subsequently converted in the vat into sugar, &c. It is found that during the process of malting a considerable loss of carbonaceous substance occurs by oxidation and evolution of carbonic acid, and experiments by Sir J. B. Lawes and others have shown that a given quantity of malt has considerably less feeding value than the equivalent barley from which it was formed.

ORGANIC COMPOUNDS OF PLANTS.[1]

The organic compounds which enter into the composition of the dry substance of plants are very numerous, but the bulk of the dry plant substance is made up of only a few. The most important arrange themselves naturally into two main classes.

I. The **Non-nitrogenous** substances, or carbon compounds containing no nitrogen.

II. The **Nitrogenous** substances, or carbon compounds containing nitrogen.

The non-nitrogenous bodies are most conveniently treated by further dividing them into two groups which differ markedly from each other in composition and properties.

(*a*) The Carbo-hydrates (starch, sugar, &c.).

(*b*) The Oils and Fats.

The **Carbo-hydrates,** or hydrates of carbon, consist solely of carbon, hydrogen, and oxygen. They are so called because the hydrogen and oxygen in them are invariably found combined in the same proportions in which they exist in water.

[1] See also pp. 11–13.

You have no doubt learned in your chemistry lesson that water consists of two atoms of hydrogen united to one atom of oxygen, and is represented by the chemical symbol H_2O. In any substance included in the list of carbo-hydrates you will find that the hydrogen always bears the same proportion to the oxygen as it does in water. The carbon also in carbo-hydrates always occurs in combinations of six atoms or in multiples of six. For example, the well-known carbo-hydrate compound, starch, consists of six atoms of carbon, ten of hydrogen, and five of oxygen, and is represented by the chemical formula $C_6H_{10}O_5$. The sugar with which you sweeten your tea in the mornings is also a carbo-hydrate compound, and consists of twelve atoms of carbon, twenty-two of hydrogen, and eleven of oxygen.

The following is a list of the leading

CARBO-HYDRATES FOUND IN PLANTS.

Starch.	Sugars.
Cellulose.	Gums.
Dextrine.	

Starch is the most important of this division of vegetable substances. It is one of the most widely diffused, and is found in every flowering plant. Our favourite dessert foods, sago, arrow-root, and corn-flour, contain more than 80 per cent of starch. Wheat grain contains about 71 per cent, and good oatmeal about 63 per cent. Starch is quite insoluble in cold water, but can be almost entirely dissolved in hot water. The presence of starch can be very readily detected by means of a simple chemical test. When treated with a solution of iodine it responds by showing a distinct deep-blue colour.

Cellulose forms the outer coating of the cell-walls in plants, and therefore is a very important part of vegetable substance, as it constitutes the framework or structure by which the softer parts of the plants are supported. It forms about one-half of wheat straw, and about 3 per cent of the grain. Linen and cotton fibre, and white paper, are nearly pure cellulose. In young plants, and in the younger parts of plants, the cellulose is soft and fragile, and is readily eaten and digested by animals; but as the vegetation gets older, the cellulose becomes hardened into rigid fibre, when it is indigestible and unpalatable, and has little feeding value. In chemical composition cellulose is identical with starch. It is not soluble in water, but in the conditions existing in the seeds of plants it is capable during germination of being converted into dextrine and sugar, which are readily soluble.

Dextrine has the same chemical composition as cellulose and starch, but unlike them it is soluble in cold water. It is formed in seeds during germination, and is believed to occur in small quantity in plant sap. It may be seen forming the glazed crust of ordinary bread, and can easily be prepared by heating starch, when it becomes changed into a solution of dextrine, which is sold under the name of British gum.

Sugars. About a dozen kinds of sugar, differing from each other somewhat in composition and properties, are found in plants. All of them are freely soluble in cold water. The most prominent members of this group are **saccharine** or cane sugar, and **glucose** or grape sugar. The latter form is produced from starch during germination, and goes to feed the young plant. It can also be easily made from starch or cellulose by soaking cotton fibre or starch in dilute sulphuric acid. Barley-meal contains about 3 per cent of sugar, and maize-meal nearly 4 per cent, while beet-root contains as much as 11 per cent. It exists in considerable proportions in many other roots and grasses, and one form is also found in the human body.

Gums. Gum in one form or another is found in nearly all plants. It exists dissolved in the cell-sap, or may form part of the cellulose tissue, as in the seed-coat of the linseed. It also exudes from many trees. Wheat grain contains 4½ per cent of gum, oatmeal 3½ per cent, and barley-flour more than 6 per cent.

Oils and Fats. This division comprises a great number of substances, some of which occur in all plants. In it are included the waxes, resins, and turpentines which occur in many plants. Wax forms the bloom of fruits, and covers the foliage of many shrubs and trees. Like the carbo-hydrates, the oils and fats are composed entirely of carbon, hydrogen, and oxygen, but differ in being less highly oxidized. In none of them is the oxygen present in as great proportion to the hydrogen as in water (H_2O). For example, the liquid fat, **oleine**, has only 6 atoms of oxygen to 104 atoms of hydrogen, and is represented by the formula $C_{57}H_{104}O_6$. Oils are usually found in the cell-sap in plants suspended in isolated globules. They tend to accumulate finally in the fruits and seeds, though at the time of flowering they are well diffused throughout the plant. In cereal grains the greatest proportion of oil is found in oats and maize, both of which contain about 6 per cent. Good oatmeal contains 10 per cent, while linseed contains 38 per cent, and the kernels of almonds more than 50 per cent. It exists in very small quantity in roots and tubers, and in somewhat greater proportion in all green and dry fodders. Turnips show about $\frac{1}{10}$ per cent, while good oat straw may have 2 per cent. Oils and fats have a feeding value about two-and-a-half times greater than the carbo-hydrates.

Nitrogenous Substances. These are carbon compounds which, in addition to the three elements carbon, hydrogen, and oxygen, are specially distinguished from the substances already considered by the presence in them of about 16 per cent of nitrogen. They also contain a little mineral matter. They are commonly called **albuminoids** or **proteids.** The following is a list of the more important proteine substances found in plants:—

Albumin (vegetable).
Glutin (vegetable fibrin).
Legumin (vegetable casein).

The proteids occur in many forms, some of which are soluble and some insoluble in water, but the soluble change very readily into the insoluble condition. They are found in every part of plants during growth, but they finally accumulate chiefly in the seeds.

Albumin. This substance exists in a soluble form in the juice of all plants, and is the vegetable form of the animal albumin which forms an important part of the blood.

Glutin constitutes the greater part of the proteid substance in the wheat, oat, and barley grain. It is the vegetable form of the **fibrin** which composes the fibre of the muscle of animals, and also the chief part of blood clots.

Legumin. This is the form of proteid that occurs in peas, beans, and lentils. In the seeds of these plants it amounts to 22 to 24 per cent. It is a vegetable form of the casein which is so important an ingredient of milk and cheese. Vegetable casein in some of its modifications is found in the sap of almost all plants. Casein is more easily coagulated or curdled than any other proteid.

PROXIMATE CONSTITUENTS OF SOILS.[1]

You have been already told that there are five proximate constituents in soils, viz. **sand, clay, lime, organic matter,** and **stones** or mineral fragments. You have also seen what these substances are, and have learned something about their qualities. We shall now proceed to consider what duties are discharged by each of these substances, and what are their special uses as constituents of the soil.

Uses of Sand in Soils. Though sand is a very abundant constituent of soils, it does not contribute any essential food directly to plants; and soils that consist almost entirely of sand are barren and worthless. But a fair proportion of sand in soils is often very useful, because it improves the physical character of the soil and makes it a more suitable medium for the support of plants. It opens the land, and prevents it from being too stiff and adhesive. It thus gives freer admission to moisture and to air with its purifying oxygen. Plant roots also penetrate through it more freely, and find in it a healthy scope for extension. It facilitates the ready passage of water downwards, and therefore prevents an unwholesome stagnation. Less obstruction is also offered to the passage of implements, as soil containing plenty of sand does not adhere to and clog them. It therefore makes the land easier and cheaper

[1] See also pp. 20–22.

to work. It also helps to produce warmer and earlier soils, because sand absorbs heat more rapidly than some of the other soil constituents.

Uses of Clay in Soils. A perfectly pure clay, like a pure sand, is incapable of growing crops, as it does not contain any of the foods essential to the growth of the crop. But ordinary agricultural clay is never pure, but usually consists of a great variety of substances. It generally contains abundance of potash and other minerals, and the presence of a quantity of clay in a soil is an evidence that the crops are likely to obtain with ease a sufficiency of most of the minerals they require. It gives what is known as "body" to the soil. Clay also affects very materially the mechanical condition of soils. It mixes with and binds together the looser sand and other materials into one uniform and homogeneous mass, and endows them with many of the most valuable physical properties. It gives them the firmness and consistency that are necessary to the mechanical support of the plant. Owing to the fineness of its particles, the clay increases the porosity of the soil,—that is, it adds to the fineness and number of the pores, and to the total amount of the porous capacity of the soil. Hence, because of the greater fineness and smallness of the pores, it adds greatly to the capillary power of soils by which, as you have previously learned, they draw up water from the subsoil to the surface, and keep the crops supplied with moisture in time of drought. For the same reason the clay imparts to the soil a greater power to retain moisture, and it is not so liable to be quickly dried up. In the same way it enables the soil to absorb more moisture from the atmosphere, and with it also some of the valuable ammonia that exists in small quantity in the air. Clay also enables the soil to hold manures more firmly, and some soluble manures that would be quickly washed out of pure sandy soils can be applied with safety to clays, which will hold them securely till the crop wants them. On the other hand, clay renders a soil colder, less easy to drain, less pervious to moisture and air, and stiffer and more costly to work, and insoluble manures do not become available to plants so readily in clays as in lighter soils. It is therefore best that soils should have a fair proportion of clay, but that the quantity in them should not be excessive.

Lime. In many soils lime occurs only in small proportion. It is then ranked as one of the chemical ingredients of the soil, but is hardly entitled to be classed as a proximate constituent. Over a wide area of country, however, lime forms not only a large, but frequently a predominating constituent of soils. Its uses will be most appropriately considered in the section on manures. (See pp. 167–168.)

Organic Matter. One of the most valuable constituents of a soil is organic matter. Some soils, such as peat, are almost wholly composed of it, while of others it forms only a very small part. It discharges exceedingly useful functions in the soil, and its presence in fair quantity adds greatly to the fertility and productiveness. Though it is very unlike clay, it has a similar power of improving the physical character of soils. It aids capillary action, and gives a greater capacity for retaining moisture and soluble manures. It also increases the power of the soil to absorb moisture and gases from the atmosphere. It improves the texture of soils more than any other constituent. It binds loose soils firmly together, yet imparts to them a fine elasticity, while it modifies the adhesiveness of stiff clays. Like clay it adds to the water-holding capacity of light soils, yet it does not, like clay, offer any impediment to the passage of water to the drains; and while it gives a soil firmness, it does not make it too tenacious, adhesive, or difficult to work, as much clay is apt to do. In the process of decay gradually undergone by organic matter in the soil, it yields up products which play an exceedingly important part in the nutrition of plants. The carbonic acid derived from it, as you have already learned, performs very necessary duties in assisting to break down and dissolve insoluble and unavailable substances in the soil, and so fit them for the use of plants. All the minerals that had been taken to assist in building up the formerly living vegetation, from which the most of the organic matter in the soil has been derived, are also now set free to feed a new generation of plants. They are liberated gradually as the organic matter decays, and they are composed of the very substances that growing plants require, and in something like the proportions suitable for them. Perhaps, however, the most valuable result obtained by the presence of organic matter in the soil is the gradual liberation of the essential plant food, nitrogen. As we have seen before, this substance is not only necessary to the growth of plants, but it is known to have a very powerful influence on their growth. It is deficient in many of our soils, and its absence is a common reason why soils are unproductive and yield only poor crops. Farmers pay a great deal for nitrogen in some manures, as much as £40 to £50 per ton, and apply it freely to soils because of the great increase it produces in the crops. But when a soil contains a fair proportion of organic matter, the farmer has a guarantee that nitrogen can never be altogether awanting in it. A regular supply is liberated as the organic matter decomposes, and is available for the use of growing crops. As this nitrogen is obtained free of any cost, the presence of an adequate amount of organic matter must add greatly to the value of a soil.

Stones or Mineral Fragments. Many soils are happily free from the presence of this proximate constituent, but in hilly and rocky countries stones usually form a not inconsiderable part of the surface soil. They are very commonly disliked by farmers because of the difficulties they place in the way of easy and thorough tillage. Deep tillage is impossible on stony soils, and even the ordinary tillage of the surface is attended with special difficulty. The cultivation is always shallower, and is generally slower than on soils free from stones, and is therefore at once less effective and more costly. The wear and tear of implements on stony soils is always great, and breakages are frequent. Implements have often to be employed of special form and of great strength, and certain implements that are very useful and economical on other soils can never be successfully employed where the surface is thickly studded with stones. Stones are also liable to interfere injuriously with the growth of such crops as the carrot, and to some extent they limit the variety of crops that can be grown, and therefore the value of the soil.

But, nevertheless, it is not to be assumed that stones are without their uses in soils. On the contrary, they perform some functions of great usefulness and value. They are often very serviceable in improving the texture of stiff clays. They favour the free admission of air and water into the soil, and they afford considerable assistance in the draining of stiff soils, for no clay, however tenacious, can be wholly impervious to water if it be broken up by the embedding in it of quantities of irregularly shaped stony fragments. Stones also absorb heat very quickly, and their presence tends to make warmer soils. For this reason potatoes planted in early spring will be seen to braird earlier on a gravelly part of a field than on any part where there are no stones. The stones also contribute their regular share to the supply of plant food for growing crops. Their exposed surfaces are being continually attacked by oxygen and carbonic acid and all the other agents that are continually working in our soils to break down and disintegrate insoluble materials. The roots of growing crops twine round them, and by their corrosive action carry off some portion of their mineral matter to transform it into their own substance. The stones are worn down very slowly by this process of reduction, so slowly that perhaps a farmer in the course of a lifetime has never noticed the occurrence of any change in the stones of his fields, but none the less the disintegration is going steadily and unceasingly on. Thus the stones continue to afford a never-failing supply of plant food to successive crops. Their presence in the soil gives not only therefore a supply of food for the crops now growing, but furnishes a guarantee that for many years to come such a supply will be available, and that the absolute and permanent exhaustion of the soil is not possible.

PHYSICAL PROPERTIES OF SOILS.[1]

You already know a little about the physical properties of soils. You have learned something of the comparative (1) **density** of soils, of their (2) **capillarity,** of their (3) **power of absorbing and retaining moisture,** and of their (4)

[1] See also pp. 23–25.

power of absorbing moisture and gases from the atmosphere.

But you have not been told that some of these properties are directly dependent on another physical property, viz. that of

Porosity.

Porosity is the state of having pores or passages between the small particles of soil. The amount of the porosity depends on the size of the soil particles. Up to a certain point, the finer the division the greater is the number of pores, the greater is the superficial area of the particles, and the greater is the total porosity of the soil. Hence, finely divided clays have more porosity than coarse sands. It is because of their greater porosity that they have, as we have seen, a greater capacity for holding water, and a greater power of absorbing moisture from the atmosphere, and a stronger capillary power. But though clays have greater true **porosity** than sandy soils, it would not be correct, according to common usage, to say that they were more **porous.** By a **porous** soil is commonly meant one with **large** pores, an open soil of loose texture, through which water passes freely. For this reason sands and light soils are called **porous** soils though they have less true **porosity** than clays.

Another property of soils that is sometimes included in its list of physical properties is that of

Temperature. The temperature of a soil is affected most of all by many conditions that lie outside itself, such as the geographical position and the climate. But the temperature of one soil compared with that of another situated in the same locality, is dependent on a few conditions only, and most of these lie in the soil itself. The temperature is affected by the material of which the soil is composed. We have already seen that the presence of stones in a soil helps to make it warmer, and the presence of sand is also favourable to warmth. On the other hand, organic matter in any quantity tends to keep a soil cool. The colour of a soil has also an influence on its temperature. It is well known that dark colours absorb heat more readily than white. So we see that in the summer season, even in our temperate climate, light-coloured clothes are worn to keep the wearer cool, whereas in winter dark clothes are preferred for the opposite reason. And in many parts of England the roofs of dairies are whitewashed to keep them from becoming too much heated by the rays of the summer sun. Soils of a brown or dark-reddish colour are therefore warmer than light-coloured soils. A more marked effect on the temperature is, however, produced by the amount of moisture in the soil. Wet soils are always cold soils. Dry soils are always much warmer. They have a double advantage in regard to temperature, for they absorb heat more quickly than wet soils, and they do not part with it so readily. But, as all farmers know, the warmth of soils is also much affected by the exposure or slope of the ground. Those soils receive most heat from the rays of the sun on which they beat directly down. Soils on which the rays strike obliquely derive less heat from them. In this northern country soils that have a slope towards the south are most fully exposed to the sun's rays. Fields that have a northern exposure are much colder, and level fields occupy an intermediate position, being warmer than the one and colder than the other. Farmers see many examples in their crops of the effects produced by the difference of exposure. If potatoes be planted early in spring, some on a level part of a field and others on a sloping part that faces the south, it will be noticed that the earliest and strongest shoots will always appear on the slope. Pastures that lie towards the north are later of coming to grass, and they are more liable to be overrun with moss than southern sloping fields. And every school-boy, if he thinks about the glen where he last gathered hazel-nuts, will remember that the largest, the ripest, and the best were obtained from the slope that faced the south, while those on the opposite side, looking northwards, were smaller and less mature.

DRAINAGE.[1]

Effects of Stagnant Water in Soils. We have already seen that stagnant water, that is, water standing still

[1] See also pp. 34–36.

in a soil and not moving through it, does a good deal of harm. We have seen that it keeps out the air with the gases in it which promote such beneficial changes in the soil, that in various ways it keeps the soil very cold, and that injurious organic acids are thus liable to be formed in it. The presence of stagnant water is apt also to cause a loss of the most valuable parts of the soil, for when heavy rains fall on a soil already saturated with water, streams rush over the surface and wash away into ditches and rivers the finest and most soluble particles of earth, which are of the greatest use to plants. The soluble portions of manures that have been applied to the fields may also be washed away in the same manner, and for that and other reasons it does not pay to apply manures to soils till they have first been properly drained. The first object, therefore, of draining land is to free the soil from all excess of stagnant water.

Effects of Water in Motion. A second effect of great importance produced by drainage is that it causes a much larger body of water to pass through the soil. When rain falls on the surface of a wet soil, much of it, as we have seen, runs off the surface and never sinks into the soil at all. But when land is thoroughly drained, the rain falling on the soil sinks down through it to the drains and runs rapidly away through the smooth tiles. Now, as we know, water standing in a soil does much harm, but rain-water running through a soil acts in many ways very beneficially on it. In the spring and summer, when plant growth is most active, rain-water is usually warmer than the earth, and in passing through to the drains it helps to raise the temperature of the soil, and thus quickens and promotes vegetable growth. The rain also carries down with it some of the oxygen and carbonic acid of the air, and you have learned how these gases act in the soil to increase the supply of available plant foods. It conveys into the soil also two other gases that are of more direct service to plants. These are ammonia and nitric acid, of which the supply thus obtained from the atmosphere forms a most valuable addition to the stock of nitrogen in the soil. And besides thus bringing outside materials to enrich the soil and increase its resources, the water passing through it greatly assists in providing food for plants by its solvent action on the particles of earth, and by the effect it produces in moving about and redistributing soluble substances in the soil, thus bringing them into contact with the plant roots and giving them the nourishment they need. In looking at the number and variety of the effects thus produced by water moving through the earth, it becomes clear that if the first object of drainage be to remove excess of stagnant water from the soil, an object of hardly secondary importance is to cause the passage of a greater body of water through the soil. An eminent agriculturist is reported to have said, "I don't drain so much to get water out of the land as to get it into the land."

Wetness of Free Soils v. Stiff Soils. It has been already pointed out that on some open and free soils in which the spaces between the particles of earth are large, water passes through easily and naturally, and artificial drainage is not required. But though such soils in themselves do not prevent the ready drainage of the water, they may be, and often are, kept wet by other causes. The soil may rest on a stiff and retentive subsoil through which the water cannot pass, or it may be constantly flooded by springs, or overrun by water coming down from a higher level. Such soils are not kept wet by their own character, but by the position in which they happen to lie. Stiff soils and clay soils may also be kept wet by their situation, but, unlike sandy soils, they also often keep themselves wet by their own inherent character. In many clays the soil is divided into such fine particles, the spaces between are so small, and they adhere so completely together, that rain-water can hardly get admission into them, and only soaks through them with much difficulty. On such soils drains have to be placed very close together, and it is useful to assist the drainage by tilling the earth deeply and using other means to open it out and improve its texture.

Methods of Drainage. You have already learned that draining is commonly effected by cutting parallel rows of trenches in a field to a depth of about three feet, and laying these with a continuous series of hollow pipes or tiles, usually round-shaped, by which the water is rapidly conveyed away as it runs into them. The rows of drains run in the direction of the greatest slope of the field, and carry the water into a larger drain that runs at right angles to the others across the bottom of the field. This drain is called the main drain, and it is fitted with larger tiles of such a size as to be able to carry away into a ditch or stream all the water passed into it by the other drains. This method of removing excess of water from a field by laying over its whole area a complete series of underground and parallel drains, is known as the Deanston or Thorough Drainage system, and is the method now almost universally practised.

Sometimes, however, land may be dried sufficiently without recourse being had to such a costly system of drainage. If a field consisting of an open loose soil be kept wet by water flowing on to it from a higher level or from underground springs of water, it may be dried sufficiently if the water running down from the heights can be diverted into some other course, or if the water rising from the springs can be caught in drains and carried away without being allowed to spread itself over the land. The method of removing the water by one or more drains which tap the springs, and prevent rather than cure the wetness of the land, is known as the Elkington system of drainage. It is not so widely applicable as the Deanston system, and it has fallen greatly into disuse, but in suitable circumstances it is often more effective as well as much cheaper.

Surface Drains. The drains that we have so far been describing are all cut deep into the ground, laid with tiles, and then covered over. They are the only drains that are possible on land that is intended to be ploughed and tilled for the growth of crops. But on high hills and mountains that are always kept in pasture and are never intended for cultivation, such deep and expensive draining is not considered likely to yield such a return in improved pasture as would repay the cost. On spots where there is any excessive wetness a cheaper method of draining is practised. A series of shallow open channels are cut on the surface of the land,

and by these it is partially dried. These channels are made to run somewhat obliquely across the side of the hill. They are cut to a depth of nine inches or so and left uncovered and without tiles, and they can be made very cheaply. These surface, or sheep drains, as they are sometimes called, suffice to take away very quickly a large quantity of water, such as sometimes falls on our mountains in sudden torrents. They make the turf on the surface much drier, and better and more nutritive grasses grow on it. Sheep kept on the hills have drier ground to rest on, and are much healthier than before the drains were cut.

Advantages of Drainage. In considering the effects produced by water in its passage through the soil we have already learned something of the advantages that are obtained by draining land. We have seen how the water not only promotes useful chemical changes in the soil, and warms it and washes out injurious salts, but also how it conveys into the earth useful plant food, and redistributes and carries the stores already in the soil to the roots of the plants. We have also seen that it rids land of excess of water, and prevents all the injurious consequences that result to soils and crops from its presence. But besides producing all these beneficial effects, the drainage of stiff and tenacious soils causes in time a marked improvement in their physical character. A soil continually saturated with water undergoes no frequent changes of bulk, and is likely to be somewhat tough and adhesive. But a drained soil is neither continually wet nor continually dry, but is sometimes the former and sometimes the latter. When soaked with rains it expands into an enlarged mass, when dried by drought it shrinks into smaller space. This alternate contraction and expansion, which extends through the whole body of earth lying above the level of the drains, acts with striking power and effect in opening up and breaking the cohesion of the stiffer and more tenacious clays. It thus exposes them more completely, and to a much greater depth, to the beneficial action of the atmosphere, and it renders the cultivation of these soils much easier, cheaper, and more effective.

On the same kind of land, drainage produces a curious benefit by mitigating in some measure the injury caused by drought. It does so by improving the capillary action of the soil, by which you will remember water is pumped up from the subsoil to the surface. An undrained clay that becomes dried up by an unusually prolonged drought is liable to cake into a hard and impervious layer through which the roots of plants cannot penetrate, and in which capillary action is impossible. Water has not been encouraged to flow down through the earth, and neither can it be drawn up. In drained land one of the most important results obtained is that water is aided to pass freely down through the soil, and the soil that allows the ready passage of water downwards will also allow its passage upwards by means of capillary action when moisture has been dried out of the surface. But drainage also lessens the dangers from drought by promoting the deeper growth of the roots of plants. Farm crops never send their roots deep down into a wet soil. The presence of air is necessary to their healthy growth, and layers of soil so saturated with water that air does not penetrate into them do not form a wholesome or suitable medium in which plants can seek for food. Hence on land soaked with moisture to within a short distance of the surface, the roots spread themselves and ramify in a comparatively shallow section of the soil. But when the ground is dried to a greater depth by draining, the crops send numerous long roots down into the lower layers of the soil in search of food. Drainage therefore increases enormously the area of available feeding ground for the crop, and should any extreme drought deprive the shallower roots of an adequate supply of moisture, the plants may receive enough to support them from the lengthier roots that extend deep down into the subsoil.

All these various changes produced on soil and subsoil by the operation of draining necessarily show very distinct results in practical farming. Stiff soils, as we have seen, are improved in texture, and can therefore be tilled more cheaply and easily, and at the same time more effectively. It is a matter of great practical convenience on all soils, but especially on clays, that drained land can be tilled on a far greater number of days in the year than undrained. Tillage cannot be successfully done on wet land, and on many soils the crop will be greatly injured if the tillage has been done when the land was not sufficiently dry. Drained soils dry quickly, and may be cultivated in the intervals between heavy rains, but undrained soils remain so long wet after rain that a good opportunity to till them may be wholly lost, and the farmer may be forced to cultivate them when he knows they are in a most unsuitable condition. His next crops invariably suffer when he does so. All kinds of manures can be more economically applied to drained than to undrained land and give better results, because in the latter some of the conditions that enable plants to make full use of the manure are awanting. Larger crops of all kinds can therefore be grown on drained soils, and the quality is also superior. A much greater variety of crops can also be cultivated on them, for only a few crops are capable of being grown at all on wet and cold soils, and none thrive well or attain to a high perfection. This is perhaps partly due to the fact that the growing season on drained land is longer than on undrained. As we have seen, the drained soils are warmer, they sooner attain to the temperature in spring at which vegetation wakens into life, and the crops have an earlier start. The higher temperature continues right through the summer, the crops make better progress, and there is an earlier harvest, which in our climate is always safer and usually better than a late one. In the same way as with other crops, pastures are improved in duration of the season of growth, in amount of produce, and in nutritive value. The grasses change their character, inferior kinds are displaced, and superior flourish, growth begins earlier in spring and continues later in autumn, and the pastures are healthier for stock. And not only are crops and fields thus improved, but thorough drainage extending over whole farms and parishes alters and ameliorates the climate, eradicates certain diseases common in damp situations, and is beneficial alike to the health of man and of all other animals.

STEAM TILLAGE.[1]

We have seen that the tillage of land is done by manual labour, by horse-power, and by steam-power. We have seen also that hand labour is too slow and too costly to be generally available in the cultivation of land. The power most commonly employed in the ordinary operations of tillage is that of the horse, and illustrations have been given (pp. 37–41) of ploughs, grubbers, &c., that are suited for horse-power, and that are used in various ways to till the land and prepare it

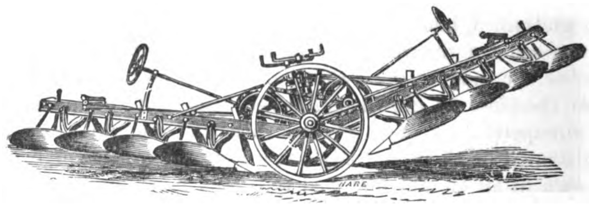

Fig. 37.—Fowler's Patent Balance Plough.

for growing good crops. But steam-power, though not employed to nearly the same extent as the horse in the cultivation of land, is nevertheless in some parts of the country largely made use of for these purposes. Its use is almost wholly confined to farms where the fields are large and moderately level, and where the land is free from stones. It is quite as well adapted for cultivating light soils as stiff soils, but it is chiefly employed on the latter, because horse tillage is difficult and more costly on such soils, and the greater power applied by steam breaks them up and pulverizes them much more effectively than can be done by the feebler strength and slower motion of the horse. The implements employed in steam tillage are similar in design and principle to those used in horse tillage, but are larger, stronger, and capable of doing more work.

The **Steam-plough** (see Fig. 37) consists of two sets of ploughs or mould-boards attached to a frame, and supported

[1] See also p. 37.

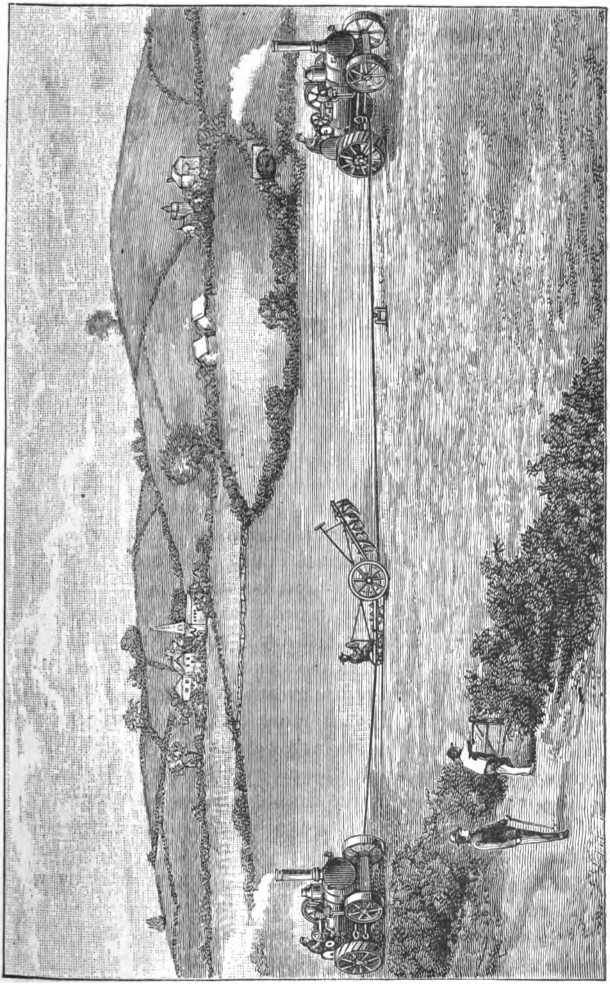

Fig. 38.—Double Engine Steam Plough.

on wheels. The sets of ploughs point in opposite directions, so that the implement does not require to be turned at the ends of the furrows, but each set is alternately employed, and while the one is lowered into the earth, the other is carried in the air. The tillage may be effected by means of one steam-engine provided with suitable tackle, or it may be done by two engines placed in the head ridges at opposite sides of the field. These drag the plough or other implement backwards and forwards between them by means of a wire rope, and move slowly along the head rigs as the work is done to keep abreast of the section to be tilled (see Fig. 38). Grubbers or cultivators, harrows, and rollers can be used as well as the plough, and the employment of these powerful steam implements is attended with great advantage on tenacious soils that are hard to open up and pulverize, because they tear the adhesive masses asunder and break down hard lumps much more thoroughly than can be done by the smaller implements and lesser force available in horse tillage. In suitable circumstances the land can also be ploughed or stirred to a much greater depth by steam-power, and the better drainage of the soil is thus greatly promoted. On clay soils it is also a matter of some importance that a great breadth of land can be cultivated in a short time, because this prevents any necessity for tilling the clays in wet weather, and allows them to be worked when they are just dry enough to be in the best condition for it. In such circumstances as have been described steam cultivation has therefore great advantages, as it affords a means whereby the farmer more completely unlocks the riches of the soil and obtains larger crops from it. But there are many soils for which steam-power is quite unsuitable, and on the greater extent of the arable land of this country it is not regarded by farmers as capable of being economically substituted for horse labour.

Steam Digger. A few years ago a new machine was introduced which cultivates the land in much the same way that is done by spade labour. The steam digger (see Fig. 39) consists of an ordinary traction-engine with a series of forks attached at the rear. As the engine moves forward over the

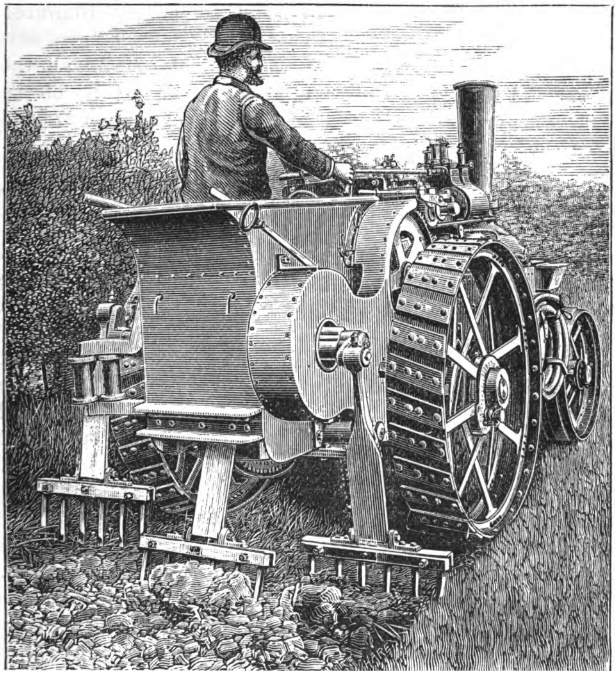

Fig. 39.—Proctor's Steam Digger.

ground to be cultivated, the forks dig up the earth and throw it behind in a far more loosely broken condition than can be obtained by the use of the plough.

MANURES.[1]

Manures may be classified in several ways. The calcareous or lime manures are usually set apart in a class by themselves under the name of "Natural Manures." All other manures

[1] See also pp. 72–92.

can be arranged in two main divisions, *i.e.* **General Manures** and **Special Manures.**

The **General Manures** are those that contain all the substances that are required to maintain the fertility of the soil. Such manures are fitted to supply food to all crops, and are therefore of general utility. The best example of a "general" manure is farmyard manure.

Special Manures are those that contain one or more of the ingredients required for the growth of crops, but not all. Such manures are useful to particular crops and for special purposes, and are not so completely or so generally applicable as the general manures. Nitrate of soda is an example of a "special" manure.

You have already had a list of the substances in soils that are useful to plants and essential to their growth. You are not to suppose, however, that all these substances are useful ingredients in manures, or that it is necessary to supply all of them to soils in order to maintain their fertility. Most of them, as, for example, silica, exist in abundance in all soils, and they are of no value in manures. Apart from lime, there are three of these substances only that are of special value in manures. These are **nitrogen, phosphoric acid,** and **potash.** Manures are valued solely by the amount of these substances they contain, and we shall classify them according as they contain one or more of them.

The following is a classified list of manures:—

GENERAL MANURES.

Valuable ingredients—Nitrogen, phosphoric acid, potash—all present.

1. Farmyard Manure,	Of mixed animal and vegetable origin.
2. Green manures and Vegetable Refuse,	Of vegetable origin.
3. Sea-weed,	
4. Rape-cake, Cotton-cake, &c.,	
5. Peruvian Guano,	Of animal origin.
6. Ichaboe Guano,	
7. Blood Manure,	
8. Flesh manures (Meat Meal, &c.),	
9. Fish manures, and Fish Guano (so called),	
10. Town Sewage,	

SPECIAL MANURES.

The special manures may be subdivided as follows:—

(a) *Nitrogenous Manures.*

Valuable ingredient—Nitrogen only.

1. Nitrate of Soda, . . . 2. Sulphate of Ammonia, . 3. Soot, ...	Of mineral origin.
4. Horn Dust, . . . 5. Hair Refuse, . . . 6. Skin and Leather, . . 7. Feathers, . . . 8. Woollen rags, . . . 9. Shoddy or Wool Waste, .	Of animal origin.

(b) *Phospho-nitrogenous Manures.*

Valuable ingredients—Nitrogen and Phosphoric Acid.

1. Crushed Bones and Bone Dust, 2. Bone Meal, ... 3. Steamed Bone Flour, . . 4. Dissolved Bones, . . . 5. Vitriolated Bones, . . 6. Phosphatic Guanos, . .	Of animal origin.

(c) *Phosphatic Manures.*

Valuable ingredient—Phosphoric Acid.

1. Superphosphate (mineral), . . 2. Ground Coprolites, ... 3. Ground Mineral Phosphates (various) 4. Basic Slag, ...	Of mineral origin.
5. Bone Ash, ... 6. Precipitated Phosphate, . . .	Of animal origin.

Many teachers would prefer to include in the list of phosphatic manures all those that have been classed as phospho-nitrogenous manures, because phosphoric acid forms the predominating, though not the only, valuable ingredient in all of them.

(d) *Potassic Manures.*

Valuable ingredient—Potash only.

1. Sulphate of Potash.
2. Muriate or Chloride of Potash.
3. Kainit.

(*e*) *Nitro-potassic Manure.*

Valuable ingredients—Nitrogen and Potash.

Nitrate of Potash.

The terms "artificial" and "light" are frequently employed in speaking of concentrated manures, and are applicable to any or all of the manures in the above lists with the exception of Farmyard Manure, Sea-weed, Green Manures, and Town Sewage.

You have already learned something about these manures. We shall now consider them a little further, and we may begin with the

NITROGENOUS MANURES.[1]

You know that all the manures of this class are useful and valuable solely because of the Nitrogen they contain. But the Nitrogen is not of the same value in all the manures, because it exists in them in different forms, some soluble and some insoluble. In some of these manures the Nitrogen becomes quickly available for the use of the plant, and in others it is only slowly converted into a condition in which plants can make use of it. The quickest acting of the Nitrogenous manures is nitrate of soda, and after it sulphate of ammonia and soot. The nitrogen in these manures is used by the first season's crop, and little or no residue remains to keep up the fertility in succeeding years. Horn-dust also, if in a fine powdery condition, decomposes rapidly in the soil, and a great part of its nitrogen is available in the year of its application for the support of an autumn-growing crop. It is therefore a very suitable nitrogenous manure for root-crops, as they are usually allowed to occupy the land till the beginning of winter. It is, however, less adapted than the other three manures for application to cereal crops, whose active growing season terminates before the end of summer. The remaining nitrogenous manures enumerated, such as feathers which are sold in considerable quantities in Ichaboe guano, or shoddy, are slower in their action and produce effects on crops for

[1] See also pp. 89–90.

some years after their application. When dissolved by the manure manufacturer they are made to yield up their nitrogen more rapidly, and they produce a more immediate effect on crops. Nitrogen in the quick-acting manures is of more value to the farmer than in the slower forms. A manure that gives up the whole of its nitrogen to the first crop to which it is applied is clearly more valuable than one that yields up its nitrogen gradually during a series of years. In the one case a ready return is obtained for the sum expended in buying the manure; in the other the return is long delayed, and the chances of loss are greatly increased.

A common quantity of nitrogenous manure to apply is one cwt. per acre of nitrate of soda or sulphate of ammonia as a top-dressing for hay or corn crops. The same quantity or more can be applied to turnips receiving no farmyard manure. Soot is applied in much larger dressings in proportion to the amount of nitrogen it contains. Its nitrogen varies from 1 to nearly 4 per cent.

PHOSPHATIC MANURES.[1]

Manures containing phosphates are useful to all crops, because phosphoric acid is present only in very small quantity in most soils, and because an insufficient proportion is supplied in farmyard manure. The most striking results from the application of phosphates are obtained from the turnip and similar crops. These plants seem to have great difficulty in collecting from the soil as much phosphoric acid as they need, and a very small quantity of a readily available phosphate placed in contact with their roots usually produces a very large increase of crop. Any of the phosphatic manures will show marked effects on the turnip crop, but on corn crops **superphosphate** is the best manure to use, and should be applied in conjunction with a top-dressing of nitrate of soda or sulphate of ammonia. You have already learned a good deal about bones and superphosphates, but some of the other phosphatic manures require a little further notice.

[1] See also pp. 83–89.

STEAMED BONE-FLOUR.

This is one of the phospho-nitrogenous manures, as it contains a small percentage of nitrogen along with its phosphate. It is prepared from bones from which the gelatine has been extracted by boiling. The bones after boiling have lost two-thirds of their nitrogen, and may contain only about 1½ per cent, but their tricalcic phosphate has increased to about 60 per cent. Their texture has at the same time been greatly altered, and they are rendered so friable that they can be ground into an exceedingly fine powder. This powder readily dissolves in the soil, and in the bone-flour we have the quickest acting of the undissolved bone manures. It is a capital form of phosphate for turnips and all root-crops.

DISSOLVED BONES OR BONE SUPERPHOSPHATE.

You have been told that this manure is formed by treating broken fragments of bone with sulphuric acid, by which the insoluble tricalcic phosphate is converted into the soluble monocalcic phosphate. You must not suppose, however, that the whole of the insoluble phosphate of the bone has been at once rendered soluble. A great part of the insoluble phosphate is left undissolved, and the manure consists of a mixture of soluble and insoluble phosphate along with nitrogen, partly in insoluble organic matter, and partly dissolved out of it. Bone superphosphate forms, therefore, a somewhat complex manure, and differs in that respect essentially from mineral superphosphate. The mineral phosphate being without a protective coating of organic matter can be acted on much more thoroughly by the sulphuric acid, and the whole, or nearly the whole, of the insoluble phosphate is converted into the soluble form. Dissolved bones are valued both for their soluble and their insoluble ingredients, but mineral superphosphate is valued solely for its percentage of soluble phosphate.

Mineral phosphates can, however, like bones, be used as manures without being dissolved by sulphuric acid.

Cambridge coprolites and **Carolina phosphates,** when ground into a very fine flour, form effective manures for turnips and other root-crops. It is essential, however, that they be ground into the finest possible state of division, and they are most suitable for peaty and mossy soils, or for soils rich in organic matter and deficient in lime.

BASIC SLAG.

This manure has only been introduced into commerce within the last few years, and its production is the result of the application of what is known as the Thomas Gilchrist process in the manufacture of steel. The residual slag contains a quantity of phosphate of lime, and forms the manure known as *slag phosphate*, *basic cinder*, or *basic slag*. You have already become acquainted with three forms of phosphate of lime, the monocalcic, the bicalcic, and the tricalcic, in the last of which you find three atoms of lime united to one of phosphoric acid. Now in the basic slag the phosphate of lime occurs in still another form, viz. as a tetracalcic or four-lime phosphate, in which four atoms of lime are united to one of phosphoric acid. The amount of phosphoric acid found in slag varies greatly, from 10 to 30 per cent; but an average sample might contain 16 per cent. The slag is rich in lime, and it also contains a large percentage of iron. The presence of iron makes it impossible to prepare the slag for a manure by dissolving it with sulphuric acid, because sulphate of iron is formed, which, when present in quantity, is poisonous to plants. The slag, however, though hard in itself, can be ground into a very fine powder, and when this is done the phosphate dissolves very readily in the soil, because in the tetracalcic phosphate the phosphoric acid and the lime appear to be very loosely bound together. It is a cheap manure, and it has given good results on root-crops and leguminous crops as well as on some pastures. Its use is specially to be commended on the lighter soils, on peats, mosses and damp meadows, and on all soils that contain an abundance of organic matter, especially if they be also deficient in lime.

POTASSIC MANURES.

Manures of this class are less employed in our agriculture than either nitrogenous or phosphatic manures. The reason is that potash is contained in abundance on most heavy soils and clays, and no additional supply is required. It is also abundant in farmyard manure, and no other potash manure is needed where farmyard manure is plentifully applied. But it is usually present in insufficient quantity in light soils and on peaty soils, and where the supply of farmyard manure is inadequate, artificial potash manures may be applied with much advantage. They produce very beneficial effects on pastures, and they are also probably required to restore the potash carried away in hay and straw wherever these are sold off the farm. Potash forms the most important and effective ingredient in the manure of beans, clovers, and all leguminous plants. It produces also a very striking effect on the potato crop, and largely increases the yield and improves the quality of the tubers. The potash manures may be applied in any of their forms. The **nitrate of potash** is the best, but is generally too expensive. It yields a large quantity of nitrogen as well as of potash. The **sulphate of potash** is a good form for all crops to which potash should be applied. The **muriate of potash** is generally somewhat cheaper, but is not on that account to be always preferred to the sulphate. The **kainit**, as you have already learned, is a very impure manure, but it is quite suitable for application to grain crops and pastures.

NATURAL MANURES.[1]

In this class are included:

1. Lime.
2. Chalk.
3. Marl.
4. Shell-sand, &c.

Lime itself is the most widely useful member of this class of manures; the others have a considerable but a more limited importance.

Effects of Caustic v. Mild Lime. You have already learned that when limestone, or carbonate of lime, is burnt in a kiln, the carbonic acid is drived off and the quicklime which

[1] See also pp. 79-82.

remains possesses burning properties and is hence called caustic lime. You have also learned that if this quicklime be exposed for a time to the atmosphere it recombines with carbonic acid and returns to its original form of carbonate of lime, which is called mild lime as contrasted with caustic lime, because in reuniting with carbonic acid it has lost the active burning properties of the quicklime. Now the action of caustic lime when applied to land is not quite the same as that of mild lime, and it is necessary that you should know exactly what the difference is. One very important point of difference is that the caustic lime is more readily diffusible through the soil, so that if it be spread on the surface of a field it gets sooner mixed with the earth beneath it, and is put into quicker and more intimate contact with its particles. The action of the caustic lime thus more quickly affects a greater body of earth, and its influence improves sooner a greater area of the feeding ground of plants. The caustic lime also acts with much more energy in promoting the breaking-down and reduction of organic matter into simpler forms capable of yielding a supply of food to plants. The breaking-up of the organic matter adds very markedly to the fertility of soils, because it renders available to the plant quantities of nitrogen which were previously locked up in insoluble organic compounds. The caustic lime acts with the same superior energy in clays, both in improving their physical and their chemical fitness to support and feed crops. It acts chemically on the mineral matters and liberates potash and other substances, and makes them available to plants. Caustic lime produces also much more striking effects than mild lime in improving the mechanical character of stiff clays. Mild lime acts mechanically on such soils, and a very great quantity is required to make a perceptible alteration on their texture and tenacity. But caustic lime not only improves these soils by mixing with them and thus diminishing their cohesiveness, but it also has a very remarkable effect in causing a coagulation or curdling of the clay. In this way the caustic lime opens up clays and destroys their tenacity much more thoroughly and more rapidly than mild lime can do.

When to Apply Caustic Lime. You are not to suppose, however, that it is always best to apply lime to soils in its caustic state, on account of its greater energy and effectiveness. You have learned that caustic lime destroys very rapidly the organic matter in soils. There are many soils to which lime can be applied with great advantage, in which there is no excess of organic matter, and the destruction of any considerable proportion of it would do these soils much injury. The liming of sands and of light and medium soils and loams is practised with much benefit, but these soils never contain too much organic matter, and cannot afford to have their stocks reduced. On all these soils not naturally rich in organic matter, it is obvious therefore that it is usually better to apply lime to them in its mild state. But on the other hand, the lime should be applied in a caustic state to all soils that contain organic matter in abundance, such as peats, mosses, newly reclaimed lands, and fields that have lain for many years in pasture. Caustic lime is also to be preferred for all stiff and tenacious clays and alluviums, in order the more effectively to open up and loosen these soils and to improve their texture, by which they are rendered more susceptible to the beneficial action of the atmosphere, and are made much easier to work.

How to Apply Mild Lime to Soils. You have been told that quicklime is very commonly carted from the kilns and set out at regular distances in little heaps on the field to which the dressing of lime is intended to be given. The heaps of caustic lime, when left exposed for a time, gradually absorb moisture from the atmosphere, and finally get reduced to a powder that can be easily spread over the field. But by the time that this change has been brought about, a great part of the caustic lime of the heap has been converted into mild lime by uniting with carbonic acid from the air. The lime that is ultimately spread over the land, when this mode of slaking is followed, consists partly of caustic lime and partly of mild lime. If it should be desired to apply the lime wholly in the mild condition, all that is necessary is to spread out the heaps well, and to leave the lime long enough exposed to the air, and then, when it has all become reconverted into the mild carbonate, to spread it, and then harrow it into the soil. This is a good method for light soils.

How to Apply Caustic Lime to Soils. You will see clearly, however, that if a dressing of lime is to be given wholly in the caustic state, as it should be on peats and clays, it is not sufficient to allow the quicklime to be slaked by exposure to the atmosphere. It has been already shown (p. 82) that the slaking can be quickly effected and the lime applied while in the caustic condition by having water poured on each of the heaps, and then having the heaps spread after the lapse of a few days. But this is so troublesome an operation that few farmers would care to undertake it, and the labour and expense of carting water all over the field would be very great. A better plan is to put the quicklime when it is brought from the kiln into one or more large heaps, at some corner of the field convenient to a water supply, and then to turn over the lime and water all the lumps. The heap may then be piled up again and covered with a few inches of earth. It should be left for a week or so to render it quite powdery, and may then be carted on to the field. It should be at once spread over the surface, and immediately harrowed in, in order that it may commence to act on the soil before it seizes any more carbonic acid from the air.

Effect of Liming on the Fertility of Soils. We have seen how lime acts both physically and chemically on soils in a number of ways, the effect of all being to raise the value of the land and to increase its cropping power and fertility. All soils do not equally require liming, nor are they all affected to the same degree. Many soils already contain a sufficiency of lime, and any addition involves an outlay for which there is little or no return. The most decided results from the application of lime are obtained from the stiff clays, and from such soils as peat and others rich in organic matter. The productiveness of these soils may be very greatly increased for many years by a dressing of lime; and not only is the yield of crops larger, but the quality and feeding value are also usually improved. All varieties of the turnip are greatly benefited by liming, and nowhere do turnips flourish better than on a recently-limed field. So much does lime add to their health and vigour, that the liming of land has often been found to act as an effective preventive of the very destructive disease of the turnip popularly known as finger-and-toe. Clover, beans, peas, vetches, and all plants belonging to the same botanical order (Leguminosæ), are also very greatly benefited by liming. Plants of this order appear to have a strong preference for lime, and they always grow most luxuriantly where it is plentiful.

CHALK.

Another manure of this class is chalk. Chemically chalk is of exactly the same composition as limestone, being carbonate of lime; but it is physically different, being softer and less stone like, and capable of crumbling somewhat readily into powder. It does not therefore require to be burned in a kiln like limestone, but is carted from the quarries where it is dug right on to the fields. It is necessary that the chalk should be put out on the fields in autumn or early winter, and it should then be in a moist condition. Frost acts on the moist lumps of chalk during the winter, and before spring-time they should be all thoroughly broken down into a fine powder like slaked lime. It should then be spread, when it acts on the soil like a dressing of mild lime.

HOW LEGUMINOUS PLANTS OBTAIN THEIR NITROGEN.[1]

You have been told that Leguminous plants, such as beans, peas, and the clovers, all contain a great deal of nitrogen, while at the same time it has been observed that they are not greatly benefited by applications of manures containing nitrogen. It has also been known that while they did not get their large supply of nitrogen from manures, neither did they obtain it from the surface soil. You have already learned

[1] See also p. 123.

COMMON FARM CROPS.[1]

Common Name of Crop.	Botanical Name.	Time of Sowing.	Quantity of Seed in Bushels per Acre.	Time of Harvest.	Average Produce per Acre. Grain in Bushels	Straw in Cwts.
Wheat (winter) ...	Triticum sativum	Oct.–Jan.	1½–2⅓	Aug.–Sept.	32	30
Do. (spring) ...	do.	Feb.–April.	2 –3½	do.	26	26
Oats	Avena sativa	March–April.	3 –6	do.	45	26
Barley	Hordeum distichum ..	do.	2 –4	do.	38	22
Rye	Secale cereale	do.	2 –4	do.	32	26
Pea	Pisum sativum	March.	2½–5	do.	32	24
Bean (spring)	Faba vulgaris	do.	3 –4	Sept.	30	27
			Lbs. per Acre.		Produce per Acre (without Leaves) in Tons.	
Turnips	Brassica rapa	May–July.	3 –4	Sept.–Nov.	22	
Swedes	Brassica campestris ...	May–June.	3 –5	Oct.–Dec.	18	
Kohl-rabi	Brassica caulo-rapæ ...	May.	3 –4	Oct.–Nov.	18	
Mangel	Beta vulgaris	March–April.	6 –8	do.	23	
Carrot	Daucus carota	do.	6 –8	do.	15	
Parsnip	Pastinaca sativa	do.	6 –8	Oct.–Dec.	11	
			Cwts.			
Potato	Solanum tuberosum ..	do.	10 –15	July–Oct.	6	

1 See also pp. 110–132.

that if a crop of red clover be grown on a field, cut, and carted from it, though a large quantity of nitrogen is taken away in the crop, yet the surface soil remains richer in nitrogen than before the crop was grown, because of the large quantity contained in the roots, broken stems, and other debris left in the soil. For many years the question of where the nitrogen came from, and how it was obtained by Leguminous plants only, and not by grasses or other plants, remained an insoluble problem, of which no satisfactory solution could be offered. Recently, however, it has been discovered that Leguminous plants are able, under certain conditions, to make use of the free nitrogen of the air as a part of their food. This exceptional power is due to the action of certain minute living organisms that are present in good soils, though not in all soils, and it is connected with the presence on the roots of these plants of little bag-like enlargements, or **tubercles** as they are called. Assisted by these organisms Leguminous plants are able to feed themselves with abundance of nitrogen in soils where other crops may be starved for the want of it. This striking fact imparts to the growth of Leguminous crops a special importance and significance in our agriculture. As you have formerly learned, nitrogen is one of the essential substances of plant food in which most soils are naturally deficient, and it is an expensive substance for the farmer to supply to his fields in the form of manure. But by growing such Leguminous crops as clover or vetches, not only does the farmer obtain very nutritious crops to feed his stock, but his soil is enriched with a quantity of nitrogen, obtained without cost from the air, and left in the earth in a condition in which it will gradually become available to feed future crops.

FUNGOID DISEASES OF CROPS.[1]

You have been told that a number of diseases in crops are caused by minute plants called **fungi**. You are probably well acquainted with the large fungus that forms the edible mushroom, but the fungi that cause diseases in plants are so extremely minute that many of them cannot be seen with the naked eye, and they have to be examined with the help of the microscope. Fungi differ from ordinary plants not

[1] See also p. 136.

only in their size but in their manner of feeding. You remember that ordinary plants obtain the greater part of their solid substance from the atmosphere in the form of carbon, which in the presence of sunlight and chlorophyll is taken by them from the carbonic acid of the air. You remember also that having thus obtained their carbon, the plants are able to build up with it in themselves the organic bodies known as the carbon compounds, such as starch, albumin, &c., and that these substances constitute by far the greater portion of the solid substance of plants. Now all fungi differ from other plants in this important particular that they possess no chlorophyll; they are unable to separate carbon from the atmosphere, and they cannot therefore manufacture their own carbon compounds. The fungi must be provided with the carbon compounds ready made as it were, or they are quite unable to obtain them. Hence it is an essential condition of the existence of fungi that they must be in a position to feed on the living substance or the dead remains of plants in which the carbon compounds have been already formed. Without the supply of living or dead organic matter derived from plants that contained the green colouring substance chlorophyll, they are quite unable to grow. Some fungi feed on dead organic matter, some on living plant tissue, and according as they do the one or the other they are conveniently divided into two great classes, though there are partially intermediate forms as well.

If you keep a piece of bread till it becomes covered with mould, you may see an example of the kind of fungus that grows on dead organic matter. Such fungi discharge duties of great importance in the world, and act as cleansers and scavengers without whose agency the earth would quickly become polluted with excess of dead organic remains.

But the fungi that cause diseases in plants belong to the class that feeds on living organic tissues, and these are known by the name of **parasites.** Not only are these parasites unable of themselves to collect carbon from the atmosphere, and to build up their own substance, but they cannot even take it from dead organic matter. They must feed on carbon compounds as they exist in actually living plants, and the parasites therefore live at the expense of other lives, and fill in the vegetable world something like the position taken by the purely carnivorous animals in the animal world.

Now in order to understand clearly the nature of the diseases of crops, it is necessary that you should know something of the structure and manner of growth of the fungi which cause these diseases. You will perhaps best do this by noticing in what particulars they differ from ordinary plants, with whose parts and their functions you are already familiar. You remember that plants consist of roots, stem, leaves, and flowers, from which are developed fruit and seed. The whole plant forms therefore a complex structure of high architectural development. But the fungi are not only smaller but belong to a much lower order of development, and they are not provided with such a complex structure of parts. Instead of roots as in ordinary plants, the fungus is provided with fine threads or filaments which spread in a prostrate or creeping fashion through the surface of the mouldy bread or through the tissues of the living leaf on which the fungus has found a lodgment. These filaments consist of one or more cells similar to those that occur in higher plants, and they send out many branches into the substance on which they are resting and feeding. From these creeping filaments there grow up erect filaments of thicker and stronger form which stand above the surface of the leaf, and may be regarded as corresponding to the stems of plants. When the fungus has grown for a sufficient length of time, a few days perhaps, round swellings appear on the tips of the erect stem-like filaments. These swellings are bags or cases containing the spores or little seeds of the fungus. The fine prostrate or root-like filaments, the stouter erect or stem-like filaments, and the spore-cases containing the spores or little seeds constitute the important parts of a fungus. You remember that a plant derives its nourishment from the earth and from the atmosphere by means of its roots and leaves. A parasitic fungus located on the leaf of some other plant derives its nourishment solely by means of its root-like filaments. These send branches right into the living cells of the leaf, suck out the cell contents, and convey them back to the creeping filaments, where they are utilized for the support of the whole fungus. Thus the parasite robs the plant on which it is growing of its substance, starves it, and breaks up its elaborate structure, and when sufficiently developed it may cause such a drain on the resources of the plant as to destroy it entirely.

At the proper time in the growth of the fungus the spore-case becomes brittle and breaks open, and multitudes of little spores are scattered in all directions. The spores of some fungi are so small that in the case, for example, of the fungus that causes the disease known as **Smut** in oats, four thousand to five thousand laid side by side would be required to cover one inch. They are thus developed in enormous numbers, and can be rapidly scattered and spread over wide areas by wind and other agencies. If the spore or zoospore of a fungus growing, let us say, on a potato plant, be blown by the wind on to another potato leaf where there is some moisture, in a very short time, if it be sufficiently warm, it begins to germinate. It throws out a little projecting tube which bores its way into the leaf, and soon grows there into a fungus like that from which it came.

Now that we have seen something of what a fungus is, how it feeds, and how it multiplies, we may go on to notice some of the more important diseases in our crops that are produced by fungi.

Bunt is a disease caused by the fungus named *Tilletia caries.* Its ravages are confined almost exclusively to wheat, of which it destroys the grain. The disease is conveyed to the crop by the spores being sown with the seed. They germinate in the soil, the fungus penetrates the young plant and rapidly grows up to the ear. It attacks as a rule every grain in the ear, and converts the whole inner contents into a mass of black powdery spores, which are so small that a single grain of wheat may contain four millions of them. The grains usually do not burst, and the appearance of disease is so slight that its presence is seldom noticed. A close observation will show, however, that the ears of diseased plants are of a deeper green than in healthy plants, and the affected grains are somewhat swollen and of a darker tint than sound grains. When the grains are ground into flour they discolour it and impart to it a very unpleasant odour. The disease can be prevented by steeping the seed for a short time before it is sown in a quarter-per-cent solution of sulphate of copper, which effectually kills the spores.

Smut. This disease is most commonly destructive on oats, but it also attacks wheat and barley. It is caused by the fungus *Ustilago carbo*, and is introduced to the crop by the spores being sown with the seed, or blown on to the corn-fields from some diseased crop, or from grasses and weeds at the sides of roads and fences, many of which are liable to be infested by this fungus. The fungus grows up the plant and attacks not only the grains themselves, but the whole of the ear. Finally it develops to such an extent that the spores burst through the ears and are scattered broadcast by the wind, blackening everything they touch, and infecting the seed for another year's crop. The attacked ears are wholly destroyed, and in some instances the disease has been so wide-spread as to have caused the loss of one-third of the crop. The spores have not the disagreeable odour of the "bunt," and as the diseased grains are broken up and scattered, the remaining sound grains are capable of yielding a pure and wholesome flour. Seed infested with spores of the fungus should be steeped as directed for "**bunt.**"

Ergot. This disease is caused by the fungus *Claviceps purpurea*. It is best known as occurring on the rye crop, and is hence often called **ergot of rye**, but it attacks also wheat and barley, and is very common on grasses, such as the rye-grasses, cock's-foot, the fescues, &c. The fungus attacks the grain or seed, but may destroy not more than one grain in the plant affected. The fungoid growth forms an enlarged dark-coloured mass, of curved horn-like shape, and perhaps twice or thrice as long and thick as the grain it replaces. The ergot does not usually seriously injure the crop, but it is regarded as a formidable disease, because of the effects the fungus produces on animals consuming it. When ground with the rye grain into flour and eaten in bread, it frequently produces fatal disease, and when consumed in our pastures by sheep and cattle, it is believed to be a frequent cause of abortion.

Anbury or Club-root.

This is the disease in turnips commonly known as "**Finger-and-toe.**" It occurs also in cabbages, rape, and similar plants. It is caused by a fungus of a peculiar character called *Plasmodiophora brassicæ*, which differs in many respects in its structure and life-history from any other fungus that has yet been mentioned. The spores of this **slime fungus,** lying in a moist position in the soil, germinate in spring and produce little moving bodies of protoplasm. These little bodies enter into the roots of suitable plants such as turnips, cabbages, &c., and at once begin to live on their host. As they grow, swellings and excrescences appear on the root, and these increase in size and gradually extend through the plant and draw all nutritive matters to themselves till ultimately the vital force of the plant becomes completely exhausted and it dies. As the roots decay, multitudes of spores are set free in the soil, where they rest quiescent till the following spring, when they are ready once more to resume active life, and to renew their mischievous work.

This disease is one of the most destructive of all those that attack farm crops, and is annually the cause of an enormous destruction of the turnip crop, which may be reduced by one-half, or, as frequently happens, may be wholly destroyed. It is therefore desirable that every possible precaution should be taken to prevent its occurrence, as no method of cure has ever been suggested. One of the most effective means of combating the ravages of this fungus and checking the disease is supplied by the general practice of growing crops in rotation. You will remember, for example, that in the Norfolk rotation turnips are not followed by turnips, but by barley, that again by clover, and again by wheat, and turnips do not recur on the same field till the fourth year. Now the fungus of Anbury does no harm to barley, or clover, or wheat. It is quite incapable of feeding on these crops, or on any crops commonly grown on farms except turnips, cabbage, rape, and other plants and weeds belonging to the family of the Cruciferæ. If, therefore, care be taken, as it easily may, to avoid repeating crops of this kind for some years, it is extremely probable, if no other means of living be afforded to the fungus, that it may be starved out, and the danger from it may be completely removed during the interval that elapses before turnips are again grown on the same field. It is, however, essential to the success of this easy means of prevention that the fields should be kept free from cruciferous weeds, such as the common charlock or wild mustard, on which the fungus can maintain itself as successfully as on the turnip crop itself. This is a condition unfortunately very difficult to carry into effect, because the wild mustard is a weed that grows very plentifully on many good turnip soils, and is hardly capable of being eradicated. To prevent the continuance of the fungus, it is therefore necessary to remove from the turnip field all diseased remains of roots, and not only should every effort be made to clear out all cruciferous weeds from the field itself, but special care should be taken to destroy them at the sides of adjacent fences and roads, where they are apt to be left to flourish in unmolested security.

The consumption of the crop on the field by sheep cannot be relied on as a means of killing the fungus, for there is no evidence that the vitality of the spores is destroyed in their passage through the animal body, and so far as is known they may be returned to the soil undigested and unchanged. When diseased roots are conveyed to the homestead and fed to cattle, the spores may be passed through them into the manure heaps, or diseased fragments of roots rejected by the cattle may be thrown on to the heaps, which are then made the means of carrying the disease to new fields to which the manure may be carted. As the farmyard manure is very generally applied to the root crop, it seems certain that it is in this fashion often made the direct means of carrying destruction to the crop it has been intended to feed. When, therefore, a diseased crop of turnips is consumed at the homestead it would be prudent to grow the next season's turnips with the aid of artificials alone, and apply the farmyard manure to some crop such as grass to which the fungus can do no injury. It has been affirmed by one investigator that the use of artificial manures containing sulphur renders the turnip crop more liable to succumb to the attack of the fungus.

Perhaps the most effective general preventive of "Finger-and-toe" that has been employed is lime. Lime applied to the land immediately before the turnip seed is sown does not produce much effect, but if applied one or two years before the turnips are grown it has been found in many instances altogether to prevent the appearance of the disease, or at least to reduce its virulence in a very marked degree. And any conditions, such as thorough draining and tillage, suitable manuring, and the use of good seed, that tend to promote the healthy and vigorous growth of the plants, will also give them strength to offer a more stubborn and effective resistance to the attacks of the fungus.

THE POTATO-DISEASE.

The potato crop suffers from a number of diseases, and is more or less injured by all of them, but one disease has so conspicuously outstripped all others in its destructive powers that it has acquired the significant designation of *the* Potato-disease.

This disease is caused by the fungus *Phytophthora infestans.* As a rule it first shows itself in the leaves of the plant in July or later, when the crop is in full bloom. Little brown spots are first noticed on the leaves, and if the weather be damp and warm and thus favourable to the rapid growth of the fungus and its reproduction, the disease will extend itself in a very few days over whole fields, and may reduce the leaves and even the stems to a mass of black rotting matter with an offensive odour. The fungus usually first locates itself on the leaf, it then extends down to the leaf-stalks, to the stem, and finally to the tubers. Meantime little erect filaments have grown up on the surface of the leaves, which are visible to the naked eye in a white bloom. These filaments have on their extremities little cases filled with animal-like spores or zoospores. These are speedily set free and are spread abroad in millions by the slightest movement of the air. When they alight on other potato leaves they germinate and penetrate into the plant, and in their turn become the source of further reproduction. The destruction of the leaves at once stops the growth of the crop, for you know that the starch stored up in potato tubers has been carried down to them from the leaves, where it was first of all manufactured. If the tubers be soft and very immature they may also be quickly destroyed by the fungus, and sometimes the destruction is so complete that the crop of sound tubers remaining will not repay the cost of digging. But if the tubers be well grown and somewhat ripe the spawn of the fungus sometimes remains in them in a dormant condition, and they present when raised a perfectly healthy appearance. In many of such apparently sound tubers the disease becomes active during the winter and they rot in pits and stores, but in other cases the spawn remains quiescent till the seed is planted in the following spring, when it becomes the means of conveying the disease to the new crop.

We have seen that the fungus commonly extends from the leaf down the stem and right into the tubers, but the disease may also be conveyed more directly to them by the little cases of zoospores falling from the leaves to the earth, and being washed between the particles of soil into contact with tubers lying in or near the surface. If the tubers be young, with tender skins, the germinating zoospore is able to penetrate into them, especially at the eyes, and set up the disease; but if they be older, or be protected by thick tough skins, they may be able to resist successfully the entrance of the enemy.

The disease, as we have seen, may be carried on to the next year by the spawn passing into a dormant condition in the tubers and remaining quiescent till the following summer, when it wakens into fresh activity. But the fungus also provides for its perpetuation in another way. Besides producing the active animal-like spores or zoospores that carry the disease at once from plant to plant, it also produces **resting spores,** which are capable of remaining till the following summer, in or on the ground where diseased haulms or tubers have been decaying, when they germinate and produce active zoospores, which then float about in readiness to lodge themselves on suitable plants.

The potato-disease spreads over such wide areas and causes such an enormous destruction of crop that every attention should be paid to means of preventing its appearance and alleviating its ravages. In the first place, as with the anbury in turnips, the practice of rotation aids us greatly in preventing the continuance of the disease. Late varieties of potatoes are seldom grown again in the same fields till an interval of some years has elapsed, and diseased haulms or tubers left to decay on the fields are thus unable to propagate the fungus in the second season unless the zoospores find a suitable lodgment on weeds growing with the next crop or by the sides of the field, or be blown to adjacent fields where potatoes have been planted. To prevent the possibility of such danger it is certainly a wise precaution to destroy totally all diseased parts of plants remaining in the potato field, and this can be done by burning them, or by gathering them into a heap and mixing with a large quantity of quicklime. Trampling the haulms down in cattle-sheds or throwing them into the manure heap forms no certain means of destroying the vitality of the resting spores. Besides securing, as far as possible, that the remains of the crop do not serve to continue the disease, it is equally necessary to destroy all wild plants and weeds on which the potato fungus finds a lodgment. Such are the henbane and the bittersweet, as well as the cultivated tomato and a number of plants frequently kept in farm-gardens.

There are, however, so many practical difficulties attending the total eradication of the fungus that it may be of more use to consider whether something cannot be done to strengthen the plant to resist its attacks, and to see if it be possible to check or alleviate its ravages. One obvious precaution ought to be taken: to plant no seed from a crop in which any disease was seen, as the apparently sound tubers may contain some resting spores of the fungus. The ordinary means of increasing the vigour of crops by suitable manuring and good cultivation, &c., do not appear to have any appreciable effect in strengthening it so as to enable it to ward off the assault of the fungus, as the disease flourishes on all soils and under every variety of cultivation. A means that is generally believed to be more efficacious is to obtain change of seed from some other locality and from a different kind of soil. The change of atmosphere and of soil seems to exercise the same sort of effect in increasing the vigour and energy of the plants as change of air does in improving the health of invalids, and this enables them to offer a much more effective resistance to the disease that threatens them. A still more successful means is to grow varieties that have only been recently introduced. Varieties of potatoes cultivated for many years seem to degenerate and in some way to lose their constitutional vigour, so that they succumb more readily to the virulence of the fungoid attack. On the other hand, varieties that have been recently produced by crossing or by selection seem able for a number of years to offer a complete resistance to the efforts of the fungus to find a lodgment in them, even in seasons when older varieties are totally destroyed by it. In this respect the farmer has it in his power to exercise a wide choice, for experience has taught what kinds of potatoes are most likely to become badly diseased and what kinds are likely to be not at all or only slightly affected. When the disease has actually shown itself in the crop it is still possible to take some steps to limit its destructive power. Various attempts have been made, and are still being made, to check the progress of the disease and prevent its spreading by applying dressings of mineral poisons, such as sulphate of copper, to the leaves of the potatoes when the black patches show that it is present in a field, and the recent invention of an effective distributing machine, the strawsonizer (see fig. 40), makes it easy to apply such dressings in a finely divided spray or powder all over the plants. The proof that any treatment of this kind is successful cannot yet be regarded as quite conclusive; but it seems probable that such dressings may prove very beneficial. Another step frequently recommended is to pull up and remove entirely from the field or from diseased patches the whole of the haulms and leaves as soon as disease is noticed. You know that disease generally shows itself in the leaf first, and that some little time elapses before it reaches the tubers. The prompt removal of

Fig. 40.—The Strawsonizer.

the leaves and stems before the fungus has grown down to the tubers will therefore preserve the latter perfectly sound, and if at the time when the disease is first noticed the crop be well matured and a fairly large yield of tubers be in the ground, this is probably the very best thing that can be done. But on the other hand, it must be remembered that the pulling up of the stems at once stops any further growth of the tubers, for the starch that goes to swell them is first of all manufactured in the leaves. If therefore at the time when the disease appears the crop be immature and the tubers small, the pulling up of the stems removes all chance of a larger crop being obtained, and it is perhaps better to allow the haulms to stand untouched, in the hope that the disease may not prove very virulent after all.

Still another means of alleviating the ravages of the disease may be tried. You remember that the fungus sometimes gets into the tubers by the falling from the leaves on to the earth beneath, of little bags of zoospores which may light on exposed tubers, or may be washed down into the soil to tubers near the surface. Now this source of danger may be altogether avoided if, when the disease is first seen in the leaves, ploughs be sent between the potato drills to run up a protective moulding of some four inches in depth on the top of the tubers. If at the same time the stems of the potatoes are twisted or bent towards one side so that the zoospores drop between the drills, the safety of the tubers already formed will be still further secured, but the injury done to the stems will probably interfere to some extent with the future growth of the crop and will tend to diminish the total yield.

INSECTS INJURIOUS TO FARM CROPS.[1]

CRANE-FLY—"GRUB."

We have learned that one of the most destructive insects that injures our crops is the Crane-fly (*Tipula oleracea*). The grub of the Crane-fly weakens and damages a great many crops, such as the cabbage, beans, and the grasses, by gnawing through the roots or stems just below the surface of the ground. The injury inflicted is usually most serious in the case of corn crops, of which many acres are much thinned and sometimes wholly destroyed shortly after the young plants have brairded. Hardly a season passes, especially if the preceding autumn has been wet and if the spring be late and the growth of vegetation slow, without more or less damage of this kind being done to the corn crops. Some steps can be taken, however, both to prevent the attacks of the grub and also to lessen the amount of mischief it can do.

The Crane-flies lay their eggs in very large numbers, chiefly

[1] See also pp. 136–140.

in autumn. They prefer to lay them near the ground in rough herbage and in shady places, about hedges, and very plentifully in rough wet land. To prevent the laying of the eggs in a field it is necessary to have it closely and barely grazed in the autumn, and if stock will not readily consume any patches of rough and unpalatable herbage it will render such spots distasteful to the fly if sheep be penned on them for a time and hand fed. The draining of land is indirectly beneficial because it brings about an improvement in the quality of the pastures so that stock graze there more closely. Liming and any other manuring that similarly improves the pasture is equally helpful, but a top-dressing of farmyard manure rather tends to encourage the flies to lay in the shelter afforded by its rough straw. An application of gas-lime spread on the surface before autumn drives the fly to lay its eggs in some sweeter-smelling fields.

When, however, precautions such as these have not been taken, and it is feared that eggs have been laid on a field, other measures must be taken to secure the destruction of the eggs or to prevent them from hatching. Harrowing the fields with a close-tined harrow or a bush-harrow will tear the eggs out of their shelter and expose them to birds. A heavy dressing of gas-lime will quite destroy them. Eggs very deeply buried by the plough may never hatch at all, or the grubs when developed may be starved and unable to make their way to the surface soil. The ploughing will be much more effective for this purpose if the plough be provided with a skim-coulter, by which the turf is pared off in a thin slice and is thrown down and buried beneath the remainder of the furrow slice. Paring off the surface and burning it before ploughing is a certain means of destroying eggs and grubs, but it is also a laborious and expensive method, and it causes a great waste of useful organic matter.

When it is seen in spring and early summer that the eggs have safely hatched, and that a field of young corn is infested with grubs, other means must be tried to destroy them and to save the crop. When the plants are growing in rows or drills, horse-hoeing will be of some use, as the action of the implement disturbs the grubs and turns some of them out on the surface where they may be devoured by birds. Heavy rolling is also beneficial, as when the soil is firmly compressed the grubs have more difficulty in moving through it from plant to plant. The rolling should be done in the evening or early morning, in order that any grubs wandering out on the surface at these times may be crushed. Rolling should be repeatedly done. When the land is not in such a state of fertility that top-dressing will be absolutely hurtful to the corn crop, the best treatment of all is to apply liberal applications of nitrate of soda. The nitrate in solution appears to be hurtful and objectionable to the grub, and it probably diminishes alike its activity and its appetite; but it acts chiefly by promoting such a strong and rapid growth of the plants that their stems soon become too strong to be eaten through by the grub, and its power of doing them injury is then practically ended.

CORN "SAW-FLY."

The Corn Saw-fly (*Cephus pygmæus*) attacks a stalk of grain by piercing a hole in the stem just at or below one of the knots, and depositing one egg there. It then goes on to other straws, and repeats the process till its supply of eggs is exhausted. The egg hatches in less than a fortnight into a long yellow maggot which feeds itself for the remainder of the summer on the soft inner substance of the stem. Just before harvest it travels down to the foot of the stem, cuts a ring round so that the straw will readily break to permit its escape, and then rests in a quiescent state till the following summer, when it emerges as a fly. The stems attacked are unable to supply a sufficiency of nutritive matters to the ear, and the grains are either imperfectly developed or not formed at all, while the straw is weak and ripens prematurely. As the maggot spends the winter in the lower part of the corn stems it can be easily killed by destroying the stubble. This may be done by paring and burning, or by paring and mixing with quicklime or gas-lime. Or if the land be deeply ploughed and the stubble buried completely by means of a skim-coulter, the maggot will be unable to emerge in the next summer as a fly.

WIRE-WORMS.

The Wire-worms are grubs of several beetles (*Eleater lineatus*, &c.). The beetles lay their eggs in the lower part of the stems of plants or in the earth beside them. The Wire-worms when hatched eat into the stems, and they go about from plant to plant and destroy far more than they can eat. The same measures that were recommended to prevent the laying of the eggs of the crane-fly on pastures are equally applicable for the prevention of wire-worms. But unfortunately the growing of crops in rotation offers hardly any assistance against the wire-worm, for it seems to feed with equal relish and voracity on all kinds of crops, and there is no hope of starving it except by having the land quite bare of either crop or weeds. It is on broken-up pastures that wire-worms are usually found to exist in the largest numbers, and their ravages are often most severely felt on the grain crop that follows the lea. A very efficacious remedy on a badly infested field has been found, however, in the application of a heavy dressing of gas-lime some time before ploughing, which kills out the worms very completely. A dressing of quicklime fresh from the kiln and quickly mixed with the soil is also useful. Paring the surface of the field and burning the refuse will destroy a large number, but the paring must be done in warm weather, as the wire-worms go deep down in the soil in cold, and the heaps must be burned as soon as gathered or the wire-worms will have left them and moved into the deeper earth. Summer-fallowing and burning all vegetable refuse on the ground is very effective, as the grubs that escape burning may be starved. When this method of extirpation is attempted all turf should be raised from the sides of fences and treated in like manner, or the fields may be anew contaminated from these places of refuge. The application of five cwts. per acre of broken rape-cake is found serviceable, as the wire-worms leave the plants and prefer to feed on the cake. The growth of a crop of mustard has been recommended as a means of preventing attack. Repeated and heavy rolling after the seed has been sown is very helpful, as the compression of the soil checks the movements of the wire-worm and keeps its destructive powers within limits. And, as was advised for grub, great reliance should always be placed on the use of every means that will stimulate the crops to make rapid and healthy progress. Good and frequent cultivation disturbs the wire-worm and promotes the growth of the plants, and manures should be employed that act with most rapid effect on the crop infested, as nitrate of soda to grain crops and superphosphate to turnips. By these means the injury done to the crops may be so much diminished that they will not only survive, but will entirely recover from its effects.

TURNIP-FLY OR FLEA-BEETLE.

The insects commonly known as the "Turnip-fly" are properly beetles (*Phyllotreta* or *Haltica nemorum*, &c.), and, as the name indicates, they are specially injurious to the turnip crop, though they also feed on other Cruciferous plants, such as the cabbage. They differ in their manner of attack from insects hitherto described, for all these inflict the greatest injury on the crop while in the grub or larvæ stage of their lives; whereas the turnip-fly does most mischief after it has developed into the final and perfect form of an insect or beetle. The beetles are little black insects that shelter themselves during winter in stubble, rough straw, or dry rubbish heaps of any kind. As soon as spring comes they begin to feed and maintain themselves on Cruciferous weeds, till the farmer is good enough to provide them with a plentiful supply of food in his young turnip brairds. The beetles then lay eggs on the undersides of the turnip leaves, and maggots hatch out in about ten days. For a week the maggots feed on the leaves; they then bury themselves in the surface soil, and in a fortnight emerge from it as perfect beetles. A number of such broods may be produced in a season. The beetles at once begin to devour the turnip leaves with such voracity that the brairds are often completely destroyed, and the seed has to be resown—often too late in the season to produce a full crop.

The means to be adopted to mitigate the ravages of the turnip-fly embrace, first of all, the adoption of any possible measures of prevention, and unfortunately hardly any are possible. The fly has to support itself on Cruciferous weeds during early spring, before the turnips braird; and if no weeds be found the flies may be starved out. But while something can be done to diminish the numbers of such weeds, they grow so plentifully and so naturally on good turnip soils that their complete extirpation is hardly practicable. One of these, the charlock or wild mustard, is a special favourite of the fly; but in the ordinary course of farming it is hardly possible to remove it wholly from certain soils. Attention must therefore be paid, in the case of this insect, rather to measures of alleviation and cure than of prevention. Various kinds of applications of dry powder have been tried with more or less success. The presence of any powder on the leaf appears to be objectionable to the fly; and the mere dusting of the leaves with dry earth, caused by driving a flock of sheep over the field when the leaves are damp with dew, has been found of itself to impose a perceptible check on the ravages of the fly. The most approved powder for dressing the leaves of the young plants is composed of a mixture of one bushel fresh gas-lime, one bushel quicklime fresh from the kiln, six pounds of sulphur, and ten pounds of soot. These should be mixed together and reduced to a fine powder, and this quantity will suffice for two acres or more. It must be spread on the drills in the morning and evening *when the dew is on the leaves*, when the powder will adhere to them. Another successful dressing has been found in paraffin-oil, mixed with soft-soap and water, of which a very small quantity can be applied over the turnip leaves, in a fine mist-like spray, by means of the strawsonizer.

As in all cases of insect injury, a chief part of the treatment ought to be directed to the pushing on of the crop as rapidly as possible. The power of the fly to totally destroy the crop is limited to the time when the plant is in the first leaf. As soon as it is able to develop its second pair of rough leaves the fly may injure but can hardly kill it. Everything should therefore be done that is calculated to promote the rapid progress of the young plants in the first stages of their growth. The proper preparation of the land, by having it reduced to the finest possible tilth, is of the greatest importance; and it is nearly as important in some districts that the spring working should be done in such a manner as to cause as little evaporation and drying of the soil as possible. A light rolling of the drills immediately after sowing is useful for keeping moisture about the seed. The manures applied to the crop should also be such as will promote quick brairding. For this purpose superphosphate is the best manure, and a very little nitrate of soda will also prove helpful. A favourite method of protection against the fly is to sow an extra quantity of seed, so that if the fly-attack be severe as many plants may escape as will give a sufficient crop. This means of prevention is open to the objection that, if there be no attack, the plants will be so thickly crowded together as to affect their own healthy growth; and in such circumstances particular care must be taken to thin the plants as early as possible; for if any delay take place in thinning them, the singled plants will be so slender and weakly that they cannot carry themselves erect. An easy and practicable precaution is, however, to mix a proportion of one-third or one-fourth part of white turnip seed along with the Swede seed that is intended for the crop. The fly prefers the leaf of the white turnip, and feeding on it will allow a sufficient number of Swede plants to escape. The white plants can all be removed at the thinning, and Swedes only be left to grow into a crop.

SUBJECT XXIV. EXAMINATION PAPERS IN PRINCIPLES OF AGRICULTURE.

First Stage or Elementary Examination.

MAY, 1881.

1. What substances are found in our soils, and what do plants feed upon?
2. Why are some soils more fertile than others?
3. Why do we drain some of our soils, and what advantages do we gain by doing so?
4. Why is farm-yard manure so generally useful for all farm crops?
5. What do you understand by the mechanical analysis of soils, how would you carry it out, and what does it help you to do?
6. What are the ashes of plants, and why do they differ in composition?
7. Describe the composition of a good food, and state what are the duties of food in the animal body.
8. Why do farmers grow their crops in a regular order, which we describe as a rotation of crops? Show the difference between a good and a bad rotation.
9. How is it that a thoroughly good tillage of the soil makes the land more productive?
10. Why are phosphates used as a manure, and how should they be prepared for use?
11. How is lime used as a manure, and how should the character of the soil influence its application?
12. Can you explain how a soil may contain a large quantity of the inorganic matter needed by plants, and yet the crops may not be able to use it? How would you overcome such a difficulty?

MAY, 1882.

1. What are the principal mineral substances found in our soils, and how are they made use of by plants?
2. What do you understand by a soil becoming exhausted, and how does this condition arise?
3. What are the results we seek to secure by ploughing and moving the soil?

4. Explain the cause of wet and undrained land being colder than land which is properly drained?
5. State the chemical agencies which favour the formation of soils, and show how the same results are promoted by mechanical agencies.
6. What substances are selected as a standard whereby we can classify our soils? State why these substances are so selected.
7. Distinguish between the "Active" and the "Dormant" matters in the soil, and show how they change from one form into the other.
8. A crop of turnips being grown on a field, and eaten upon that field (say by sheep), what does the soil gain, and what does it lose?
9. Describe the conditions which are necessary for securing a safe fermentation of farm-yard manure.
10. Why are phosphates so gencrally necessary and useful as manures for the land?
11. Nitrate of potash being too expensive to be purchased for manure, what other means have we for securing a cheap supply of it?
12. When should lime be used upon the land in a caustic condition, and when in the form of carbonate? Show how each form is obtained for use.

MAY AND JUNE, 1883.

1. How may we make the fermentation of farm-yard manure rapid, and how can we also make it safe?
2. What are the special requirements of a good seed-bed, and why are these conditions necessary?
3. What are the advantages we gain by the tillage of the land, and how may they be explained?
4. How is the carbonic acid of the atmosphere made use of by plants, and what do plants gain by its use?
5. What do you understand by a rotation of crops, and why is this practice desirable?
6. What changes do limestone and chalk undergo in being burnt in a kiln, and what advantages do we gain by making them into caustic or quicklime?
7. When should carbonate of lime be used in preference to caustic lime, and how may the advantage be explained?
8. On what soils are the advantages of fallowing the greatest, and why are these improvements specially seen on these soils?
9. Describe the composition of a perfect food, and show the several duties which have to be performed by it.

10. What are artificial manures? Explain why we use them on farms.
11. Why do we drain some of our fields, and in what way does good drainage cause an improvement in their fertility?
12. How does a soil lose its phosphates, and how should the loss be made good to the land?

MAY, 1884.

1. What is meant when we speak of the *organic* and *inorganic* constituents of plants?
2. Explain why frost and changes in temperature pulverize soils.
3. Give two examples of rotations of crops.
4. Explain the origin of alluvial and of peaty soils.
5. Why is a period of "rest" or fallow conducive to the fertility of soils?
6. Name the conditions requisite for the successful germination of seeds. How are they ensured in agriculture?
7. Explain the meaning of the phrase "habit of growth."
8. What ingredients (constituents) would you expect to find in substances recommended as fertilizers?
9. Why may we assume all animal or vegetable refuse to possess manurial value?
10. Write a description of a fertile soil under the following heads:—
    (1.) Its chemical composition.
    (2.) Its texture, including that of subsoil.
    (3.) Its surroundings.
11. What is the usual course pursued in order to "clean" a piece of "foul" or weedy land?
12. Why is thorough tillage or "cultivation" necessary to the successful growth of crops?

MAY, 1885.

1. Name all the elementary substances which are to be found alike in fertile soils, in the ashes of plants, and in the ashes of animals.
2. What substances, in addition to the above, are to be found in all fertile soils, and in the combustible parts of plants and animals?
3. What is actually meant when we say that a soil is "poor," "worked out," or "exhausted?"
4. Why is the texture or mechanical condition of soils and subsoils of equal importance with their chemical composition?
5. What are the principal functions of the roots, the leaves, and the flowers of plants, respectively?

6. Explain why grass intended for hay is better cut young than old; why straw cut comparatively green is more nutritious than when cut old or dead ripe; and why mangel-wurzel and root crops ought to be allowed to mature or ripen before they are stored.
7. Explain why beans and peas are especially suitable foods for growing animals; and why maize and barley, although also suitable for growing animals, are especially so for mature fattening animals.
8. Why ought turnips to be given sparingly to sheep and cattle, and in conjunction with other foods? Name suitable combinations of such foods with turnips.
9. Why is farm-yard manure best applied in the "long," "green," or "fresh" state to stiff soils; and "short" or well-rotted to light soils?
10. Supposing the case of a clay soil intended for roots—what are the advantages gained by cleaning, manuring, and ploughing it before winter, instead of postponing these operations until the spring?
11. How would you proceed to prepare a clover or "seed" field for wheat *or* for oats?
12. Name some waste products possessing merits as fertilizers: and state the chemical reasons for the beneficial action in each case.

MAY AND JUNE, 1886.

1. Describe the way in which our different kinds of soil are formed.
2. What chemical materials are found in soils, and into what two groups may they be divided?
3. What food do plants make use of for promoting their growth, and how do they get the food they require?
4. What do we mean by a good rotation of crops, and state some of the advantages we gain by it?
5. Why does farmyard manure differ so much in its fertilizing value?
6. Take any one of our artificial manures, and give an account of its origin or mode of production, and state the advantages gained by its use on the land.
7. Why do we plough and otherwise cultivate soil before sowing the seed?
8. What special advantages are gained by Autumn cultivation?
9. How does the drainage of land render it better able to yield good crops?
10. What are the differences between light and heavy soils, and what crops are best suited to each?

11. What substances are found in our farm crops which are valuable as food? What duties do they respectively perform in the animal body?
12. How may we economize the use of food for farm stock?

MAY, 1887.

1. Enumerate the mineral or ash constituents of cultivated plants.
2. What descriptions of soil should you expect to find overlying and derived from (1) the London Clay; (2) the Upper Chalk; (3) the Lower Chalk?
3. Are stones useful in soils? If so, how?
4. In what ways do tillage operations render soils more productive?
5. Why are animal and vegetable refuse generally possessed of high manurial value? Give six good examples.
6. How do plants absorb their food from the soil and from the air? What do you understand by the phrase—"The food of plants?"
7. What are the conditions of successful germination of seed? Describe the changes which take place in a seed during the process of germination.
8. What is your opinion as to the relative values of starch, sugar, and fat as foods for fatting animals? To what uses are these substances put in the animal body?
9. What are albuminoids? In what stock foods are they most abundant? What purposes do they serve in animal nutrition?
10. What do you understand by the Norfolk rotation, and how may it most easily be converted into a five, six, or seven years' rotation?
11. Demonstrate that continuous dressings of nitrate of soda to the exclusion of other fertilizers, would tend to exhaust a soil. How might such exhaustion be prevented?

MAY, 1888.

1. What do you understand by a soil being exhausted, and how does this condition arise?
2. Are stones useful in soils? If so, how?
3. Can you explain how it is that a soil may contain large stores of plant food, and yet such a soil may not be fertile?
4. Distinguish between the dormant and active ingredients of the soil, and show by what means they change from the one condition to the other.
5. What are the ashes of plants, and why do they differ in composition?

6. Mention any inorganic matter which is found in soils, and is useful for vegetation, but which is very rarely received into the plant. Explain its duties.
7. What do you understand by a rotation of crops, and how should such rotations be arranged?
8. Why are phosphates more generally necessary as manure than any other purchased manure?
9. Describe the advantages to be gained by fermenting farmyard manure, and show how this fermentation can be most safely carried out.
10. In what forms do we use lime as a manure, and what are the special advantages of each?
11. How is it that an active cultivation of the soil enriches the land, and thus becomes a substitute for manure?
12. What advantages are gained by land being properly drained?

MAY, 1889.

1. Why are clay soils usually rich? What are the causes of barrenness in sandy and peaty soils?
2. At what periods of the year would you sow wheat, barley, winter vetches (tares), winter beans, mangel-wurzel, swedes, and white turnips? In answering this question, state what particular district or locality you have in view.
3. How would you judge wheat and barley, respectively, to be fit to cut? On what consideration is the difference of practice in cutting these two cereals based?
4. Name nine constituents of a fertile soil which are taken up by plants.
5. Give a three course, a four course, and a five course rotation of crops.
6. Why is farmyard manure universally esteemed as a fertilizer?
7. Jethro Tull found that he was able to grow wheat year after year without manure, provided that he thoroughly tilled the soil. Explain this fact, and say upon what descriptions of soil such a course might be adopted with success.
8. What are the advantages of steam cultivation over ordinary horse tillage? Are these advantages more likely to be realized on "heavy" or on "light" soils, and why?
9. Show, by examples taken from the practice of good farmers, that light land requires to be rendered firm or solid before it is fit to grow corn crops.
10. What substances, and in what quantities, would you add to turnips and straw in order to more quickly fatten a bullock?
11. Why are turnips and straw a good combination of foods for cattle?

MAY, 1890.

1. State the chemical agencies which favour the formation of soils, and show how the same results are promoted by mechanical agencies.
2. Explain how it is that a soil may contain large stores of plant food, and yet such a soil may not be fertile.
3. On what soils are the advantages of tillage operations the greatest, and why are these improvements specially seen on these soils?
4. What are the advantages we gain by good farming, and how may these be explained?
5. What do you understand by a rotation of crops, and why is this practice desirable? Give examples.
6. What are the special requirements of a good seed-bed, and why are these necessary for healthy germination?
7. Explain the cause of wet and undrained land being colder, and less fertile, than land which is properly drained.
8. Why are phosphates so largely used as manures, and in what forms are they applied to the soil?
9. How is lime employed as a manure, and how does the character of the soil influence its use and application?
10. How can we make the fermentation of farmyard manure rapid, and how can we make it safe?
11. Distinguish between the organic and inorganic constituents of our crops.
12. Describe the composition of a good food, and state what are the duties of food in the animal body.

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1. How have peaty soils been formed? What are the general characteristics of these soils?
2. Name four of the most important constituents of plant ash, found in soils; and four well-known fertilizers, which are used to replace them.
3. Explain why wool, blood, fish, and animal refuse are valuable as fertilizers, and why refuse sugar, oil, starch, or woody fire are not valued for manurial purposes.
4. Why are the liquid and solid excrements of animals always to be relied upon as fertilizers, and why are turnips, vetches, or green rye valuable as manures, whether eaten by animals or ploughed in?
5. How would you prepare a piece of ley land (*i.e.* seeds or clover lair) for wheat or oats?

6. On what soils, and under what circumstances, would you recommend bare fallowing, and on what soils would you prefer to grow a root crop instead?
7. What objections are there to feeding cattle and sheep on turnips alone? How may turnips be used so as to constitute a valuable addition to the food of cattle and sheep?
8. How much wheat, barley, oats, turnip seed, or clover seed, would you consider sufficient for sowing one acre of land? State if Irish, Scotch, or English acres are meant.
9. Why is wheat cut before it is fully ripe, and why is barley cut when fully ripe? What changes take place in the straw of cereals during ripening?
10. Why should fattening animals be kept quiet, warm, and comfortable? And why should breeding animals and store stock be allowed a fair share of exercise, and live much in the open air?
11. Name some of the principal differences between the cultivation of corn and roots.