CHAPTER VII

SPERMATOPHYTA. PART III

A. Physiology of Plants

The physiological processes necessary for life are, on the whole, the same in plants as in animals. No matter how simple or complex an organism is, it must carry on certain kinds of activities in order to live. There are three classes of these functions. First, *Metabolism,* which is the totality of chemical processes which occur in protoplasm and involves processes such as digestion, circulation, respiration and excretion. Second, *Adaptation,* or adjustment to the environment. Third, *Reproduction,* which is not exactly necessary for the life of the individual organism, but is essential to the continuance of the species. Plants differ from animals in that many of them can manufacture food from inorganic materials, while animals depend on organic materials for food. We have already considered reproduction in plants, and therefore in this section we will take up only metabolism and adaptation. We will first study metabolic functions.

Photosynthesis is the process by which starch is made in the green leaf from carbon dioxide and water. Carbon dioxide is taken into the leaf through the stomata. It enters the air passages and is taken up by the mesophyll. Water is delivered to these cells by the xylem tissue of the veins. We do not know *exactly* what happens. If we did, there would be factories in which starches would be made from carbon dioxide and water. However, we know something about the process.

To accomplish this manufacture in the leaf, energy is necessary. This is furnished by the sunlight and it is apparently the red and violet rays of sunlight that are mostly used. These are absorbed by the chlorophyll, and this, or something in it, is the agent which enables the change to take place. The unabsorbed rays of sunlight passing through chlorophyll give a green sensation to the eye. Chlorophyll is soluble in alcohol, ether and chloroform. However, such solutions of it are ineffective as starch formers. Apparently the carbon dioxide and water are split into their component parts and then recombined. The formation of starch probably occurs in a series of steps. One suggestion is that carbon dioxide and water unite to form carbonic acid gas, H_2CO_3. An enzyme splits off oxygen from this, making formic acid (HCOOH) and oxygen. Then another enzyme splits off more oxygen, making formaldehyde (HCOH) and oxygen. Later molecules of formaldehyde synthesize to form glucose, a simple sugar, ($C_6H_{12}O_6$). The amount of glucose formed increases in sunlight and decreases in the dark. There is a certain optimum intensity of light at which it takes place most rapidly. This means that too intensive light is not favorable. It is not formed in the dark. There is also an optimum temperature. With the increase in the carbon dioxide up to a certain point, there is also an increased production of sugar. As fast as the leaf makes sugar, it is converted into starch, and this is stored in the cells of the leaf. During the night the excess starch stored in the leaf is reconverted to sugar, passed down conducting tissues and may be converted into starch elsewhere; possibly stored in an underground stem, as in the potato. A square meter of leaf surface makes about ten grams of starch per day or three pounds per summer. It takes over a thousand liters of carbon dioxide to do this. After chlorophyll has been extracted from green leaves, they are white, and if starch is present, they will turn blue in iodine solution. Plants grown in an atmosphere devoid of CO_2 do not make starch. Van Helmont, a Flemish scientist of the early seventeenth century and one of the founders of physiological chemistry, planted a willow tree in a certain quantity of dry soil. He added nothing but water to the soil. At the end of five years growth, both tree and soil were weighed. The tree had increased greatly in weight but the weight of the soil remained about the same. From this Van Helmont concluded that materials for growth were furnished by the water he had added. This of course was only *partly* correct. It is interesting to note that he also observed that when wood was burned, part of its substance was dissipated in the form of what he called the " spirit of the wood " or what we would call a gas, and what we now know to be carbon dioxide. Van Helmont did not ascertain the rôle of atmospheric carbon dioxide in the growth of his willow tree. Photosynthesis stores energy, for by it a supply of energy-yielding material is manufactured. The sugar (or starch) thus made is essential for the formation of new protoplasm, new cells, *i.e.*, growth.

Plastids. An important group of cytoplasmic bodies called *Plastids* are characteristic of plant cells. There are three principal types. (*A*) *Chromoplasts* are present in colored floral leaves and in fruits. They are little bodies which contain pigments imparting the color to the petals or to fruits such as the apple and tomato. (*B*) *Leucoplasts* are white or gray, unpigmented bodies around which starch grains form from sugar solution in the cells of storage tissues. (*C*) *Chloroplasts* are of particular interest to any understanding of the biology of the green leaf. They are very small porous bodies covered with fine particles of chlorophyll in suspension. It can readily be seen that a much greater surface of chlorophyll exposed to sunlight is attained by the presence of many small particles covered with chlorophyll than if the cell contained one large body thus covered. There are said to be two types of chlorophyll pigments, each with a definite function. Other pigments are associated with those of chlorophyll. For example, *xanthophyll* is pale yellow, while *carotin* is rather orange in color. Both xanthophyll and carotin may be present in the chromoplasts of flowers and fruits. They cannot, however, perform the function of photosynthesis. Chlorophyll is needed for this. Harvey found that photosynthesis occurs in plants illuminated with light from nitrogen-filled tungsten electric lamps. Chlorophyll is constantly being made and constantly destroyed. It functions in solutions containing proper compounds of C, O, H, N and Mn. Iron must also be present. Chlorophyll apparently absorbs light rays, for the most part, from the red and from the violet end of the spectrum. It is believed that the energy furnished by these light rays is converted by the chlorophyll into energy which is used in photosynthesis. About 20% of the total energy of the light is stored in the products of photosynthesis. Some plant cells contain red or blue pigments dissolved in the cell sap. These are known as *anthocyans* and are present, for example, in red onions or in red and blue flowers.

During the summer, chlorophyll is destroyed about as rapidly as it is made. In the autumn, its manufacture gradually ceases and so the leaves are no longer green. Xanthophyll and carotin pigments now reveal themselves in the color of the autumn foliage.

Or, possibly, the nights have been frosty and such a condition favors the accumulation of sugars and anthocyans and so the red leaves of maples, oaks and sumachs are prominent. The browns and blacks are merely the colors of dead cellulose walls and the various shades of color seen in autumn leaves are varying compositions of these with the cell pigments.

Respiration. Oxygen is necessary for animal and plant life. Oxidation is the keystone of the many processes of metabolism. Carbon dioxide and water are the by-products of oxidation. Plants *take in* oxygen chiefly through the stomata of the leaf and also through the stem and roots. This is one phase of respiration. The waste products of oxidation are carbon dioxide and water, which are eliminated chiefly through the stomata. This is the other phase of respiration. Respiration occurs in all plants and animals. Photosynthesis takes place only where there is chlorophyll; respiration takes place in all living cells of plants and animals. Photosynthesis occurs only in the light; respiration continues through the night and day. Photosynthesis manufactures food; respiration occurs where oxidation burns up food. In photosynthesis, carbon dioxide is absorbed and oxygen is a by-product; the reverse is true in respiration. Photosynthesis stores energy; respiration accompanies the release of it.

Transpiration. Water, which is a by-product of photosynthesis, collects in the air spaces of the leaf in the form of water vapor. From these spaces it passes out through the stomata into the atmosphere. Light, warmth, dry air and wind increase this movement of water. Some of the water (the greater part of it) has arrived in the leaf, via the conducting vessels of the veins and stem. Removal of it by transpiration makes possible a further movement of liquids up from the earth. Besides external conditions favorable to photosynthesis, a brisk movement of water to the leaf is essential. If transpiration exceeds absorption, the plant wilts. In transplanting, care should be taken not to destroy root hairs. The root system should be disturbed as little as possible. Moreover, after re-planting, the leaf area should be reduced, the plant should be covered and water added around the roots in order that absorption shall be greater than transpiration. Water loss in the cactus is greatly reduced by the reduction of transpiration area to that of the surface of the stem, for the leaves are represented by spines. In the rubber plant, stomata are at the bottom of pits. On the under surface of some leaves, hairs are present, thus restricting the free play of air currents about the stomata.

Transfer of Water and Mineral Salts. Water and solutions of mineral salts rise to the tops of the tallest trees. A great number of long ducts of extremely minute diameter traverse the plant. Through these water and mineral salts, dissolved in the water, pass from the earth to all parts of the plant. Just what forces are responsible for this movement of fluids, we do not exactly know. The cause is probably the resultant of a number of forces. Mesophyll cells of leaves secrete a solution on their outer surface. This becomes concentrated by evaporation, which causes more water to be drawn from the interior of the cells and these in turn absorb more water from the veins and aid the rise of sap. Osmotic pressure of the sap is greater in more elevated cells as compared with cells at lower levels, and this would tend to create an upward passage of water from cell to cell. Then again, capillarity would explain a partial rise of liquid in these tubes. Transpiration or removal of water from the upper end of the system of ducts would also aid its movement upward. The *very minute diameter of the ducts*, which thus present a relatively large surface area in proportion to the inclosed fluids, is probably an essential part of the mechanism. Capillary attraction would serve to support the very small weight of water at any one point. Variation in osmotic pressure, transpiration, avoidance of a vacuum and pressure from below would make for a movement of fluids. Transpiration alone does not account for the ascent of fluids in stems. When some stems are cut off near the ground, water oozes out of the cut surface of the rooted portion. The cut end may be connected with a mercury manometer and it is found that the "root pressure" raises the column of mercury over the pressure of the atmosphere. This indicates a positive force, apart from the phenomena occurring in the leaves.

Protein, Carbohydrate and Fat Manufacture. From the sugar made in their leaves and from compounds of N, C, H, O, K, Fe, S, P, etc., plant cells can make more protoplasm. This is a process of synthesis of proteins. Certain compound proteins are characteristic of certain seeds; for example, gluten of wheat flour, and zein of corn. Plant proteins are markedly present in peas, beans and lentils, also.

Some of the carbohydrate made, is stored not as starch but is changed to fat. This is true of the olive and the seed of flax (linseed oil), cotton, and also other seeds, usually called *nuts,* such as the peanut. Glucose is soluble in water, but starch and fat are not, and so glucose is converted to starch or fat for storage. The energy that is stored is valuable as well as the carbon, hydrogen and oxygen. Cane sugar ($C_{12}H_{22}O_{11}$) is stored in such plants as the sugar beet and sugar cane. Much of the glucose made by plants is converted into cellulose and forms the wood and bark of trees; the fibers of the flax stem from which linen is produced and the fibers of cotton, associated with the cotton seed. The word *assimilation* refers to the building up or formation of more protoplasm from proteins, fats, carbohydrates and mineral salts.

Enzymes are protein-like compounds that hasten the speed of chemical reactions. Many enzymes are found in plant tissue, and life processes are fundamentally dependent upon the presence of these enzymes. Enzymes are produced by the living cells.

Hydrolyzing enzymes add water and split molecules. Thus, cane sugar is made into glucose and fructose[1] ($C_{12}H_{22}O_{11} + H_2O) = 2(C_6H_{12}O_6)$. Such enzymes are *hydrolases. Monosaccharids, disaccharids, polysaccharids,* are converted from one to the other by means of enzymes. By *dehydration synthesis,* glucose and fructose are made into cane sugar with the loss of water, thus

$$2(C_6H_{12}O_6) - H_2O = C_{12}H_{22}O_{11}.$$

Lipases act on fats and oils, changing them into fatty acids and glycerine, in which form they may be transported. Other enzymes change carbohydrates into fat and fat into carbohydrates.

Proteases convert complicated proteins into amino-acids. The building up of complex proteins and protoplasm itself involves the presence of special enzymes.

Fermenting enzymes change sugar to alcohol. Probably all chemical life processes involve enzymes.

The photosynthetic manufacture of starch by enzymes has been described in terms of enzymes as follows: First: An *oxidase* changes water and carbon dioxide to formaldehyde; *aldehydase* changes formaldehyde to glucose; a *maltase* changes glucose to

[1] Glucose and fructose have the same chemical formula, *i.e.,* $C_6H_{12}O_6$, but not the same atomic arrangement in the molecule.

maltose; a *dextrinase* changes maltose to dextrine; an *amylase* changes dextrine to amylum, a soluble starch; and finally *coagulase* changes amylum to insoluble starch. Some investigators, on the other hand, deny that chlorophyll action is fundamentally enzymatic.

Digestion and Secretion. *Digestion* is just as necessary a process in plants as animals. It means the changing of an insoluble food into a soluble form. Digestion takes place in a fluid medium. We have seen that the green leaf stores some of the manufactured carbohydrate for a time. If this storage process continued, a condition would soon result whereby the normal functioning of the leaf would cease. When night comes, further starch formation ceases. Enzymes *secreted* in the cells digest the starch tp a simple sugar which is transported to other parts of the plant. For example, new root-tip cells are forming. They absorb some of this sugar and so obtain part of the material needed to make the requisite amount of new protoplasm they will possess when mature. Protoplasm is everywhere disintegrating. More supplies are needed for repair. So digestion constantly goes on, rendering storage starch available for living cells. The starch of a potato is digested for the use of the new potato plant and that of the wheat grain, for the use of the new wheat plant. Similarly proteins and fats are also digested in plant cells; the gluten of the wheat grain is made available as amino-acids for the young wheat plant and the oil in the peanut for the young peanut plant. Secretion of enzymes is involved in these processes.

Oxidation has been referred to in our discussion of respiration. Oxidation simply defined is the combustion of carbon compounds by oxygen, liberating energy and forming, as by-products, CO_2 and H_2O. Life is a series of complex chemical reactions. Energy utilization characterizes many of these reactions. It is evident in such fundamental processes as cell division and growth. Metabolism is sometimes thought of as being composed of two series of reactions. The first set, leading up to the formation of protoplasm, is known as *anabolism;* the second set, disintegrating processes, *katabolism.* Oxidation is a katabolic process. Glucose, $C_6H_{12}O_6$, is a common product of photosynthesis. Its formation results in the transformation of kinetic energy into potential energy. The oxidation of one gram of glucose releases four calories of heat energy and forms the compounds, CO_2 and H_2O. Oxidation of glucose in plant and animal cells is brought about by means of enzymes called oxidases, which operate at ordinary temperatures.

Excretion. As a result of katabolism, chemical compounds are formed which are of no use to the organism. In fact, their presence hinders cell functions. So they are discharged from the cell and eventually from the organism. Such substances are called excretions. Water and carbon dioxide leaving the plant are two of the principal excretory products. The formation of cellulose, wood and bark and of such substances as resins, gums, perfumes, nectar and even poisons are other examples. Excretions are often confused with secretions. The reason for this is that there is no common single word to express the facts exactly. Possibly the best that can be said is this: the *process* by which cells *make products* to be *discharged* from them is called *secretion*, as, for example, the secretion of resins, gums or enzymes. If the product is to be employed in some further physiological activity, it is called a secretion (*noun*) as, for example, an enzyme; but if it is of no further use — but is, as far as the plant is concerned, waste matter, — it is then called an *excretion*, as, for example, carbon dioxide and the gums and resins. Plants accumulate wastes in the wood and bark, formed season after season. Only a small part of an enormous tree is really alive. This includes the growing points of stem and roots, the cambium and a few cells adjacent to this and many cells of the leaves.

Growth is a physiological process involving cell division, the attainment of mature size and special form and function of the new cells. It involves the formation of more protoplasm, more plastids, the retention of more cell sap and the laying down of more non-protoplasmic structures such as cellulose walls; it results in a further extension of the root, stem and leaf system. Someone once contrasted the growth of crystals with that of organisms. Crystals grow by accretion, *i.e.*, the addition of similar material to the faces of the crystal. Living organisms grow by intussusception, *i.e.*, growth from within. But growth in organisms is not formless, aimless, indefinite. It occurs by the formation of new and specialized cells and the formation within them of more nuclear matter and more cytoplasm and the deposition between them of more non-living matter such as cellulose in plant cells or bone in certain types of animal cells. Usually the sum total of all these processes expresses itself in increased size. When we plant a potato or onion, we soon see a green plant above the ground. *For a time*, the compounds forming the living material of the young plant are derived from the potato or onion planted. The potato itself decreases in size as a result, but the new plant increases in size. It is a matter of transfer of materials although other vital processes are at work as well. The germination of the seed involves growth. After young plants attain physiological independence, they convert inorganic materials into protoplasm for *further growth*. Plants do not store nutriment in seeds for the use of man. The food is stored there for the use of the embryo plant to be utilized at the time of germination. Growth involves the formation of more protoplasm than that needed to replace protoplasm broken down in the living process. Growth continues longer or more indefinitely in plants than in animals. In a way, plants grow as long as they live. Many instances of this have been observed in various animals. The higher animals, however, have a definite growth period, they attain a mature size and beyond this they do not go. If, in the process of metabolism, they make more protoplasm than they can use, the extra amount is excreted although some may be stored in the form of fat.

Adaptation. Animals quickly adjust themselves to changes in external conditions. Plants also constantly adjust themselves to such changes, but more slowly. Most animals make the proper adjustments by the aid of their sensory, nervous and locomotor systems. The plant makes its adjustment by the process of growth and hence the response is slower. Plants at times are destroyed by agencies from which animals can easily move to a place of safety.

There are various types of changes in external conditions which affect living organisms. For example, there are physical changes when objects come into contact with the organism. These are recognized as mechanical stimuli. Then there are changes in temperature and variations in light. Chemical changes are variations in water and the concentration of salts, alkalis, acids, oxygen and carbon dioxide surrounding the plant. The plant protoplasm, especially that of cells immediately affected by the stimulus is sensitive to changes. This sensitiveness is known as irritability. The change in environmental conditions which produces a response is called a stimulus. It probably brings about a temporary modification in the physico-chemical constitution of the cells "irritated."

In animals, sensory cells are stimulated and the chemico-physical change is converted into a nerve impulse which presently brings about a movement by the locomotor apparatus. The plant makes a response also, but this is accomplished by growth. More cells are formed in one place than in another and the plant slowly turns *in an appropriate response.* Plants have no nerves and no muscles. A turning or a response to a stimulus is called a *tropism.* If the response is toward the stimulus, the tropism is positive; if away, it is negative. The clinging growth of the ivy to the wall is an example of positive thigmotropism. The growth of the root at right angles to the surface of the earth toward the earth's center is an example of positive geotropism in which the stimulus is gravity; the growth of the stem in the opposite direction from the root is an example of negative geotropism; the growth of a stem toward the light is an example of positive phototropism, while the roots exhibit negative phototropism; the extensive growth of the root system toward a greater water supply is an example of positive hydrotropism. The root tip is so sensitive to appropriate stimuli that Darwin was led to say that " there is no structure in plants more wonderful as far as its functions are concerned, than the tip of the radicle —." Gager points out the importance of these tropisms to agriculture. As one illustration of this, he points out that it makes little difference how seeds fall when planted, since positive geotropism will cause the root sooner or later to grow down. It would be practically impossible to plant crops if every single seed had to be placed with the embryonic radicle pointing downward and the epicotyl upward. If the top of a tree is removed, one of the remaining topmost *lateral* branches grows *upward* and in a few years there is little evidence of the earlier injury. This is not only negative response to gravity and positive phototropism, but involves other obscure processes. While the main stem and main root show direct response to such stimuli, the growth response of branches, as a rule, is at an angle to the stimulus and branch roots are transversely geotropic. It must be remembered that the whole organism is subjected simultaneously to a number of stimuli. Because of this, no one stimulus is, as a rule, evidenced to the elimination of the effects of a stimulus of another type. The position of the plant as a whole is the net result of all the stimuli acting upon it. In order to ascertain the effect of one stimulus, the investigator must maintain all but one type of stimulus as usual and change that one stimulus markedly and then note the effect that this has on the growth response. Suppose we arrange sprouting seeds so that all the conditions are normal except that the radicle is at a right angle to the force of gravity. Slowly we can see that the root turns in growth downward. Or, we can admit light to one side of a plant only. Gradually it will grow toward the light. It is an interesting problem to study the position of leaves of different types of plants and trees. We see leaves of different size and arrangements, and see that in general leaves are placed so as to secure optimum illumination for all.

In some plants the response to contact is relatively rapid. This is true of the Mimosa — the sensitive plant. This plant has many, small, pinnately divided leaves. If we strike the tip of one of these, the leaflets close up toward each other, beginning at the tip where the stimulus was applied. If the stimulus is stronger, then the petiole also bends down and if the stimulus is still stronger, other leaves respond until the whole plant responds. The reaction suggests that some type of impulse is being communicated. The response occurs at the rate of from 8 mm. to 20 mm. per second, *i.e.*, too rapid to be a growth phenomenon. It has been shown by Ricca that the stimulated part secretes a chemical substance which passes into the circulating system and as it passes other parts, causes them to react. But this type of response is ordinarily not manifested in plants.

B. General Biology of Roots, Stem and Leaf

Relation of Roots to Water and Soil. The principal functions of roots are to anchor the plant firmly to the ground; to absorb water and mineral matter from the soil; to absorb oxygen, to give out carbon dioxide; to store water and food and to support plants which do not possess rigid stems, but which clamber over other plants. If most of the roots are removed, the plant dies. We can cut off a stem near the ground and new stems grow up again, but serious injury to the root system will usually kill the plant. Corn plants (Fig. 97) develop bracing or prop roots near the base of the stem. Roots grow out into the soil seeking the optimum water and food supply. Liebig once said that they apparently had eyes for this purpose. This is not literally true, of course. It can be explained as a growth response to the stimulus of water. If necessary, roots will grow deep into the soil after water. Plants require a great amount of water in growth and in formation of seeds. Briggs and Schantz found that wheat requires 500 times as much water by weight as the dried weight of the seed produced, corn over 350 times as much and potatoes over 600 times as much. Grovesnor reports that cane plants absorb 1000 pounds of water to make one pound of sugar. Few people realize the extent of the root system. This matter has been extensively investigated by Weaver — in the case of many hundred plants. For example, mature Marquis wheat plants, about 2.5 feet high, have a very thick root system for three feet in depth and some roots extend into the soil for a distance of six feet. Roots hold or bind the top soil together and prevent it from being washed away by the rain. Complete destruction of forests oftentimes has been followed by the loss of the top soil which is rich in plant food. This top soil is essential to plant growth. The destruction of forests also decreases the rainfall. It is claimed that on this account areas of the earth's surface, once fertile, are now barren. The fertility of a region depends partly upon the mineral content of the top soil, on the amount of nitrates, phosphates and humus present. Great quantities of this top soil are washed annually by the rain into rivers and so into the sea.

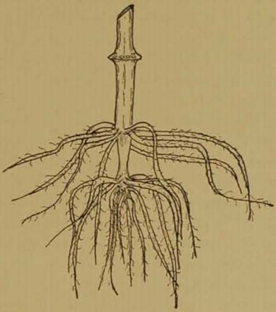

FIG. 97. — Lower end of corn stem showing upper tier of "prop" roots formed after the earth around the stem was "hilled up."

Although most roots cannot breathe if immersed in water, yet some plants are so constituted as to permit this. Roots of willow trees growing alongside a stream are often submerged in the water and the trees seem to thrive. On the other hand, some plants grow in the air and their roots can take in moisture from the air. Some plants can be propagated from roots. For example, the dahlia possesses a *multiple* fleshy root. When one of the roots is placed in the ground in the spring, a new dahlia plant develops. Pieces of the root of rose bushes, when carefully handled, will produce new rose plants. Poplar trees grow very rapidly. When once started, and if the conditions are favorable, these trees form long roots and from these roots many new young poplar trees spring up. Some seed plants live on other seed plants. The first type may be partially or wholly parasitic on the second — the host. In such cases, the parasite sends a special modified root into the tissue of the stem of the host and thus derives its food supply from the host. In this way the dodder which has no chlorophyll or leaves obtains sugar and mineral salts. The mistletoe obtains chiefly mineral salts and water from its host. Mistletoe has pale green leaves.

It has been found that certain molds grow on the tips of the roots of certain trees, such as pines, oaks and beeches. These fungi cover the root tips with a tangled mass of threads and probably take the place of root hairs. Moreover, the trees do not thrive unless these fungi are present.

The Soil. The *soil* constitutes one of the two great environments of plants. The greater part of the weight of soil is made up of rock particles. The size of these particles varies and they are of irregular shape, with air spaces here and there between them. Well-tilled soil makes for a greater number of air spaces. Plants will not grow well in very compact soil. Rain falling upon loose soil percolates slowly down through it. If the soil is packed down, the rain does not penetrate but runs off. If the soil is composed exclusively of rock particles, it penetrates too rapidly and may collect over waterproof layers too far beneath plants to be of any use to them. If the rock particles are mixed with decayed organic matter, or humus, the surface water not only percolates more slowly through the soil, but more is retained. In comparatively dry soils a thin film of water is found adhering to the rock particles. This is of little use to the plant because the rootlets do not possess the power to remove this hygroscopic film. However, if the soil is of the proper constitution, a considerable supply of water will be found associated with it in the same way as water associates itself with the cotton fibers of a lamp wick, namely, by capillarity. If the tips of the roots are absorbing this capillary water from one point, the adjacent water of capillarity will move from the points of greater saturation to the region of less saturation. Air is vitally necessary for the life of the ordinary root unless there is some special structure present to obviate the immediate absorption of water directly by the root. Well-tilled soil makes for greater water-holding power, for conservation of water and for ample air supply. It also removes accumulations of carbon dioxide and encourages the destruction of injurious bacteria by exposure of the soil to sunlight. Otherwise such bacteria may accumulate in the soil.

Water dissolves chemical substances necessary for plant growth. Compounds of sulphur, potassium, calcium, magnesium, phosphorus, iron and nitrogen are found in soil. These elements occur in soil water as carbonates, sulfates and nitrates. The compounds of calcium tend to neutralize soil acids which are injurious to plant growth. Magnesium is needed in the formation of chlorophyll, and this important compound cannot be produced unless an iron compound is present in the cell sap. Potassium salts appear to aid in the formation of carbohydrates. Some proteins contain phosphorus and sulfur and of course these elements must be present in compounds which are soluble in cell fluids. The roots of some plants, such as the potato, appear to be able to absorb weak ammonia solution although this is injurious to most plants. Long-continued growth of crops on a certain area of land diminishes the amount of soil minerals. Unless they are restored to the soil, the crops grown will be failures. The principle involved in the use of commercial fertilizers is to restore these compounds to the soil.

Organic matter comes from the decay of dead animals and plants. Certain groups of bacteria break down the complex compounds of dead tissue into simpler and simpler compounds. The final results are water, carbon dioxide, ammonia and the most important of all, nitrates. These soil nitrates are absorbed with the other mineral compounds and are used in the manufacturing of protoplasm. In this process water and oxygen and sugar in the plant cells are also necessary.

Rodents, insects, earthworms, Bacteria, roundworms, Algae, Fungi, etc., inhabit the soil. The living animals burrowing through the soil cultivate it to a certain extent. They aerate it. The beneficial effect of earthworms on soil was thoroughly investigated by Charles Darwin. By far the greatest beneficial work on soils is accomplished by certain types of Bacteria. As stated above, they decompose the dead bodies of plants and animals, and this decomposed organic matter forms humus, and when mixed with rock particles, makes good soil. Certain Bacteria, *Nitrosomonas*, change ammonia into nitrates. *Nitrobacter*, another type of Bacteria, changes nitrites into nitrates.

Roots and Nitrogen Fixation. Bacterium leguminosum, another type of Bacteria, lives in little masses (Fig. 21), nodules or tubercles, on the roots of peas, beans, clover and alfalfa. Over four thousand of these have been found on the root system of a single plant. These Bacteria have the wonderful power of absorbing nitrogen gas from the air in the soil and making a nitrogen compound which can be absorbed by the roots of the plant. In other words, large and vigorous plants may thus grow in soil comparatively poor in nitrates. These are called *nitrogen-fixing Bacteria* and soil may be inoculated with them. The farmer grows a heavy crop of alfalfa enriched by the nitrogen-fixing Bacteria on the roots. He plows this crop under. The crop will decay in the ground and then the soil will be richer in nitrates. The farmer can later grow better crops of corn and wheat on what was previously poor soil. Certain results are of interest here. A crop of clover or alfalfa, plowed under, supplies the soil with about one hundred pounds of nitrogen to the acre. It is as valuable as many loads of manure. A good crop of corn or wheat will remove from fifty to seventy-five pounds of nitrogen per acre from soil.

Root Hairs. The tough bark of old roots is impermeable to the plant fluids within and to the soil water without. But soil fluids must find their way into the plant if life is to go on. Water is needed for the manufacture of more sugar. The sugar supply is constantly used up in the life of the plant. Nitrogen and other necessary elements derived from the soil must enter if the protoplasm, broken down by normal life processes, is to be restored or increased. Root hairs are structures which make possible the intake of water from the soil. The wall of the root-hair cell is permeable to water and to the minerals dissolved in the water. It is lined with a thin film of protoplasm, thus forming a sac of living matter inside of which is cell sap and outside of which is soil water. This protoplasmic sac is not freely permeable. It will not permit the cell sap to escape. In this way the sugar is conserved. It is quite permeable, however, to the substances dissolved in the soil water and to some compounds more than to others. Water can pass through it freely in either direction. Because the concentration of the fluids within is greater than that of the soil water, there will be a movement of fluid from without the cell, through the living membrane into the sap cavity. The concentration of the plant fluids of the inner cells adjacent to the outer root-hair cells is greater than in the latter cells, hence there will be a movement of fluids from the root-hair cells into the next inner row of cells. For similar reasons there will be a movement of liquids from the second tier of cells to the third and from the third to the fourth and so on. Solutions of soil salts diffuse through the cellulose and protoplasmic membranes into the interior of a root-hair cell.

Turgor. Everyone is familiar with the fact that on certain very dry days, small non-woody plants wilt, and that if provided with plenty of water, they again stand vigorously erect. Everyone is familiar with the rigidity developed in an inflated balloon due to the outward pressure of the air imprisoned within. When the balloon is deflated, it becomes flaccid or wilts. The sap cavities of plant cells are well filled with water which has been absorbed and the cells are rigid, due to the outward pressure of the contained fluids on all parts of the cytoplasmic and cellulose membrane. The rigidity of each cell may not be very great, but there are millions of cells and the sum total of all their rigidities is sufficient to maintain erectness. This outward-bearing pressure of contained liquids of a plant cell, due to osmotic pressure, is known as *turgor*. If the cell fluids become depleted due to conditions of drought, then turgor is absent and the plants droop. The cells of the young root possess turgor.

Herb, Shrub and Tree. *Herbs* have relatively soft and tender stems (Fig. 98). These stems die down to the ground during the winter or other unfavorable conditions. New stems grow up when the proper conditions again prevail. A *shrub* is a comparatively low-growing bushy mass of woody stems which do not die down in the winter. Such plants usually do not attain any great size in temperate climates. The lilac is an example of a shrub. A *tree* possesses one main stem or trunk which in some species attains great height and diameter. Its woody structure enables it to support a great mass of leaves and branches. The branching habit of trees is quite characteristic of each species, so much so that in many cases the tree may be identified by its form. The branches bring more leaves into sunlight and air.

Annual, Biennial and Perennial. An *annual plant* is one which develops from the seed, produces roots, stem, leaves, flowers and seed all in one season. Annual plants die down at the end of the summer season. They cannot survive long periods of drought, and winter is a dry period so far as the plant is concerned. The species does not disappear because the plant has produced seeds and it is one of the functions of the seed to protect the embryo from destruction during drought or cold. Examples are peas, beans and many common seed plants. A *biennial plant* develops only roots, stem and leaves from a seed during the first season. It, however, forms a fleshy root in which a surplus of starch made by the leaves is stored. In the spring of the second season another plant develops from the fleshy root. This plant also has stem and leaves but fibrous roots; it also has flowers, and seeds are produced. Two growing seasons are required to complete the cycle. We purchase seeds of beets, carrots and turnips from the seedsman — the harvest is a crop of fleshy roots at the end of the season. But the seedsman plants fleshy roots and raises plants that produce seeds.

FIG. 98. — Cypripedium, "Lady's Slipper," a perennial herb. The flower is so constructed that insects entering to gather nectar leave pollen from some other Cypripedium and carry off pollen from the flower as they leave. (Photo by Fread.)

Perennial plants such as a shrub and tree live year after year. From the point of view of evolution, perennial plants are regarded as the more ancient type, while herbaceous plants are a recent development. Indeed, it is the opinion of some students that herbaceous or annual plants will become the dominant vegetation of the future. Herbaceous plants grow rapidly, and during the summer time alone, in temperate climates, manufacture enormous quantities of starch and cellulose. Our common crop plants, and especially corn, have been called *sun-energy traps*. Omitting consideration of the grain, farm wastes such as corn-stalks and straw of our country alone contain, it has been said, potential energy equivalent to our entire output of soft coal and gasoline. Annual plants seem to be more vigorous power transformers than perennials.

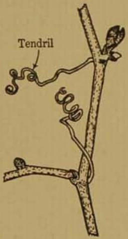

FIG. 99. — Tendrils of wild grape.

Modifications of Stems and Leaves. The cactus is a green stem whose spines are modified branches. The green part of a cactus plant is virtually stem tissue in which food is made and stored. The so-called leaves of "Smilax," a decorative plant, are flattened branches, while the tendrils of the pea are modified leaflets, and those of the grape (Fig. 99) are branches. When a young tendril establishes contact, the outer tissue grows more rapidly than that next the support, with the result that the tendril *grows* tightly around it. This reaction to contact is called *thigmotaxis*. The English Ivy is supported on walls by aerial roots. In the Virginia Creeper, the ends of the tendrils have discs which stick to walls (Fig. 100).

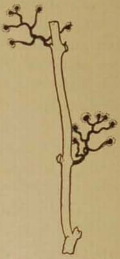

FIG. 100. — Holdfasts at ends of tendrils (branches) of Virginia Creeper.

Rate of Growth. Corn plants may grow ten feet high in one season. Pine trees are only three inches high at the end of the same period. Some species of pines grow fifteen inches a year for the first fifty years; then five inches per year during the next fifty years. They may live two hundred years, but during the second century grow but an inch or so in height each year. Hardwood trees grow but part of an inch in thickness during the first half century and after that but a fraction of an inch per year. Forest fires destroy such growths of wood in a few hours. A pine tree takes fifty or more years to produce wood enough to make a board twelve inches wide, one inch thick and twelve feet long.

Size and Age. Stems vary in size, and in some cases it is difficult to recognize the stem, as in the dandelion plant, where the leaves grow in a rosette almost from one point. Some plants have slender stems, but they thrive by climbing up over other plants or on the side of buildings, as is the case with the Virginia Creeper. The giant redwood, Sequoia, is one of the tallest, largest and oldest of all living organisms. The largest and oldest specimen is "General Sherman" a tree in the Sequoia National Park. It is 280 feet high, 36.5 feet in diameter and probably nearly 4000 years old.

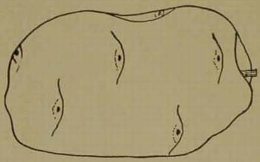

FIG. 101. — Tuber of potato plant.

Storage of Food. We have already noted that the rhizome of the fern is an underground stem. Many seed plants have underground stems also. The *tuber* of the potato (Fig. 101) is the terminal portion of a specialized underground stem in which starch is stored. The "eyes" contain buds and each of these can produce a new plant. The food for the early growth of this new plant is derived from the starch stored in the potato. The fleshy body of beets and carrots is a storage root. The stem is very small but from it arise numerous leaves. The bulb of the onion or Narcissus (Fig. 102) has a small, short, broad stem covered with fleshy storage leaves. In all these cases, food stored in stem, root or leaf is used for growth of the new plant.

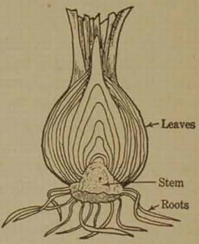

FIG. 102. — Section of Narcissus bulb.

Pruning. Trees tend to produce an excessive number of buds, branches and leaves with the result that many die and sooner or later are broken off. This is a sort of natural pruning. Intelligent pruning of trees by man is an important part of forestry practice. However the cut surfaces should be painted over to prevent entrance of fungus spores and thus avoid disease. It has been observed that a fruit tree if neglected will produce a wealth of branches but little fruit. With correct pruning greater growth energy goes into the production of larger and better fruit. In the case of plants grown for flowers, removal of some of the flower buds will result in fewer but larger and more perfect flowers. Single giant chrysanthemums and dahlias are produced by saving only the most promising-looking bud.

Origin of New Varieties and Grafting. New varieties have been produced by cross-pollinating closely related forms. The resulting type is known as a "hybrid." It often happens that such hybrids do not breed true, *i.e.*, their seed does not produce offspring similar to themselves. Very often the hybrid possesses very superior qualities. Man has discovered, however, that the new type can be preserved and cultivated by a sort of vegetative reproduction. This is accomplished by a process called *grafting*. An example of how this is done is given here (Fig. 103). Very young saplings are grown from the seed of a hardy variety of the same but relatively useless kind so far as fruit is concerned. The stem of this plant is cut off near the ground. The cut is made in a special way. To the cut end of the stem connected with the root system of the hardy plant is attached the cut end of a branch of the hybrid which grows the new variety of fruit. The branch is called a *cion* and the plant to which it is attached is called the *stock*. Cion and stock are fitted with the cambium tissue of each in contact. They are securely fastened together and the *bandage* coated with *grafting wax*. The branch grows to the stock and from both will develop a fruitful tree. This new tree is practically the offspring of the parent hybrid. In this way, the hybrid variety can be perpetuated indefinitely. Seedless grapes and navel oranges are propagated in this way. It is thought that seedless oranges once appeared on a branch of an ordinary orange tree. The sudden appearance of a variation differing distinctly from the usual range of variations is called a *sport*. Grafting is employed in the commercial production of most of our fruit trees and such shrubs as roses.

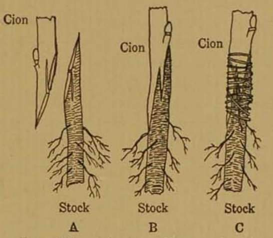

FIG. 103. — Root grafting. *A*. Cion and stock prepared for joining; *B*. Cion and stock joined; *C*. Cion and stock tied securely with waxed cord. From Gager: *General Botany*, copyright 1926, P. Blakiston's Son & Co., reprinted by permission.

New varieties of potatoes are produced by cross-pollination, but the new variety is continued commercially by vegetative propagation, since the farmer plants pieces of potatoes and not seed. On the other hand, the inventor of new varieties of grain, produced by experimental cross-breeding, is forced to plant the new seed produced. The application of principles of heredity discovered in the course of modern research in genetics has brought success in many cases of grain hybridization.

Carnivorous Plants. Some plants are carnivorous, but this remarkable phenomenon is rare. In the pitcher plant, the pitcher is a special leaf on the inside of which are stiff hairs pointing downward. At the bottom is a little pool of water. Special glands on the leaf secrete a fluid which attracts insects. When they enter, they crawl about inside the pitcher and some fall into the water where they drown. They decompose and are digested. The food compounds derived from their bodies are absorbed by the plant.

Man's Supply of Plant Food. Although a great amount of the world's supply of starchy foods is stored in underground stems and roots, yet the main supply is formed in seeds. The thin watery sirup of the sugar-cane stem is one source of commercial sugar. The juice of the sugar beet (storage root) is another important source of sugar.

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