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A composite scene of living red and brown algae from widely separated areas in the Atlantic and Pacific oceans. The brown alga is the giant kelp (*Macrocystis*), a valuable fertilizer. By E. Cheverlange

OLD AND NEW PLANT LORE

A SYMPOSIUM

By
Agnes Chase
A. S. Hitchcock
Earl S. Johnston
J. H. Kempton
Ellsworth P. Killip
Daniel T. MacDougal
Albert Mann
William R. Maxon

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Part I

THE WORLD OF PLANTS

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CHAPTER I

FUNDAMENTAL LIFE PROCESSES IN PLANTS

THE study of plants is called botany. The word botany may suggest a vague world outside of man's ordinary experience, a world dominated by long and fearsome Latin names. As a matter of fact, forbidding Latin names form a very small part of botany and need repel no one. Furthermore, the average man actually has more knowledge of botany than he realizes. Agriculture, horticulture, gardening—even the making of a lawn—are applied botany. He knows also that potatoes, rice, and bread contain starch and that sweet fruits and sweet potatoes contain sugar; and he realizes, if he gives the matter sufficient thought, that starch and sugar are plant products and that plants are a great factory in which much of our sustenance is manufactured. This world of plants, with which we animals share the earth, is of such interest and beauty as to be well worth at least enough study to open our eyes to its everyday marvels. So much study we propose to give here.

We shall consider plants from three standpoints: first, how plants live and grow and reproduce themselves, how they scatter their seed, how they are adapted to their environment, how they are distributed over the face of the earth today, and how they were distributed in ages past. All this is, in a broad way, plant physiology. Next, we shall consider how plants are related to each other through a common ancestry reaching back millions of years. The classification of plants is an attempt to show this relationship, and is called systematic botany. Finally, we shall consider the relation of plants to man, showing how man derives his food, clothing, and shelter, his necessities and his pleasures alike from the plant kingdom. The study of the uses of plants is called economic botany.

Plants, like animals, can not exist without air, food, and water; but, though their requirements and life processes are similar to those of animals, their organs are not analogous. Plants breathe, but they have no lungs; they digest food, but have no stomach; the crude sap ascends their stems and the elaborated sap is diffused downward from the leaves, but they have no heart to pump it nor any real circulatory system; they respond to stimuli—for example, a tendril curls when it touches a support, and a leaf turns toward the light—but they have no brain nor nervous system. Nevertheless plants do have organs that are specialized for certain purposes, and it is interesting to note how the structure of an organ is adapted to its function.

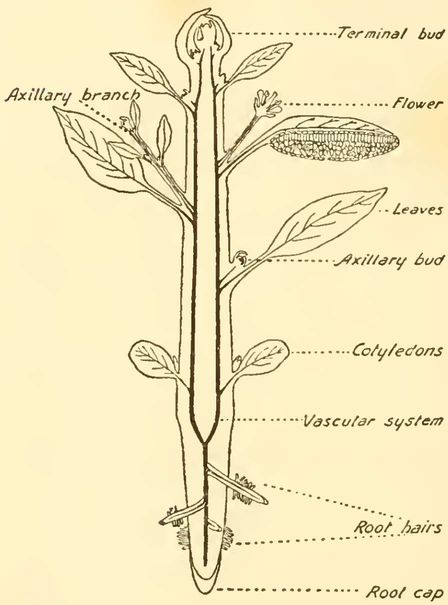


FIG. 1. Diagrammatic representation of the principal organs of an ordinary seed plant. After Holman and Robbins

A baobab tree, showing disproportionate growth of the trunk, on the dry plains of Africa. The smaller objects in the branches are fruits, the larger are beehives made of hollow logs. Photograph by Hitchcock

FUNDAMENTAL LIFE PROCESSES

To illustrate the life processes of higher plants, let us take a common tree. The three primary sets of organs are: the roots, the trunk and its branches (stems), and the leaves (Fig. 1).[1] The roots hold the tree in place and absorb water and nourishment from the soil. The trunk supplies a channel for the flow upward and downward of the sap and mechanically is so built as to support an adequate leafage, and yet not be top heavy; it divides into branches and branchlets, successively smaller, finally ending in the twigs. The branches are large at the base and taper toward the extremities, thus giving a strength and suppleness that enable them to withstand storms. This is made easier for them by the fact that the twigs and leaves yield to violent winds, bending before them and presenting a minimum surface to the blast. The leaves are borne only on the twigs, that is, on the branchlets of the current year's growth; (however, the leaves may persist for more than one year). In a manner to be described later, the leaves elaborate food for the plant, using water from the soil and carbon dioxide from the air, the elaboration taking place only in the sunlight. The leaves are flat, so that they present the greatest possible surface in proportion to their mass to light and to air, and they are so arranged on the twigs that they catch the greatest possible amount of sunlight. If the tree stands by itself so that light comes to it from all sides, the branchlets are evenly distributed in all directions and, if left untrimmed, they may reach nearly to the ground. In such a tree scarcely a ray of sunlight penetrates to the center of the mass of foliage and it casts an almost unbroken shadow upon the ground, showing that the leaves catch every ray of sunlight. The leaves at the periphery are full of vigor; those toward the inside get along as best they can with diffused light; if the shade is too dense they give up and fall to the ground. If the tree is part of a forest the struggle for light becomes severe and

[1] Cordial acknowledgment is made to the United States Department of Agriculture for the loan of Figures 1, 3, 4, 38, 39, 40, 42, 47, and 49.

leaves are found only on the crown at the top. If the tree grows on the bank of a stream it may be forced to send slender branches far out over the water to seek light from the side.

Roots

The roots have two functions: first, to hold the tree in place and support it against bending and twisting by storms; second, to absorb nourishment from the soil.

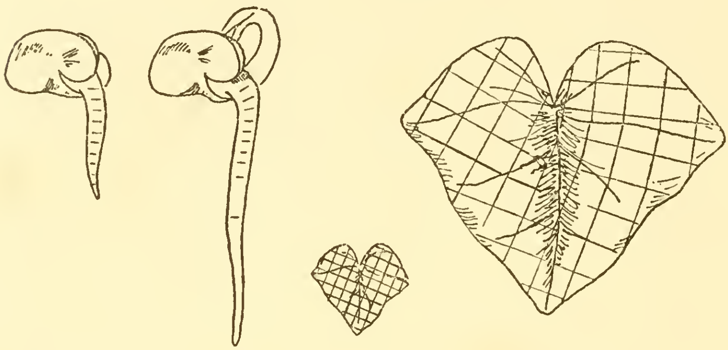


Fig. 2. How areas of growth are determined. Left, young root marked with equidistant lines, and their displacement by subsequent growth; right, young leaf marked off in squares, and their displacement by subsequent growth. After Kerner

Roots branch extensively but only the ultimate branchlets grow in length, the growing area being just back of the tip (Fig. 2). It is obvious that if roots grew in length in other areas the side branches would be scraped off by the resistance of the soil. The part of the fine rootlets where growth takes place may be only an inch, or even less, in length. To protect the end of the tender young root as it pushes through the soil there is a little cap which is being constantly repaired by new cells in front as the worn cells are sloughed off the sides (Fig. 3). A short distance back of the growing end there is an area on which root hairs are produced. To the naked eye these root hairs look like white fuzz or velvet, but when slightly magnified the fuzz is seen to consist of slender hairlike cells. The area of root hairs moves forward with the growth of the rootlet, the old hairs dying off behind and new ones forming in front. These minute organs have the power to absorb soil water, that is, rain water that has filtered through the earth and dissolved small quantities of whatever minerals are contained in the soil. The combined absorbing action of millions of root hairs sets up a considerable pressure, which tends to force the soil water, or sap, up through the trunk and into the branches. Root pressure, as this force is called, can be measured by cutting off a small tree a short distance above the ground and attaching a measuring apparatus (manometer) (Fig. 4). The pressure may at times be as much as fifty feet (equal to that of a column of water fifty feet high). In young plants of corn or wheat root pressure causes drops of water to exude from the unexpanded tips of the young leaves during the night. Early in the morning the drops sparkle on the points of the leaves and are usually taken for dew drops. They disappear by evaporation under the influence of the sun.

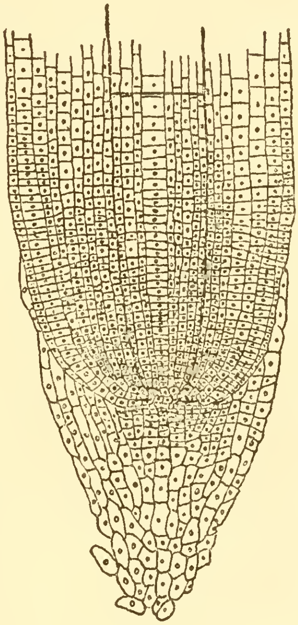


Fig. 3. Section through tip of a growing root. The mass of cells at the end forms the rootcap, at the base of which is the growing point. After Holman and Robbins

Roots may grow to a considerable distance in search of water; those of the alfalfa plant, for example, have been found occasionally to extend to depths of more than fifty feet, though the plant itself may be only two or three feet high. The roots of willows become troublesome at times by growing into tile drains and there branching profusely until they fill a section of the drain like a large plug and stop the flow of water. The guilty willow tree may be many yards from the plugged drain.

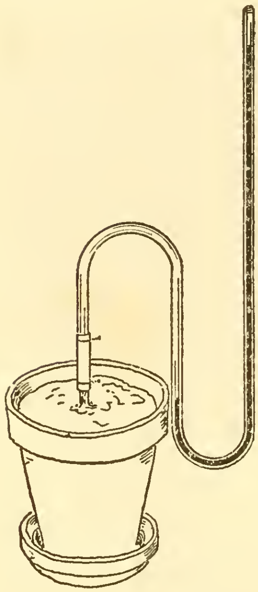


FIG. 4. Manometer to measure root pressure. As the roots force water into the glass tube the mercury rises. After Holman and Robbins

Although roots grow in length only at the ends, every part of them may grow in thickness. In most of our forest trees this "secondary" growth is very evident. The effect of the thickening of roots under pavements, where the bricks, stones, or even cement slabs are raised, is a familiar sight. Roots penetrating crevices of rocks and afterwards thickening may scale off slabs or layers of the rocks, thus aiding in converting them into soil.

The tree obtains its food from the soil and the air. The dissolved minerals in the soil water constitute the earthy part of this food, and this is the part that is left as ashes when the wood is burned. But while the food offered in any given spot is the same for all the plants growing there, the roots to a certain extent make a selection, different species absorbing widely differing quantities of minerals. An individual of one species may take in twice as much calcium, for example, as its nearest neighbor. When the sap within a plant is saturated with a given mineral its roots absorb no more of that until the plant in its vital processes uses up what it has. Thus a plant may have use for calcium sulphate, possibly because of the sulphur contained in the mineral. The calcium of the calcium sulphate (which is soluble) may be separated from the sap in the form of the insoluble calcium oxalate and stored as crystals, thus reducing the amount of calcium sulphate in the sap, whereupon the roots absorb more of this substance to make up the deficiency. As a result the plant takes up much more calcium sulphate than its neighbor of some other species. It is because crop plants may take different amounts of constituents from the soil that they may require different fertilizers to supply their need.

Certain elements are essential to the proper nourishment of plants. This has been demonstrated by growing plants in jars of water to which have been added definite amounts of mineral constituents. In these experiments it was shown that the want of certain elements would cause aberrations in growth

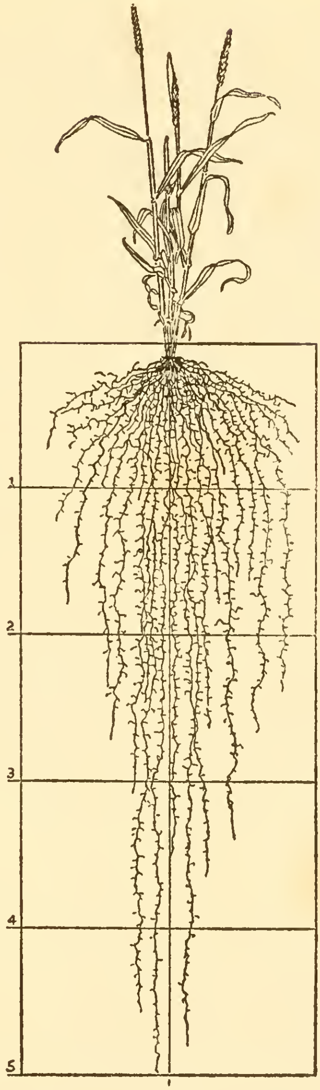


Fig. 5. The extensive root system of a wheat plant. After Weaver

or function. For example, when iron was lacking the plant could not produce the green coloring matter (chlorophyll). It was also shown that higher plants need magnesium, calcium, potassium, phosphorus, sulphur, and nitrogen as well as iron. Furthermore, certain plants require minute quantities of other elements, such as boron, manganese, copper, and zinc. Usually virgin soils contain sufficient quantities of all these minerals in the form of "salts," carbonates, sulphates, phosphates, silicates, and so on, or as oxides or hydrates. The important element, nitrogen, comes into the plant usually in the form of soluble nitrates, a fact which has an important bearing on the deficiency of this mineral in crop-bearing soils. Plants growing under natural conditions, through the shedding of their leaves and by their disintegration when they die, return their mineral content to the soil. Crop plants do not do this, as a large part of each plant is removed in harvesting, and the mineral content is lost to the soil. Continued cropping may soon cause a deficiency of certain elements, one of the first to give out being nitrogen, because most of that element present in the soil is in the form of soluble nitrates. All soils contain an inexhaustible supply of sodium, magnesium, and silicon, but deficiencies in nitrogen, phosphorus, and potassium may be readily brought about. The agriculturist must supply the deficient elements by applying fertilizer.

There is usually enough iron in all soils to supply the needs of plants, but a remarkable case of iron starvation was brought to light a few years ago in connection with the culture of pineapples in the Hawaiian Islands. On certain soils the pineapple plants failed to produce sufficient chlorophyll and were therefore pale or bleached, a condition known as chlorosis. Investigation showed that, though there was plenty of iron in the soil, the large amount of manganese present prevented the plants from absorbing the iron. This condition was remedied by

PLATE 2

Phenomena incident to air requirements of tree roots

Gatun Lake, Canal Zone, showing remains of the forest killed when lake was formed

Air roots of a kind of mangrove (*Avicennia nitida*), submerged at high and bare at low tide

Photographs by Hitchcock

PLATE 3

Dry cypress swamp, Texas. The knees of the cypress convey air to the roots in the wet season. Courtesy of the U. S. Forest Service spraying the plants with an iron solution. The iron was absorbed by the leaves, and the plant was able to manufacture the normal amount of chlorophyll.

In order to function properly roots must have air. Under ordinary conditions soil is loose enough to contain sufficient air in the interstices, but any abnormality that affects the air supply threatens the life of the plant. Thus trees not accustomed to an excess of water will be killed if the ground is submerged for a considerable length of time. They may withstand flood-waters, which eventually recede, but if the water stands permanently above the roots, thus excluding the air, they will be killed. The effect of permanent submersion was well illustrated in Panama, where all the forest trees flooded by the waters of Gatun Lake (Plate 2, left), impounded by the great Gatun Dam, were killed. A familiar example of the effect upon trees of a reduced supply of air to their roots is presented by the shade trees of city streets. A piece of open ground is left around the tree when the sidewalks are laid. This open surface may supply sufficient air to small trees, but as the trees grow larger they require more air. In residential sections roots will usually penetrate beneath the sidewalks to the open front yards near by and thus obtain air as well as nourishment. But in the business sections of the city there may be no open spaces into which the roots can penetrate. The result is retarded growth and ultimately the death of the trees. Smoke and noxious gases and the lack of proper nourishment may also help to bring about these results.

At one place on the north side of Park Road in the city of Washington there is a high terrace. At the inner edge of the sidewalk is a wall six feet high, above which the ground slopes up steeply. On the other side of the street the houses, each with a small grassy yard in front, are nearly on a level with the sidewalk. Many years ago a row of elm trees was planted along each side of the street. The trees on the lower side grew normally because the roots could utilize the front yards of the houses. Those on the terrace side of the street, though of the same age as the others, were much smaller. They appeared to be only a third as old as the others and were in poor condition. These trees sent their roots under the sidewalk and under the wall but were unable to find the air they needed because they were still many feet below the surface. Within recent years, however, the stunted trees have taken on new life and are growing vigorously. Evidently the roots have at last reached up to the surface soil.

Trees growing on a lot which is to be filled in can be preserved by building a well around each tree to prevent the roots from being entirely cut off from their air supply. If the filling is not too deep the roots may ultimately reach an air supply at the surface of the added soil.

Trees that grow in swamps and so have their roots submerged may have special means for conducting air to the roots. The knees of bald cypress (*Taxodium distichum*) (Plate 3) are branches of the roots that reach above the surface of the water and conduct air below. At low water a cypress swamp with the numerous knees sticking up to a height equal to the usual level of the water in the swamp presents a curious aspect. The common mangrove (*Rhizophora mangle*) conducts air down through its tangle of stilt roots. Other mangroves (for example, *Avicennia nitida*, Plate 2, right), produce a swarm of vertical roots for carrying air. These are exposed at low tide and submerged at high tide. Swamp and marsh plants in general have some contrivance for conducting air to the roots. Usually there are air channels or spongy tissue within the stem, leading down to the root system; a few plants, such as winged loosestrife (*Ludvigia alata*), produce spongy or corky tissue on the outside of the stem from a short distance above the water line to a considerable distance below it.

Man is constantly attempting to change soil conditions for the benefit of his crop plants. He mulches the surface of the soil with hay or straw, or loosens the top soil, giving it a "dust mulch," to prevent too much evaporation. He supplies fertilizers in order that his crops may have proper and sufficient food. In regions where the rainfall is insufficient he supplies water by irrigation. Sometimes in his efforts to improve on nature he makes serious mistakes through ignorance of the principles involved. A striking example of this is seen in the effect of over-irrigation in some of our western States. Thinking that if some water is good for crops, more would be better, some ranchmen were in the habit of flooding their fields with irrigation water, giving the crop much more water than it actually needed. The excess evaporated, but, of course, left behind its mineral content. Successive irrigations and evaporations brought more and more mineral—or "alkali," as it is called by the ranchmen—to the surface, until this became so concentrated that crops suffered. The more the irrigation the worse the result. Finally crops were inhibited by the excess of mineral and the fields became "alkali" wastes supporting only certain resistant native plants of no value to the ranchman. Investigation showed that the effects of over-irrigation could be gradually remedied by drainage. The reverse process now took place; the excess of irrigation water dissolved the "alkali" and carried it away through the drains.

Stems

The stem or trunk supports the leafy crown of the tree and supplies it, through branches and twigs, with the minerals and water absorbed by the roots. The stem consists of an elaborate structure of strong hard wood, a system of specialized tubes, and a protective covering of bark. But, however tall and stately the tree may be, the trunk is made up, as is the smallest herb, of minute cells.

A typical vegetable cell has a wall of firm material (cellulose), and the cavity is filled, or partly filled, with protoplasm, which is the living substance of the plant.

Protoplasm itself, as seen under a high-power microscope, is a colorless fluid, denser than water and resembling the white of an egg. In active plant cells it can be seen, because of the small granules it contains, to move around the cell in streams. Within the cell are various bodies: the nucleus, a dense portion in which the directive power of the cell probably lies; the chlorophyll granules that give the green color to plants; other color bodies; and, sometimes, oil drops, crystals, and other substances. When first formed, cells are much alike but they soon develop into the shape and structure necessary to perform the particular function for which they are destined.

If we examine with a microscope a cross section of a mature twig of any common tree, we can see that it is marked off into five circular zones, one inside the other. At the center is the pith; second comes a zone of wood; third, a thin layer of growing cells, called the cambium; fourth, a zone of young bark; and finally, the epidermis (Fig. 6). The cylinder of pith at the center consists of soft, roundish, thin-walled cells, the contents of which soon die and are replaced by air. The zone of wood just outside the pith is made up of two kinds of cells. One kind is thick walled, several times longer than wide, and has pointed, overlapping ends, which enable each cell to cohere firmly with its neighbors and so to give strength to the stem. The cells of the second kind are larger than wood cells and coalesce to form long tubes, which run lengthwise through the wood. The tubes are usually strengthened by spiral ridges on the interior of the walls, for which reason they are often called spiral ducts. Jumping for a moment the thin circle of growing cells, we find a zone of young bark and outside of this the epidermis. The young bark, like the wood zone, is made up largely of two kinds of cells; bast cells, which are thick-walled like the wood cells but proportionately much longer (also, though thick walled, they are flexible); and thin-walled cells forming tubes. These tubes have sieve-like openings in the walls or partitions, through which nutritive material is carried.

Between the wood and the bark is the all-important cambium, a thin layer of growing cells, quite regular in

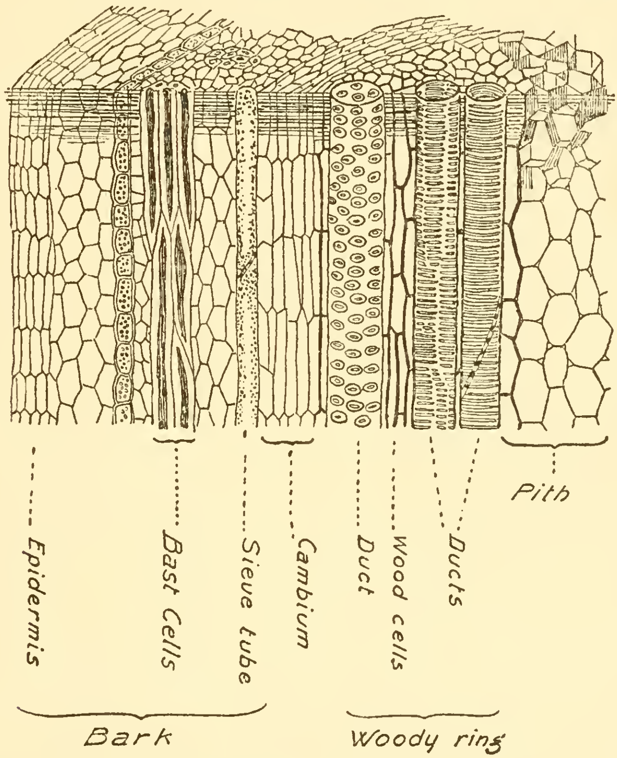


Fig. 6. Cross and longitudinal sections through a woody stem. After Kerner

shape and only a few cells thick. It is continuous from the twigs through the trunk and large roots to the small branches of the roots. To the cambium the stem owes its growth in thickness. It is an undifferentiated growing layer. When active the inner layer of cells is changing into wood, the outer layer into bark, while the central part continues to be cambium. The growth in diameter of the twig, branch, or trunk means that the cambium is adding wood to the outer circumference of the wood zone, and bark to the inner circumference of the layer of bark. As the youngest and largest layer of bark is the innermost, the outer bark is always too tight and is continually being cracked and split by the pressure from within. The trunks of many of our common trees, such as the oak, maple, and walnut, become furrowed. The bark of the planetree or sycamore (*Platanus*), scales off in large plates; that of the canoe, or paper, birch (*Betula*) peels off in beautiful sheets (Plate 5). In regions where there is a distinct winter season, during which the tree is dormant, the cambium grows most rapidly in the spring, when the young twigs are forming. The farm boy knows that this is the time to make willow whistles, and he cuts a young twig and hammers it with the back of a pocket knife. This crushes the juicy cambium, the bark readily slips off, and the makings of a whistle are at hand.

The greater part of the trunk of a large tree is no longer living matter; a layer of sapwood just inside the cambium, the cambium itself, and a layer of bark just outside are all of the trunk that is really alive. The inner wood and outer bark are dead and serve the tree only mechanically. The sap, that is the soil water absorbed by the root hairs, ascends through the young wood.

Trees are killed by girdling, which consists in removing a band of bark a few inches wide, and deep enough to include the cambium, from all the way around the trunk. This interrupts the downward movement of the elaborated sap by which the roots are supplied with nourishment, and death follows as soon as the nourishment stored in the roots has been exhausted. Girdling to this depth does not interfere with the upward current of water from the roots; hence the leaves do not wilt. But if the girdling is deep enough to cut through the young wood (sapwood)

PLATE 4

Base of a mora tree in the rain forest of British Guiana. The buttresses support the tall trunk. Photograph by Hitchcock

the leaves wilt at once. Trees girdled in summer usually die before the following season.

Because of the rapid growth in the spring the tubes in the wood are much larger at that time, but decrease in size as the season advances (Plate 6). The abrupt transition from the compact fall growth of the wood to the large tubes of the spring growth produces a well-marked ring (Fig. 7). Normally one such ring is formed each year, so that the age of a tree can be told by counting the rings in the wood. It is by the number of rings that we know our giant sequoias (*Sequoia gigantea*) to be from two thousand to three thousand years old. These rings even bear witness to changes of climate in ages past. Dr. A. E. Douglass, of the University of Arizona, has found that the thickness of

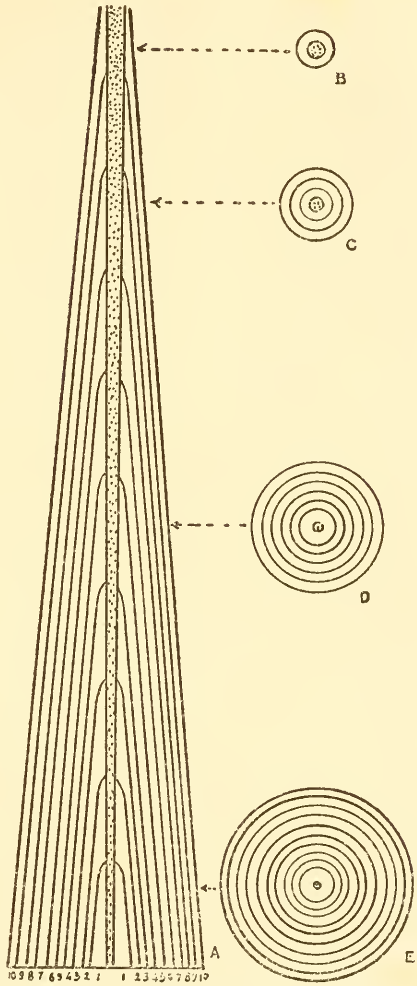


Fig. 7. Diagrammatic representation of the growth of a woody stem for ten years. The concentric rings show the age of the trunk at any given height. After Holman and Robbins

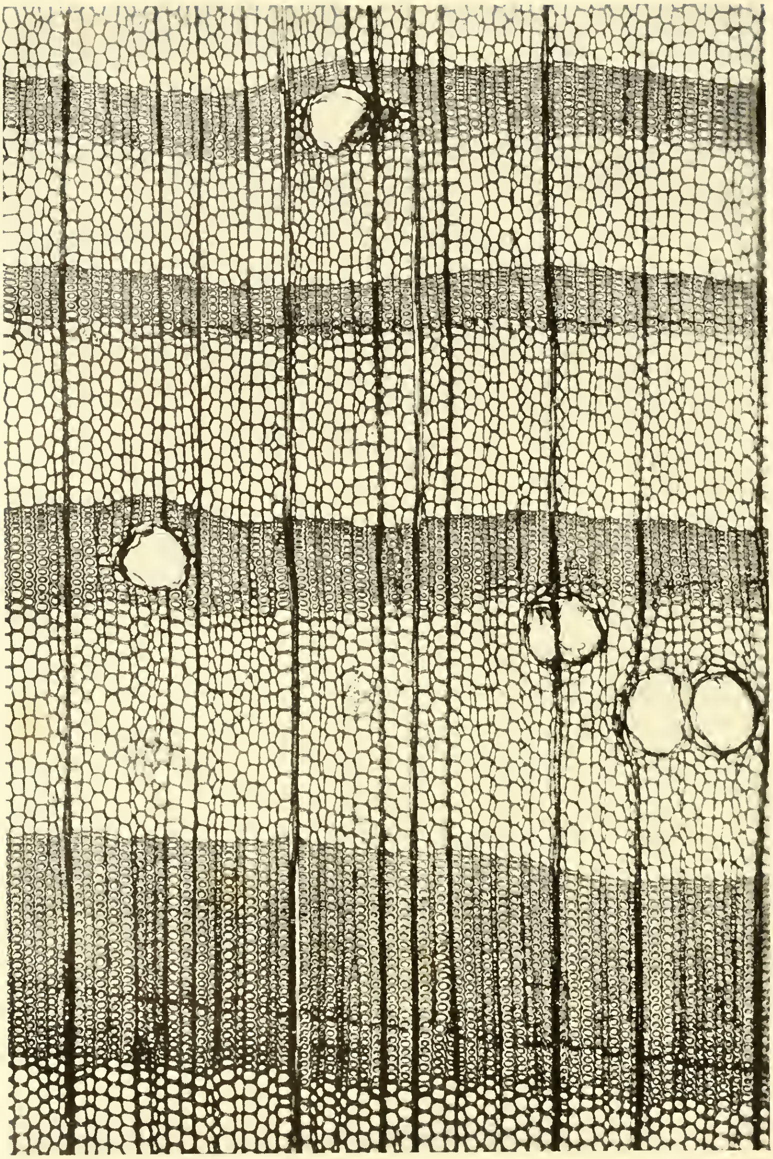
the rings varies according to the dryness or humidity of the growing seasons. He has shown that characteristic thickening or thinning of tree rings indicates that in former centuries long periods of drought alternated with long periods of humidity. Doctor Douglass has also made tree rings serve as calendars of past events. Comparing the series of rings formed several centuries ago by old trees recently felled with series in the wooden beams found in the homes of the cliff dwellers and other ancient peoples of the Southwest, he has succeeded in accurately dating events in the lives of these aborigines that took place a thousand years ago. Thus he has determined that the "Cliff Palace" was founded in the year 1073, and that "Pueblo Bonito" flourished from 919 to 1130. Further studies by this method may make it possible to fix with approximate accuracy dates reaching back two or three thousand years.

Although the trunk and its branches increase in girth throughout the growing season, only the young twigs increase in length, and this increase takes place during a short period. In the climate of Washington the year's linear growth in the twigs of most trees is completed by the first of July and the buds of the succeeding year are already fully formed. A twig grows in length throughout and not merely at the end as does a root. A leaf bud is a miniature twig compressed into a small space. The young leaves, or the beginnings of them, are already there, crowded together on the very short axis which is to elongate into the stem. The bud is snugly covered by overlapping scales which protect it from drying out. In the spring the buds swell and throw off the bud scales. The axis of the bud increases both in length and thickness and separates the expanding leaves.

After the twig has attained maturity all linear growth ceases. Tree trunks are sometimes used as "live" fence posts to which fence wire is stapled. As the years go by the distance between the wires remains the same, showing

PLATE 5

Clump of paper or canoe birches, the bark of which peels off in thin sheets. Courtesy of the U. S. Forest Service



Cross section of trunk of a pine tree as seen under a microscope, showing the annual rings. Courtesy of the U. S. Forest Products Laboratory that there is no increase in the length of the trunks, though sometimes the whole tree is lifted several inches out of the ground by the growth in thickness of its own roots. The fence wire may become deeply embedded in the bark as the trunk increases in girth.

In the maple tree it can readily be seen that the leaves grow opposite to one another on the twigs (Fig. 8, left),

Fig. 8. Left, twig of maple, showing the four-ranked arrangement of opposite leaves; right, elm leaves illustrating a leaf mosaic. After Kerner

but in many other trees the leaves may seem at first glance to be scattered at random. But the arrangement of leaves is foreordained in the bud and is the same for all plants of the same species. They may be opposite as in the maple, buckeye, and lilac, or alternate as in the elm. In the opposite arrangement the leaves are in pairs, one on each side of the stem. But successive pairs stand at right angles to each other, the leaves thus being four-ranked upon the individual twigs.

In the alternate arrangement, in which there is but one leaf at a node (the point whence the leaf springs), there are two principal types, the two-ranked and the five- or eight-ranked. In the two-ranked arrangement, the leaves are on opposite sides of the stem, but one above the other, thus bringing the third leaf above the first on the same side of the stem, the fourth above the second, and so on. Examples of this are the elm, the linden or basswood (*Tilia*), and the mulberry. It is a curious fact that the leaves so arranged are usually unsymmetrical at the base and turn on their stalks (petioles) so as to lie in one plane. The larger lobe at the base lies next to the twig and over it, thus filling up the space between its neighbors and utilizing the light.

In the five-ranked type the leaves are arranged in a spiral. Starting with the lowest leaf on the twig, the next leaf above is two-fifths of the distance around, the third one is four-fifths the distance, the fourth one, still going around the same way, is six-fifths, the fifth, eight-fifths, and finally the sixth is ten-fifths, or twice around the twig and stands directly above the first (Fig. 9, left). The leaves are, therefore, in five rows as one looks down the twig from above. The eight-ranked type differs from the five-ranked in that the spiral goes three times around the twig, bringing the ninth leaf above the first. The five-ranked and eight-ranked arrangements may sometimes be found on the same tree. Nearly all trees with alternate arrangement of leaves that are not two-ranked are either five-ranked or eight-ranked, or both, though in some trees, such as the pine, the arrangement is more complex. The twigs of any tree are arranged in the same order as are the leaves, for buds are borne normally only at the ends of twigs and in the axils of the leaves. (The axil is the upper angle between a leaf and the stem bearing it.) With this in mind we are able to determine whether an organ is developed through the modification of a leaf or of a stem. Thorns, for example, may be derived from leaves or from stems (sometimes from other parts). If they are derived from leaves (as in the barberry), they will have buds or branches in their axils; if they are developed from stems (as in the honey-locust), they will spring from the axils of leaves. The prickles of the blackberry, raspberry, and rose are irregularly distributed over the stems and

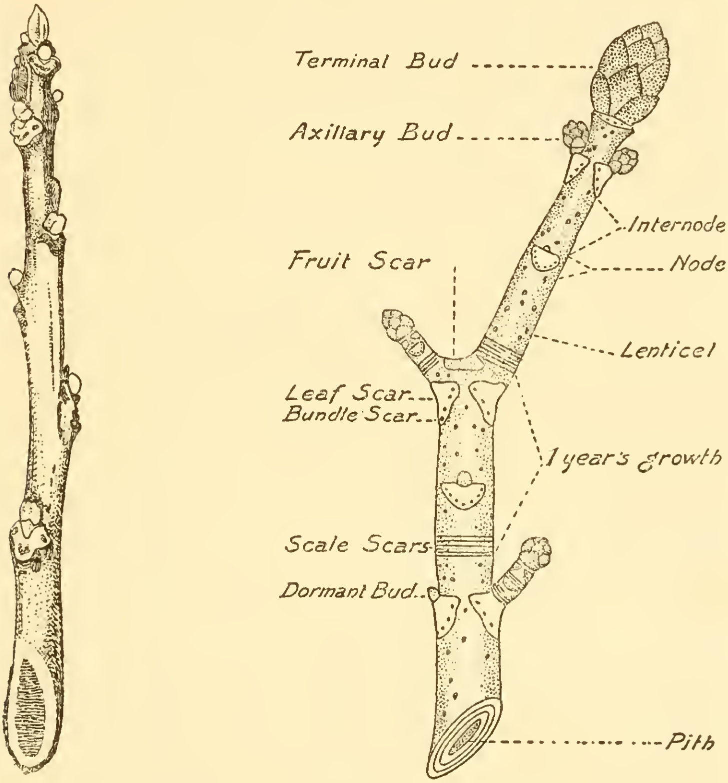


FIG. 9. Left, twig of walnut, showing five-ranked leaf scars, each with a bud in its axil, and diaphragmed pith; right, twig of horse chestnut, showing buds, leaf scars, and other parts used for distinguishing trees in winter. After Blakeslee

can be peeled off with the bark showing them to be outgrowths of the epidermis and cells immediately beneath.

The nature lover who enjoys the beauty of trees in winter will find much of interest in the study of winter leaf buds. Buds, bud scales, and leaf scars are almost as characteristic of a tree species as are its leaves; in fact, the scales are but modified leaves. In northern climates nearly all buds are covered by water-tight scales, which protect the tender twiglet from injury by moisture and from evaporation in the cold dry winds of winter. The sight of magnolia buds wrapped in gray fur overcoats, or the buds of slippery elm wrapped in little brown blankets might lead one to suppose that these coverings are protection from the cold, so prone are we to personify everything, even plants. But plants are not "warm-blooded," so blankets can not keep them warm; they must take the temperature of the surrounding air.

As bud scales enlarge in the spring their derivation from leaves becomes evident. The shellbark hickory and its relatives have large buds with numerous bud scales which show the transition from bud scales to ordinary leaves. In the hickory and horsechestnut the expanding bud scales take on lovely tints of yellow and rose, like petals of a flower. In some plants, such as the sumac, the bud scales do not fall but develop into leaves. In the flowering dogwood the scales of the winter flower buds actually do develop into what are commonly supposed to be the petals of a flower. The real flowers are very small and crowded together in a little head, whereas the four large white "petals" are the expanded bud scales, their little purplish-brown tips being the very scales that covered the bud through the winter. The bud of the tulip tree is a beautiful illustration of the fact that a bud is an undeveloped young branch. There are two outer bud scales which meet all around at their edges and inclose the rest of the bud. After the removal of this outer pair, there can be seen lying against one side a perfect miniature leaf, the blade folded together and bent forward on the petiole. Bud scales grow within bud scales and as each pair is removed a similar but successively smaller leaf will be seen. In the plane tree, or sycamore, there is a single conical bud scale inclosing the remainder of the bud. The scars from the successive bud scales make the lines that encircle the twigs of this tree.

There is a bud in the axil of every leaf, but only a few of them develop in a given season. The others remain dormant. If, however, the leaves are removed from a twig, some of the dormant buds spring into activity and put forth leaves. This is how trees defoliated by gypsy moths or other pests save their lives. The growth of leafy sprouts along the trunks of trees is due to the development of dormant buds, the bases of which have grown each year just enough to keep them near the surface of the bark.

To a certain extent trees are able to regulate their foliage to the amount that is needed. This may be increased by the development of dormant buds, or decreased by shedding the leaves—an alternative resorted to when, because of drought, the evaporation is too great for the amount of soil water available. In the fall in northern regions most trees drop all their leaves and hibernate until the approach of spring. In the Tropics or subtropics, where there is a marked change from wet to dry seasons, many of the trees drop their leaves in the dry season and remain dormant until the rains begin again. Trees that drop their leaves and remain dormant are called deciduous trees; those that retain their foliage throughout the year are called evergreen trees. In northern climates the evergreen trees are chiefly or entirely conifers (pines, spruces, and the like); but in the Tropics a large proportion of the arboreal flora is evergreen. However, even in evergreens the leaves are not everlasting. They have a certain life cycle, are active for a certain length of time and then die. In tropical rain-forests new leaves may be constantly forming as the old ones are constantly dying and being cast off. Our conifers may retain the leaves for one or two years or even longer, according to the species.

The leaves of deciduous trees separate from the twig by a definite line of demarcation, leaving a smooth scar of a shape characteristic for each species of tree. These leaf scars, together with the shape and arrangement of the buds and their characteristic bud scales, and with the color and surface of twigs, enable the keen-eyed nature lover to distinguish the trees of his locality in winter as easily as in summer.

In many herbaceous plants the structure of the vascular system is simpler than in trees, as the stems live only during one growing season; but their life processes are essentially the same. The bundles of conducting tissue in some are isolated and appear as woody strings. In certain translucent stems, like those of the sultana and touch-me-not, one can see the bundles rather distinctly without cutting the tissue. In some herbaceous stems they may be so close together as to form a woody ring, much as in trees. In these there is a cambium layer, and it is this which enables the stem of the sunflower, for example, to increase in diameter.

Leaves

The leaves of trees have two important functions. They regulate the evaporation and they manufacture food for the use of the plant.

The soil water that the roots absorb and the trunk carries upward, evaporates from the leaves, leaving there its mineral contents. Under favorable conditions enormous quantities of water are raised from the soil and passed through the leaves. There is a popular fallacy to the effect that the sap of a tree flows up in the spring and down in the fall. As a matter of fact the flow of the soil water is always up through the young wood and continues throughout the year except when the tree is frozen. There is also at the same time a slow current of elaborated food running downward through the young bark for the use of the roots, and from one part of the plant to another.

The upward flow of sap is controlled partly by the activity of the roots and the amount of water in the soil, partly by the temperature and humidity of the air, and partly by the structure of the leaves. At the most, root pressure can force the water upward only a few feet (exceptionally as much as fifty feet); and the ordinary suction power of a free tube could not raise the water more than about thirty feet, which is the maximum height water can be raised in a single-valved suction pump. Just how the water is drawn or forced up in trees that reach well above these heights is yet a subject of controversy among botanists. Some of the giant sequoias and redwoods, in America, and some of the species of eucalyptus, in Australia, probably grow as tall as 325 feet.

The upward current controlled by evaporation from the surface of the leaves is called the transpiration current. To explain the method by which the leaves accomplish this partial control of the upward flow of sap, we must examine the structure of those organs. The leaves of ordinary deciduous forest trees are flat and have a complex system of branching and interlacing veins and ribs. The main rib, running from base to apex, is the midrib. The ribs are extensions of branches from the vascular system (wood and bark) of the twig. They contain the tissues of

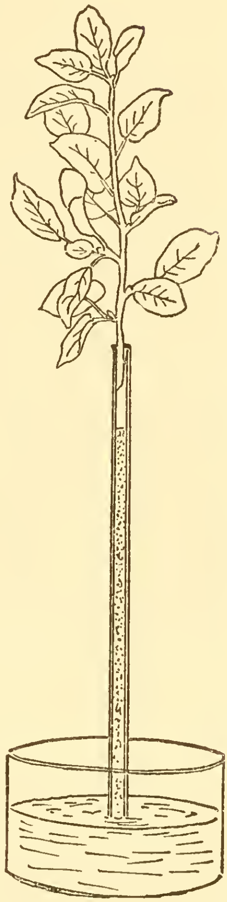


FIG. 10. Branch standing in glass tube in a dish of water draws water up as it evaporates from the leaves. After Holman and Robbins

this vascular system but lack the cambium, hence they have no power of growth after being fully formed. The vascular system of the leaf constitutes its framework, and also serves for the distribution of liquids throughout the leaf.

Both surfaces of the leaf are covered by an epidermis of closely arranged cells with no spaces between them (Fig.

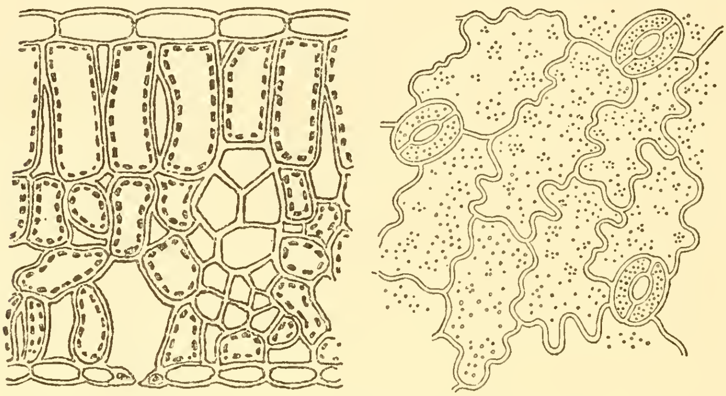


FIG. 11. Left, section through a green leaf; a veinlet is cut through near the center; black dots are chlorophyll grains; right, epidermal cells of a green leaf, showing three breathing pores. After Smith and Kerner

11, left). Between the two surface or epidermal layers there are thin-walled cells loosely arranged and with a varying amount of air space among them. Here and there among the epidermal cells are the breathing pores (called stomata, singular stoma). These highly important and curious structures require some explanation. A breathing pore consists of two guard cells with a small opening between them as shown in Figure 11, right. The two sausage-shaped guard cells are very sensitive to moisture, absorbing it readily and just as readily giving it up. As they absorb moisture they lengthen, but, being fixed at the ends, they are forced apart, and so create a larger space between them. On losing moisture they lie flat against each other, closing the opening. In other words, when the air is moist the pores open; when the air is dry they close. The multitude of stomata, therefore, form an automatic system controlling evaporation. But the stomata are not the only means by which water may escape from the leaf. More or less moisture passes out directly through the epidermis, the amount depending on the thickness and composition of the outer cell wall. In plants of dry climates the epidermis usually contains substances that resist the passage of water, and most plants of arid regions possess some device by which to hinder evaporation and so enable them to endure drought. Such devices in the leaf include, among many others, hairy covering, mucilaginous or resinous juice, and fleshy or woody structure. (See page 79.) However, most of the moisture passes out of the leaves, except in plants of uniformly humid regions, through the breathing pores; hence the loss can be regulated.

It should be noted that the moisture passes from the leaves in the form of vapor, first from the cells into the air spaces of the leaf and then through the pores.

The breathing pores are usually confined to the lower surface of a leaf, or at least are more numerous there. They are present in large numbers but because of their small size occupy only a small proportion of the surface. One author gives the number of stomata per square millimeter (a twenty-fifth of an inch, squared) as follows: Apple, 250 beneath, none above; olive, 625 beneath, none above; pea, 216 beneath, 101 above; corn (maize), 158 beneath, 94 above. The breathing pores can be detected with a good hand lens.

Water can not pass into ordinary plants through the leaves. If plants lose more water than the roots take in, the leaves wilt. Plants that wilt in the daytime may revive at night; not, however, because the leaves have absorbed the dew, but because lessened evaporation in the cooler night air has enabled the roots to catch up in supplying water.

The second important function of the leaves is that of manufacturing food for the plant. This process is probably the most important chemical reaction in the world, for all animal life is dependent directly or indirectly on plants for its food. Only plants can convert the inorganic elements into organic food, and plants can do this only in their green parts, normally the leaves. In the cells of the leaf is the green coloring matter of plants, the chlorophyll, in the form of minute granules visible individually only with a microscope of considerable magnification. Within cells containing chlorophyll the living protoplasm is able, in the sunlight, to produce carbohydrates from carbon dioxide and water. This process is called photosynthesis (combination by means of light), and takes place only in the light—actively in bright sunlight, more slowly in diffused daylight; it stops altogether in darkness.

It is probable that the first carbohydrate to be formed is sugar, but this, being soluble in the cell sap, can not be seen. The first visible product is starch. The chemical reaction by which sugar is produced is expressed in its final form by the equation

$$\underset{\text{carbon dioxide}}{6CO_2} + \underset{\text{water}}{6H_2O} = \underset{\text{sugar}}{C_6H_{12}O_6} + \underset{\text{oxygen}}{6O_2}$$

The carbon dioxide is a component of the air and enters the leaves through the breathing pores. It constitutes but a small portion of the air (by volume three hundredths of one per cent), but is the basic material from which all life is derived. Carbon dioxide is one of the products of combustion. For example, when wood burns the oxygen of the air unites with the carbon of the wood to form carbon dioxide, which disappears in the smoke. This is the reverse of what happens in photosynthesis, for as the equation given above indicates, carbon dioxide is absorbed and oxygen is given off in that process. The release of oxygen during photosynthesis may be observed if water plants are watched closely in the sunlight: the bubbles of oxygen can be seen rising through the water. Furthermore, the intake and the outgo of gas can be tested in a laboratory by placing a plant under a bell jar; and the amounts of carbon dioxide used and of oxygen given off can both be measured.

Sugar, starches, and similar compounds are known chemically as carbohydrates because they contain only carbon, hydrogen, and oxygen, with twice as many hydrogen atoms as there are oxygen atoms. These carbohydrates, the product of photosynthesis, are the food of the plant. From them the plant manufactures all the multitudinous substances that are found in its various tissues, including the protoplasm itself.

Some Details of Plant Chemistry

The mineral elements taken up from the soil by the plant are incorporated in various ways. The important element nitrogen, for example, enters from the soil in the form of nitrates and nitrites. Although nitrogen is plentiful in the air, ordinary plants are unable to make use of it from that source; they must obtain it from the soil. It is interesting to note that the soil in its turn does not acquire this element from the rocks from which soil is formed by disintegration (for they do not usually contain nitrogen), but rather from the air and from the action of soil bacteria. The element is washed out of the air to the earth in the form of oxides of nitrogen, which are formed by the action of lightning flashes in forcing nitrogen into combination with oxygen. The high voltage of the electric flash is sufficient for this purpose.

The action of soil bacteria is the other source of nitrogen in the soil. Certain kinds of plants, especially legumes (members of the family Leguminosae, such as peas, beans, clover, and alfalfa), have small nodules on the roots, within which live bacteria. These bacteria have the power of taking free nitrogen from the air, and converting it into compounds which can be absorbed and utilized by the plant. The discovery of this action of bacteria in root nodules was made only within recent years, though it had long been known that soil upon which clovers and other leguminous plants had been grown was richer than other soils. The age-old practice of crop rotation with clover as one of the crops was based on this empirical knowledge.

While photosynthesis takes place only in the green parts of plants, the digestion of the food and the conversion into protoplasm and other substances used by the plant in its growth may take place in any living cells, even in the same cells that are engaged in photosynthesis. These processes (called metabolism) are essentially the same as the digestive and constructive processes in animals. Animals take in food already elaborated and use it for their own living needs; green plants first manufacture their food from the constituents of the soil and air and then use this food in much the same manner as do animals.

During metabolism, which involves a slow burning or oxidation, oxygen is absorbed and carbon dioxide is given off. This explains why roots die if they are cut off from an air supply, as they could not then obtain the oxygen (see page 9) necessary for the activity of the living root cells. Photosynthesis takes place only in the light, but metabolism takes place in both light and darkness. During photosynthesis the green tissue gives off much more oxygen than it takes in for use in metabolism, and it is in general true that plants give off oxygen in the daytime and carbon dioxide at night. Because of this it has been suggested that plants should not be allowed in sleeping rooms at night, especially not in sick chambers. However, a few plants in a sick room need cause no apprehension, for the amount of carbon dioxide exhaled is so small in proportion to the air of the room, and is so quickly diffused, that it has no appreciable effect on the composition of the air of the room. A person or a lamp or a gas jet would produce much more carbon dioxide in a room than would a few house plants.

The walls of plant cells are impermeable to solids, but allow liquids to pass through by diffusion so that only liquids can be transported from cell to cell, and from one part of the plant to another. Minerals taken up by the roots are in solution in the sap, and food elaborated by the leaves must also be in solution before it can be carried to the roots and other parts of the plant for their nourishment. However, plants store quantities of food in the form of solids because these economize space and resist decomposition better than do liquids. The potato plant, for example, manufactures organic material in the leaves, a part of which accumulates in the form of starch. This starch is converted into a soluble form—mostly into one of the sugars—and is transported to the tubers underground, where the sugar is again converted into starch for storage. Later, when the potato tuber "sprouts," the starch is again converted into sugar so that it may pass into the young shoot. Seeds, such as corn and wheat, are storehouses for starch until the time of germination, when the starch is converted into sugar to pass into the seedling. Carbohydrates are usually stored in the form of starch. Proteids (nitrogen-containing compounds) are stored in other forms; the so-called aleurone grains of the outer layer of the grains of cereals are one of these.

How are the liquids converted into solids and the solids again converted into liquids? This process takes place within the plant cells but can be made to take place artifically in the laboratory. While the exact chemical changes can not be explained in all their detail, it is known that a substance is present which brings about the conversion without losing its own identity or decreasing in amount in the process. Such a substance is called an enzyme. There is a particular enzyme for each kind of conversion.

Specialized Plants

A few flowering plants (such as the pondweeds) live entirely submerged in the water of ponds and streams. These plants absorb water directly through the leaves as there can be no evaporation to cause an upward current from the roots.

Certain other flowering plants are parasites. The mistletoe grows upon trees, driving a rootlike process

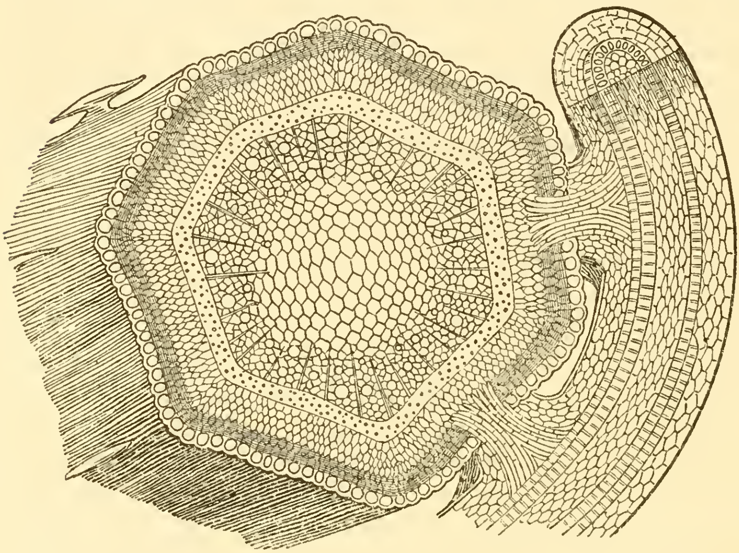


Fig. 12. Dodder parasitic on a hop vine. Cross section shows protuberances from the dodder penetrating stem of the hop. After Kerner

into the wood of the host plant. It absorbs sap from the host but is not entirely parasitic as it has green leaves of its own and can therefore manufacture food for itself. The dodder or love vine, on the other hand, is completely parasitic (Fig. 12). This curious plant is a salmon-colored twining vine which grows upon weeds and shrubs in the summer and fall, often covering them with a tangle of stringlike stems. Such plants absorb all their nourishment from the host plant, to which they attach themselves by little protuberances that penetrate the stem. Complete parasites, of course, need no chlorophyll. Certain flowering plants, such as the beechdrops and cancer-root, are root parasites, attaching themselves to the roots of their host; and certain others of similar aspect are saprophytes, growing on decaying vegetable matter.

Besides the flowering plants to which we have given attention in preceding paragraphs, there is a world of more simply organized plants (thallophytes, see page 87), ranging from the ferns—the most complex—through mosses, liverworts, lichens, algae, and fungi, to the bacteria—the simplest of all. Those who have had no botanical training may not have recognized the simpler organisms as plants. It may be stated that the fundamental life processes are the same in these as in the higher plants. If the plant lives entirely submerged in water, it absorbs nourishment directly from the surrounding medium. If it is entirely parasitic (as are rusts, smuts, and their like), it absorbs its nourishment from its host, and, having no need to manufacture food for itself, it will have no chlorophyll. If it is saprophytic (living on decayed organic matter) like mushrooms, it will also lack chlorophyll. These plants will be more fully described in Chapter VI.

CHAPTER II

HOW PLANTS SEEK THE LIGHT

Green plants must have light or they will die, and the struggle for existence among them is in part a struggle for light. This competition is particularly severe in dense forests where tall trunks support a canopy of leaves. The lower branches die as the shade increases, leaving tall pillars with branches only at the top. In tropical rain-forests, the trees of average height provide a canopy with here and there a giant overtopping it. Below the canopy are two or three other layers of vegetation, getting along with less and less light. Finally, the floor of the forest may have, because of the diminished light, only a scant covering.

In general, leaves and stems tend to grow toward and roots tend to grow away from the light. All growers of house plants are familiar with the curving of their plants toward the greatest source of light, a phenomenon which is mechanically explained by the fact that the side of a stem or petiole away from the light grows faster than the side toward the light. The effect of light upon growth is called heliotropism. It is discussed in detail in Part VII of this volume.

A curious and efficient disposition of leaves in relation to light is shown in the basal rosettes of many herbaceous perennials or biennials, for example, the common mullein, the shepherd's purse, and the dandelion. The leaves lie flat on the ground or are more or less ascending. The peculiarity of rosettes is that the younger and shorter leaves lie over the spaces between the leaves below them so

PLATE 7

Wisteria climbing on the porch of a house in Washington.
Photograph by Hitchcock

A cultivated banyan tree at Honolulu with air roots sent down from the branches. The roots have been trimmed. Photograph by Hitchcock that a maximum use is made of the light. Arrangements of leaves by which they fit into a pattern to utilize the light—whether it be in basal rosettes, on the twigs, or on any other part of a plant—are called leaf mosaics (Fig. 13).

Climbing plants reach the light at the expense of their neighbors. Instead of building a strong trunk or stem

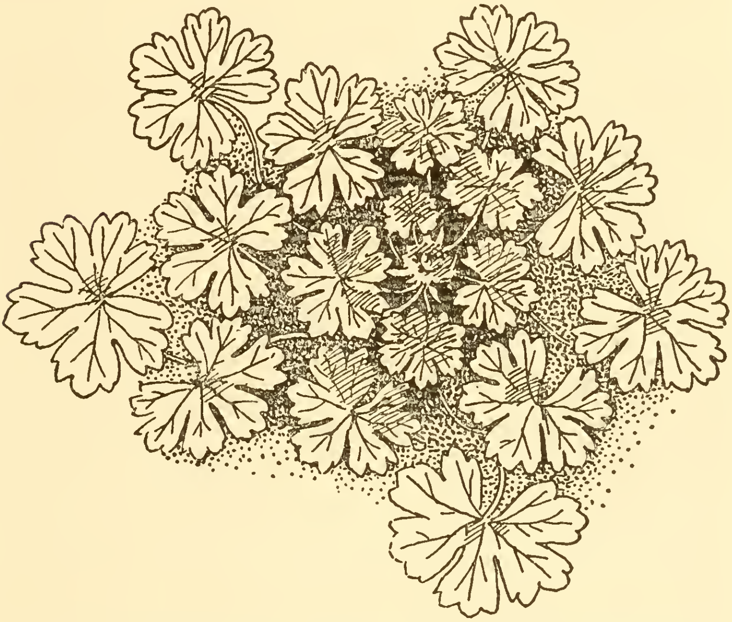


FIG. 13. Leaf mosaic. The leaves are so arranged that they get the greatest amount of light and do not shut off light from each other. After Kerner

themselves, they utilize the strength of the plants on which they climb. Woody vines, or lianas, are numerous in tropical forests, often binding trees together in impenetrable tangles. In northern regions lianas, though few, include the grape, Virginia creeper, bittersweet, and others. Vines may not be able to get a start beneath the trees in a dense forest. They generally begin their growth when the supporting plants are young and grow along with them except along the edge of a forest or clearing. In fact a dense tropical forest is in a static condition (a climax vegetation, according to the ecologist). There can be no new growth of trees or woody vines until an opening is made by a hurricane, the fall of an old giant, or by some other accident.

Plants climb in four ways: By clambering; by means of rootlets; by twining; by means of tendrils.

Clambering bushes stretch up, over, and through their support, depending for their rise on rapidity of growth. Some kinds of blackberries and roses climb in this manner. These plants are aided in clambering by the retrorse prickles which prevent the stems from slipping back.

Plants climbing by rootlets represent a stage in which definite organs for climbing are produced. In nature such plants use as supports the trunks of trees or cliffs but under artificial conditions they climb on walls of wood, brick, or stone. The rootlets are found in large numbers along the side of the stem next to the support, familiar examples being the English ivy (Fig. 14, 1) and the poison ivy. The little roots break through the bark of the stem at irregular places, a fact which proves them to be roots and not stems. Roots such as these, which are not a part of the primary root system but break through the epidermis at some other place, are called adventitious roots (Plate 8). In vines that climb in this way the rootlets all turn toward the support and the leaves turn toward the light.

In twining plants the main stem is able to swing in a circle near its upper end (Fig. 14, 2). It swings freely until it strikes a support, then winds around this in a spiral. The mechanism by which twining is accomplished is somewhat complicated. An area on one side of the stem grows faster than the other side and the growing area at the same time advances, but just what controls this unequal growth is not known. The slow sweep of the free end is

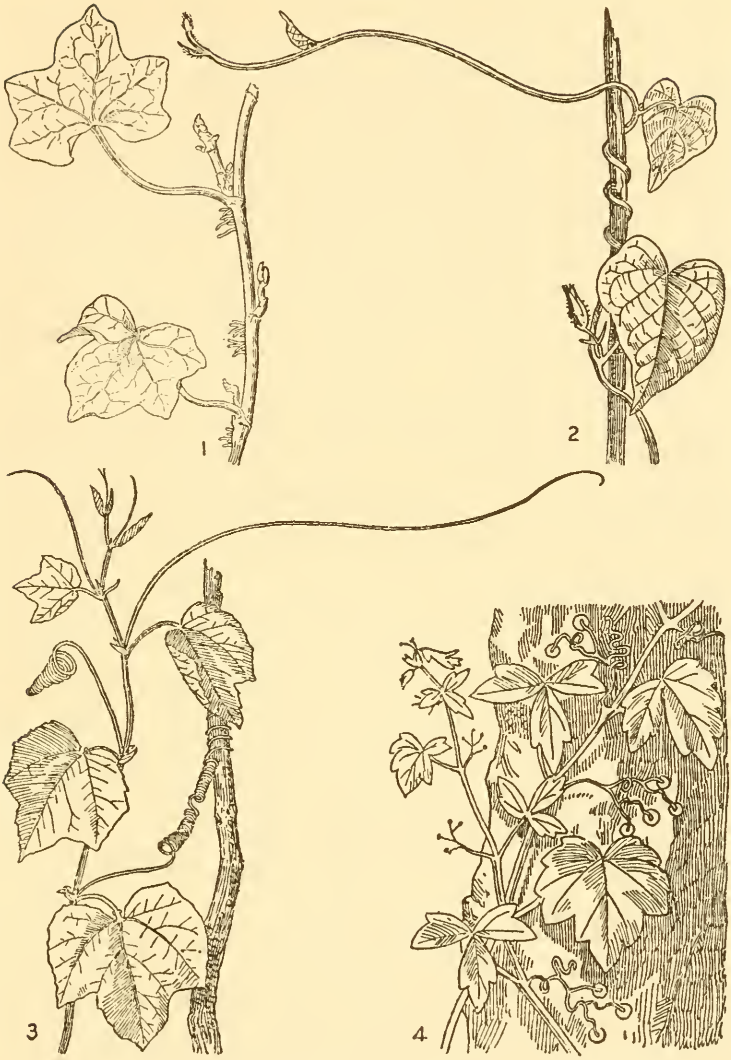


FIG. 14. Climbing mechanisms. 1, English ivy, showing adventitious climbing roots; 2, morning-glory, climbing by twining; 3, passion flower, bearing twining tendrils; 4, Boston vine, climbing by tendrils that end in clinging disks. After Gray and Kerner

halted when a support is reached, and the contact of the support stimulates the spiral growth to suit the support. The twining of stems always takes place in the same direction in the same species, though some species turn to the right and some to the left. Moreover, the twining is independent of light or other surrounding conditions. Delicate climbers like the morning-glory are unable to twine around a support of too great a diameter. They can twine around a thread but not around a post of even moderate size. If the twining tip encounters a support too large to encircle, it slides up and passes the support on the nearer side.

The fourth category of climbing plants possesses highly specialized twining organs, the tendrils, which may be modified forms of stems, leaves, or parts of leaves. The tendril of the grape is a specialized stem—the continuation of the main axis. It is pushed into a lateral position by the axillary bud, which then takes its place as the main stem. The tendril is opposite a leaf but has no leaf below it, and the branches of the tendril come from the axils of minute bracts which represent leaves. All these facts show that the grape tendril is a modified stem and not a leaf. In the garden pea, on the other hand, it is the terminal portion of the compound leaf, including the end of the axis of the leaf and the uppermost pair of leaflets, which is developed into a tendril. In the virgin's-bower (*Clematis*) the petioles of the leaves twine in one or two spirals. The greenbrier (*Smilax*) develops a pair of tendrils near the base of the leaf.

The movements of tendrils and their branches are the same as the movements of twining stems. The tips swing in a circle and twine in a spiral around a small support. When the tendril of the grape, for example, reaches a certain age it rather suddenly contracts into a spiral. If the tendril does not succeed in reaching a support before this contraction takes place, it forms a single spiral and is of little use to the plant subsequently. If the end reaches a support and twines around it, a double spiral is formed between the grape stem and the support of the tendril, half of the spiral twining one way and half in the opposite direction. The double spiral is the result of purely mechanical conditions. If a rubber band having one end fixed and the other free is twisted by the fingers the free end revolves. If both ends are fixed and it is twisted in the middle, it forms a double spiral as does the tendril. The coil of a tendril below the point of support (Fig. 14, 3) draws the main stem closer to its support and also serves as a spring to take up any motion of the plant caused by wind or other forces.

Certain tendrils produce disks at their extremities by which they can attach themselves to flat supports (Fig. 14, 4). The Virginia creeper climbs in this way as does the Japanese creeper or Boston vine (*Ampelopsis Veitchei*) so common on the walls of houses in the eastern cities of the United States.

CHAPTER III

HOW PLANTS REPRODUCE

So far we have considered the plant as it lives from day to day. In time it must succumb either to accident or to old age, though the duration of the individual body varies widely, depending on a number of conditions. As in animals, nature has provided for a continuation of the species by means of reproduction. The simplest plants—the bacteria and one-celled algae, for example—reproduce by division of one cell into two, each cell growing to full size, when it in its turn divides, and so on. In some bacteria this division takes place as often as once in twenty minutes. Such division is similar to growth, in which cells divide but remain attached. The active part of yeast is a minute one-celled plant in which the cells are formed by budding, that is, by a bulging out of one side of the cell until the new plant is as large as the old. The single cell soon forms a colony of loosely aggregated cells, which are easily separated. In a filamentous alga there may be a single row of cells. As the cells divide they remain attached, end to end, and the filament increases in length. In ordinary higher plants cell division is the basis of growth, but it takes place in two or three directions, forming a solid tissue.

Commonly, however, even in the lower plants there are special bodies or organs that reproduce the plant. In the lower plants these bodies are called spores; in the higher, seeds.

The phenomenon of sexuality in animals is, of course, well known to all. The individual animal is male or female, and through the fertilization of the female by the male a new individual, the offspring, is formed. The process of fertilization (the union of two bodies of protoplasm to form a single body) in plants is fundamentally the same as in animals. The simplest kind of fertilization is illustrated by certain filamentous algae. In these the walls of the cells of two adjacent filaments bulge out to produce tubes which meet and form a continuous passage. Through this the protoplasmic contents of one cell pass into the other and the united contents form a ball with a thick cell wall. This new body is a spore, often called a resting spore, because when the filament disintegrates owing to freezing or drying up of the water of the pond in which it grew, the spore sinks to the bottom and remains dormant until the return of favorable conditions when it germinates, thus forming a new individual.

In the alga we have been discussing there appears to be no difference between the two cells that unite. But physiologically the cell which receives the protoplasm is the female cell and the one which gives, or fertilizes, is the male cell. In all except the lowest forms of life there is a distinct difference in appearance between the cells of the two sexes. In some algae the male cell is able to swim to the female cell, probably attracted by some chemical emanating from the latter. The methods of fertilization observed in the fungi and algae are of great variety and of absorbing interest.

Besides the sexually formed spores, the fungi and algae often produce spores without fertilization, that is, asexually. Asexual spores often serve for the immediate and quick spread of the species, while the sexually formed spores are more likely to be resistant bodies that carry the species through unfavorable seasons or conditions.

The spores of many fungi, such as bread mold, are familiar to every one. Bread mold produces a tangled mass of very fine threads (the mycelium) which is the body of the fungus (Fig. 15). In time small black dots can be seen scattered over the mass. These dots are little cases full of minute spores so light that they are wafted through the air to alight on other pieces of bread, where they germinate. The common blue mold of fruits, bread, and vegetables forms minute tufts of spores; the parts of wheat rust that are visible to the naked eye on the leaves and stems of grain are the spores—spots or lines of red or black; the ugly mass of black powder typical of corn smut is made up of countless myriads of spores; finally, mushrooms, toadstools, puffballs, bracket fungi, and so on, are all spore holders—the visible parts of fungi whose filaments penetrate decaying wood and rich soil, this part being known as the mycelium (see page 40).

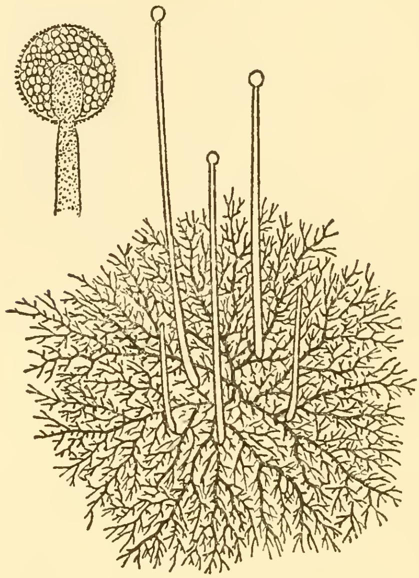


FIG. 15. A mold, showing the branching of the filaments; the upright organs bear minute spore cases. The small figure shows a spore case of bread mold containing spores; much enlarged. After Goebel

The spores of mosses are borne in the little capsules at the summit of the stems, whereas the spores of ferns are found for the most part in spots or lines on the backs of the leaves or fronds (Plate 17).

The reproductive bodies of flowering plants are the seeds, which are infant plants all ready to grow into individuals like their parents. If an apple seed or a bean or a peanut is opened, it will be seen to consist of two

PLATE 9

The floral parts of a lily (*Lilium washingtonianum*). The six colored leaves include three outer sepals and three inner petals. Within are six stamens each bearing an anther. In the center is the pistil, of which the style, bearing the stigma, protrudes beyond the stamens; the ovary is hidden in the base of the flower. By F. A. Walpole

thick little leaves with a bud between them. Here is the whole plant in miniature; for the bud, called the plumule, is a little stem, which develops leaves above and roots below. All seeds are produced by flowers. Incidentally, though acorns and walnuts are known to be seeds, it may surprise some to learn that oaks and walnut trees have flowers.

The flower consists of a highly specialized branch with leaves, and is wholly consecrated to the service of the next generation. A large, relatively simple flower like the lily will serve to illustrate the parts (Plate 9). There is on the outside a showy set of six parts in two series of three each. The outer series is the calyx, made up of sepals; the inner series is the corolla, made up of petals. Within these parts lie the six stamens, each consisting of a slender stalk (the filament) on which rests the two-celled anther, which in turn incloses a yellow powder, the pollen. In the center of the flower is the pistil, consisting of the enlarged base (the ovary), a rather slender stalk (the style) and a broadened tip (the stigma). Within the ovary are the little ovules which later become seeds. In the flowers of other plants the shape, size, and number of the parts may show great variation from those of the lily. The rose, for example, has a green calyx, a white, red, or yellow corolla, and numerous stamens and pistils.

The process of fertilization in flowers merits description. When the anther is mature it breaks open, releasing the pollen which consists of a fine, usually yellow, powder, the grains of which are barely visible to the naked eye. By various means (to be described later), the pollen is transferred to the stigma. When the stigma is mature—that is, ready to receive pollen—the surface is usually sticky or hairy so that the grains of pollen adhere to it. The grains now germinate by sending out a slender tube much like a root hair. This pollen tube grows down into the tissue of the stigma, through the style and into the ovary. The tube seems to be led through the tissue by the attractive force of a chemical in the cells through which it passes. Within each ovule is a single cell—the egg cell—whose function is to be fertilized, that is, to receive the pollen. The pollen tube finally grows through a small opening in the ovule and reaches the egg cell. The contents of the pollen tube, which have kept close to the growing end, fuse with the contents of the egg cell. This process is fertilization. One pollen tube fertilizes one ovule and only one. If fertilization of all the ovules is to take place, there must be as many pollen tubes as there are ovules.

After fertilization the egg cell divides and subdivides, that is, commences to grow, and finally forms a small plant. Thus the ovule is converted into a seed but remains within the pistil which meantime has undergone change and has become the fruit. In most seeds there is a cessation of growth after a certain period, and then the seed and fruit are said to be ripe. The seed actually consists of the small plant (the embryo) and, either within the embryo or surrounding it, a quantity of nourishment to support it during its further growth (germination). The whole is surrounded by the seed coat. The embryo is plainly visible in some seeds, such as those of the morning-glory and the maple, and the crumpled seed leaves may be green and all ready to start growth anew. In other seeds the embryo is a mere speck embedded in the nourishment. Thus the grain of corn shows a small straight embryo (germ) at one side of the lower end. In the peanut the embryo occupies all the space within the seed, and consists of the two large seed leaves (cotyledons), lying face to face, the small stem from the end of which in germination the root grows, and a pair of small leaves (the plumule) from between which the shoot grows.

The major part of the nourishment stored in the seed is commonly starch, as in our grains, beans, and peas. Oil is stored in the castor bean and in all oily seeds. There is some oil in the corn kernel. Proteids (compounds containing nitrogen) are also present, especially in the bean and its allies. The gluten of wheat is a proteid. Many seed coats are very hard and resistant; for example, in the honey-locust, in various sea beans that are washed up on southern shores, and even in the apple. This hard seed coat prevents the loss of water by the seed and also prevents the premature absorption of water.

Pistils with one ovule form one-seeded fruits that may have the aspect of a seed. The sunflower and all the other Compositae—the family to which it belongs—have so-called "seeds," which are in reality one-seeded fruits. Where there is any difficulty in distinguishing between fruit and seed, opening the questionable object provides a simple way out. If it is a fruit, the seed will be found loose on the inside, wrapped in its own thin coat; if a seed, the seed coat will prove to be grown tight to the contents. This distinction breaks down in grains (wheat, maize, and the like), because in them the seed is grown fast to the wall of the fruit.

Pollination

The methods by which the pollen of the flower reaches the stigma are varied and curious and not always as simple as one might suppose. In some flowers the anthers are in close proximity to the stigma and the pollen comes in immediate contact with the stigma of the same flower. Such flowers are said to be self-pollinated. If one takes the trouble to examine the flowers in his own vicinity he will notice at once that commonly there is no such proximity of anther and stigma. In fact, most flowers are so constructed that self-pollination is impossible or difficult or, at least, less likely than cross-pollination in which the pollen of one flower fertilizes the stigma of another. Charles Darwin noticed this condition and asked himself why it existed. "Why does nature so commonly appear to abhor self-pollination?" He inaugurated a series of experiments to find out the effect of self-pollination as compared with cross-pollination, using several species of plants in parallel tests—half the plants of each species being self-pollinated by hand, the other half being cross-pollinated. In nearly all the tests the cross-pollinated plants produced more and better seeds. Furthermore, the plants raised from cross-pollinated seed were usually more vigorous than those from self-pollinated seed.

On the whole, cross-pollination, that is, having two distinct individuals as parents, is an advantage to the offspring. Only a few of the numerous and curious devices by which cross-pollination is brought about can be referred to here, but the reader will find it exceedingly interesting to examine the flowers of his vicinity and determine the methods used.

The pollen of a few flowers is transported by water, but wind and insects (sometimes humming birds), are the transporting agencies employed by most flowers. The tape grass furnishes a striking example of the use of water currents to effect pollination (Fig. 16). The plants are diecious. The staminate flower-buds, before expanding, break away from their pedicels and float on the surface; there they expand and shed their pollen around the pistillate flowers which are sent to the surface at the same time. After pollination the stalk of the pistillate flower coils in a spiral, drawing the flower under water to ripen its seeds.

Plants adapted to wind pollination produce vast quantities of dry pollen—thousands of times as many pollen grains as there are ovules to be fertilized; for wind is a wasteful distributor. Wind-pollinated flowers are usually inconspicuous and in many trees and shrubs they make their appearance before the leaves which would interfere with the flying pollen. The elms, ashes, and some of the maples, the spicebush, alder, and hazelnut bloom while the trees are still bare of leaves. In many of the wind-pollinated plants, especially trees and shrubs the flowers,

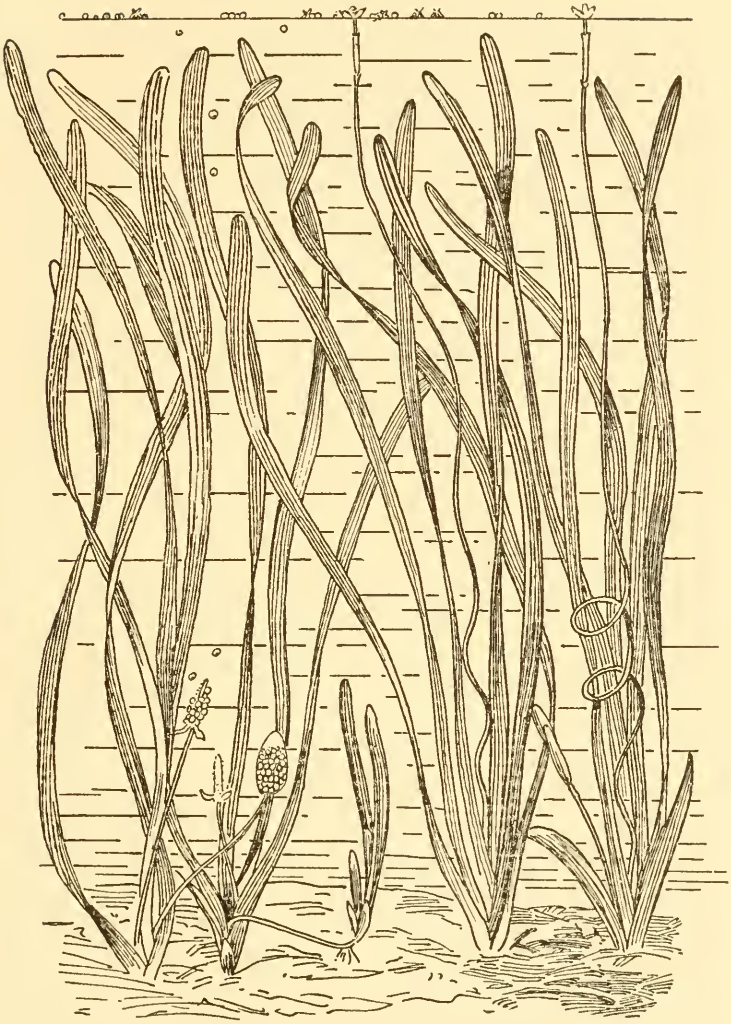


FIG. 16. Pollination of the tape grass (*Vallisneria*). The submerged plant pushes its pistillate flowers to the surface. The staminate flowers (in bud) are shed in the water but rise to the surface, open, and float about, touching the stigmas. After Kerner

are unisexual; that is, the stamens and pistils are borne in separate flowers, either on the same plant—as in the sedges (*Carex*), maize, oaks, and hickories—or on separate plants—as in the willows and poplars. In the oaks, hickories, birches, and alders the staminate flowers are numerous on a flexible axis, forming catkins from which the pollen is easily shaken out by the wind; but they grow below the few pistillate flowers, which are set close to the twigs, so the pollen will not fall on these flowers.

Even when flowers are perfect—that is, have both stamens and pistils—as in the lily, there is usually some structure or characteristic which facilitates cross-pollination. There are two general characteristics of this nature found in both wind- and insect-pollinated plants. The first is described as the "prepotency of foreign pollen," which means that when foreign pollen and pollen from the same plant fall upon a given stigma, the foreign pollen "takes" quicker—that is, grows faster down through the style of the ovule. The other characteristic is that in a given flower the anthers do not mature at the same time that the stigma is receptive. If the stigma is receptive first it must be fertilized from another flower. If the anthers mature first most of the pollen is removed from them before the stigma matures.

Plants adapted to insect pollination produce far less pollen than do those adapted to wind pollination, and many pollen grains are sticky—in some plants, such as orchids and milkweeds, so sticky that they adhere in masses. The most highly specialized devices to bring about cross-fertilization are to be found in insect-pollinated flowers.

Such flowers usually have showy corollas, for example, the roses, petunias, and morning-glories; or if the flowers are small they are massed in showy heads, as in red clover, yarrow, or wild carrot; or if the flowers themselves are inconspicuous they may be surrounded by showy bracts, as in the flowering dogwoods, snow-on-the-mountain, and poinsettia. The calla or calla lily is a striking example of inconspicuous flowers in a showy bract, for the "lily" is a spathe surrounding the minute true flowers, which are borne on a club-shaped axis. This showiness is thought to be a guide to insects. But whether it is or not, what really draws insects to flowers is either pollen or nectar. Also, many flowers have an odor which attracts insects. This odor may be agreeable (to the nostrils of man) and attractive to moths, butterflies, and some other insects, or, as in the carrion-flower and skunk-cabbage, it may be disagreeable to man and attractive to flies and beetles.

In flowers adapted to insect fertilization, the stamens and stigmas are so arranged that when the insects visit the blossoms for nectar the anthers come in contact with a certain part of the insect's body, dusting it with pollen which is scraped off on the stigma of the next flower visited before the anthers are reached.

As there are multitudes of insects and multitudes of flowers the devices which result in cross-pollination are almost infinite. The common sage (Fig. 17) is adapted to pollination by bumblebees. On entering a flower for nectar the insect hits the lower part of the stamen lever and brings the anther down on her back. At this time the stigma is not mature and remains in the upper lobe of the flower. Later the stigma opens and curves down to a position where it will rub against a visiting bee and so pick up pollen from her back.

The pollination of the lady's-slipper, or moccasin flower (*Cypripedium acaule*), is shown in Figure 18. When a bumblebee visits the flower she falls into the slipper, as indicated in the first drawing. She sips the nectar among the hairs near the stigma and finally makes her escape in the only way possible—that is, through the opening at the base of the flower. On her way she is forced to pass first the stigma, which scrapes pollen from her back, and then the anthers, which rub against her back and give her a new supply of pollen for the next flower.

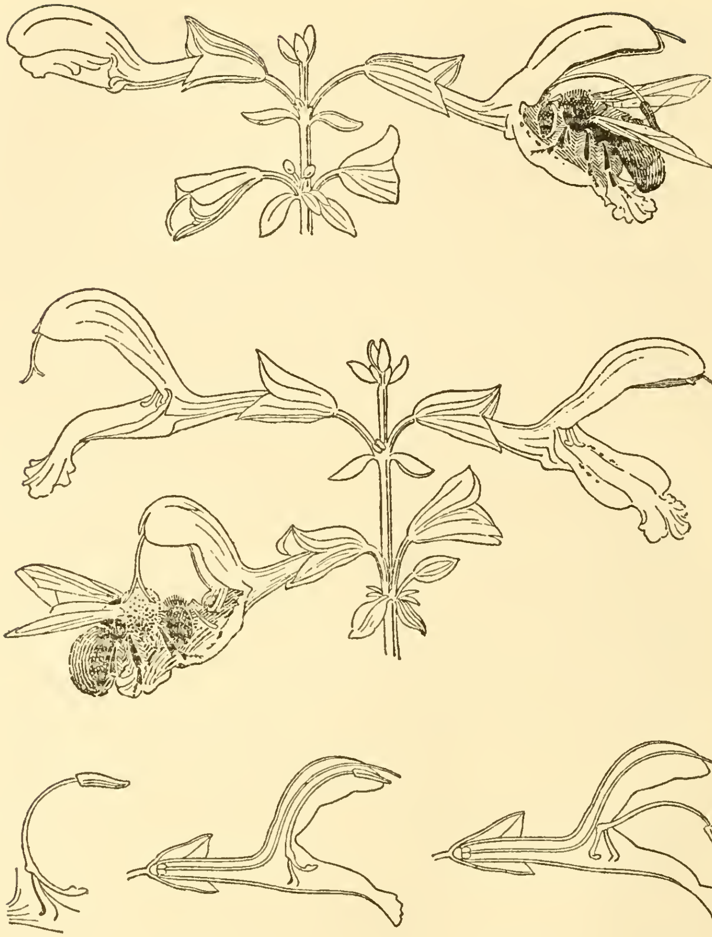


Fig. 17. Pollination of the sage by a bumblebee. Upper, bumblebee entering a flower, the stigma of which (above) is immature, and striking the lower branch of the anther, which brings the upper branch down on its back; center, bee entering another flower, in which the mature stigma (the lobes spread apart) scrapes off pollen from the bee's back (this flower has already shed its pollen); below, diagrams showing the structure of the stamen. After Gibson

PLATE 10

Flowers of night-blooming cereus, a climbing cactus. Each flower has many sepals, petals, and stamens and one pistil with several stigmas. Photograph by Hitchcock

PLATE 11

Yucca growing on Mount Wilson, California. The flowers are pollinated by the yucca moth. Courtesy of Ferdinand Ellerman

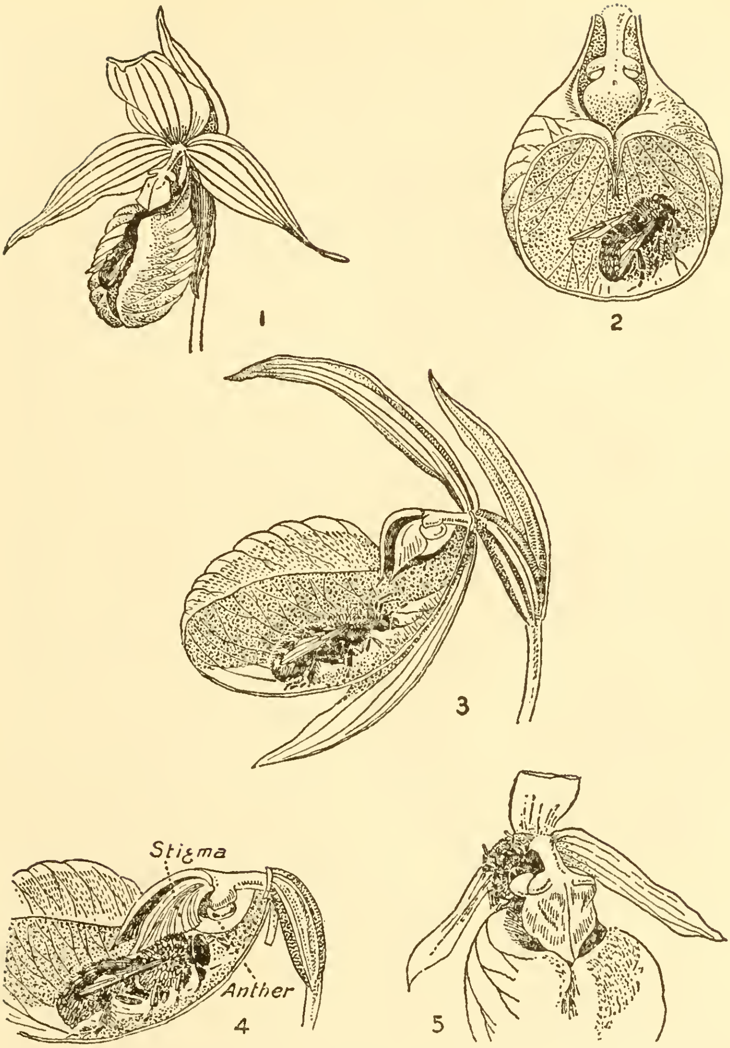


FIG. 18. Pollination of the lady's-slipper. 1, bee entering the sac; 2–3, in the sac, feeding on the nectar; 4, rubbing its back (covered with pollen from another flower) against the stigma; 5, getting a new supply of pollen from the anther on its way out. After Gibson

The pollination of the yucca (Fig. 19) is one of the most remarkable in the vegetable kingdom, because it involves the exercise by the insect of an instinct that appears like reason. The yucca flower is built on the plan of the lilies—it is bell-shaped and has six divisions of the perianth, six stamens, and a stigma with three short branches. The yucca moth is rather small, scarcely as long as the ovary of the flower in which she lays her eggs. The grubs, or larvae, of the moth feed on the ripening seeds. The flowers can not be pollinated except by the aid of this moth. If the moths are kept out by a covering of gauze, no seeds develop; nor do they if the yucca is grown in gardens where the moth does not occur. The moth lays her eggs in no other plant. Hence the plant is dependent on the moth for its pollination and the formation of seed, and the moth is dependent on the plant for nourishment for her larvae—an absolute interdependence. But the most wonderful part of the relation is yet to be told. Before laying her eggs, the moth visits a flower and gathers a mass of pollen which she holds in a ball under her

Fig. 19. Pollination of the yucca. One of the flowers is cut open to show the moth planting pollen in the depression between the stigmas. After Kerner

"chin," that is, below her head. She then flies to another flower where she lays her eggs in the ovary. Immediately after this she crawls up to the stigma and, taking some of the pollen from its store, places it in the forks of the three branches of the stigma and rams it down tight. She may repeat this process more than once. Ordinarily only about a third of the seeds in a capsule are destroyed by the larvae. Of course, if all were destroyed the moth would exterminate the yucca and defeat her own ends.

There are many cases of interdependence between certain species of plants and certain insects, the flower having become modified to such an extent that only one species of insect can reach the nectary and in doing so pollinate the stigma. As in such combinations, one species of insect has a monopoly on one species of plant, the insect depends on the plant for its food—that is, nectar. In such situations, common among orchids, the plant and the insect must inhabit the same region. There is reason to believe that there have been instances where the extinction of the insect has brought about the extinction of the plant, or the reverse.

There are all gradations between such highly specialized flowers adapted to one kind of insect and simple open flowers, like those of the buttercup, where many kinds of insects can get nectar. The flowers of a large number of plant species are able to use their own pollen in self-pollination in case cross-pollination fails. Thus the wheat flower is open for cross-pollination only about fifteen minutes, but will self-pollinate after the flower closes if cross-pollination has failed.

The plans of nature are sometimes circumvented; or possibly we might say that two plans sometimes conflict. Certain large tubular or bell-shaped flowers, like those of the trumpet creeper (*Tecoma*), secrete considerable nectar at the base of the corolla. Such flowers are usually pollinated by long-tongued moths or butterflies or by humming birds. Now the carpenter bee has learned to bite through the corolla near its base and pilfer the nectar, and the holes sometimes seen in these long corollas bear evidence of the work of these insect thieves.

The various methods of pollination and the devices to secure cross-fertilization have an important bearing on horticulture. For instance, the grower of strawberries knows that certain varieties of this fruit are pistillate only. Although the wild strawberries have perfect flowers, there are several cultivated varieties in which the stamens are reduced in number or are abortive. The planting of such varieties by themselves would be futile because the flowers would not be pollinated, and so no fruit would be produced. The grower, therefore, plants at intervals rows of some other variety that produces plenty of pollen. Insects—most of them honey bees—transport the pollen.

Growers of orchard fruits have found it to their advantage to have colonies of honey bees nearby, especially when the orchards are large, for otherwise there might not be a sufficient number of insects to pollinate the flowers.

Some forty years ago the failure of a certain orchard to bear fruit brought out an interesting fact not previously known. A grower decided to set out a commercial orchard of Bartlett pears on a large scale. When the orchard came to maturity he was much disappointed to find that, though the trees blossomed freely, they produced only a few fruits. Incidentally, the mystery was increased by the fact that what fruit was produced was confined to the trees along the edges of the orchard. An investigator from the United States Department of Agriculture studied the case and found that the Bartlett pear was self-sterile, that is, the flowers could not be fertilized by their own pollen. As all Bartlett pear trees have been produced by grafts from one original tree they are essentially parts of a single individual. Consequently, if one tree was self-sterile with its own pollen it would likewise be sterile with the pollen of the other trees of the same variety.

The few fruits produced at the edges of the orchard were the result of chance fertilization by pollen of other pear varieties carried from a distance by bees. The problem was solved by grafting other varieties of pears at intervals in the orchard and by keeping bees to transport the pollen. It has since been found that several other varieties, not only of pears but of other fruits, including the Winesap and Delicious apples, the Burbank and Wildgoose plums, the Napoleon cherry, and the J. H. Hale peach, are self-sterile or too nearly so to be grown profitably without planting other varieties nearby to supply pollen for cross-fertilization.

Horticulturists have learned to use cross-fertilization to produce new varieties of plants artificially. Strictly speaking, fertilization between two varieties results in a cross; and fertilization between two distinct species results in a hybrid. The terms are not always carefully distinguished. The mechanical part of the process of producing a cross or a hybrid necessitates transfer of the pollen by hand from the anthers of one plant to the stigmas of another. Meantime the stigma to be fertilized must be protected against pollination from its own flower or from any outside source. Usually the stamens are removed before maturity from the flower to be fertilized, and the emasculated flower is protected by bags or by some other means from being reached by foreign pollen. In recent years large numbers of desirable new varieties of orchids, irises, narcissuses, roses, orchard and small fruits, grains, and many other plants useful to man have been originated by crossing and hybridization. It should be understood, however, that not all crosses are better than the parents. Only a few individuals out of the large number produced by numerous trials will show superior characters and be worthy of further attention.

When a cross combining the desired characters of the two parents is obtained it is propagated by vegetative means, if this is possible, thus insuring the uniformity (under like conditions) of all the plants. Annuals, of course, may usually be propagated only through the seed. It is then necessary to examine the progeny and select for further propagation only those that show the favorable characters of the parent. Growers of annual plants for commercial purposes are constantly selecting to keep the variety pure and in accordance with the type desired.

The seed is a device for spreading a species through time and space; it is a living plant in a dormant or resting state during which there is time for its dissemination. A few plants, such as the common mangrove of tropical seashores, have no such period of rest. In them the embryo continues to grow while the seed is attached to the tree. It throws out a thick heavy root, the young plant falls from the tree and strikes root in the mud. In plants whose seeds are dormant for a time, the length of the period of rest differs greatly between species. In the soft or silver maple (*Acer saccharinum*) the seeds germinate within a few days after ripening. But even in this short time their large wings may carry them a long distance with the aid of the spring gales. The seeds of the sugar maple (*A. saccharum*), on the other hand, do not germinate until autumn. Seeds of the wildrice (*Zizania*) will not germinate if they once become dry. Some seeds require a long period of rest and can not be forced to germinate before their time; some require a period of low temperature treatment. A knowledge of the peculiarities of seeds in this respect is necessary to the plant grower. Some seeds retain their vitality for only a single season and others retain it for many years. Many experiments have been tried to test the viability of various kinds of seeds according to age, and one author found that a few seeds of three species of legumes would germinate eighty years after the time of their production. Judging from the rate at which long-lived seeds lose their viability, it is thought that the extreme probable limit of viability of any kind of seed is between 150 and 250 years. Stories of the germination of seeds taken from ancient tombs may be classed as myths or as based upon the trickery of guides or workmen.

Dispersal of Seeds

The numerous and curious devices by which cross-fertilization is secured are matched in interest by the

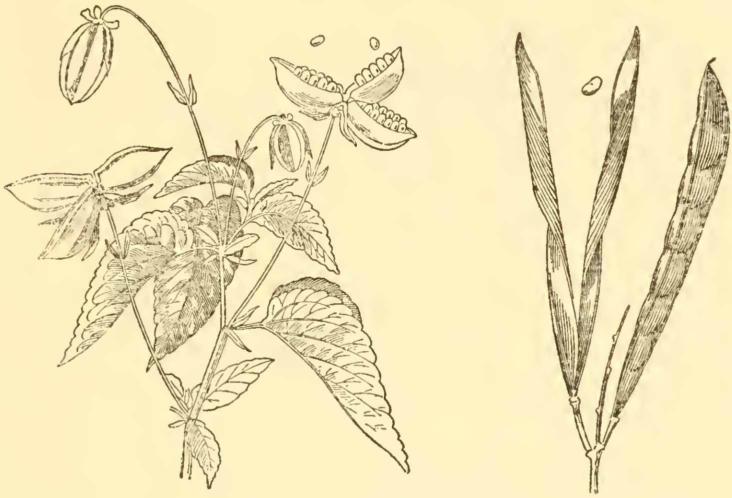


Fig. 20. Contrivances for throwing seed. Left, violet pods, whose sudden opening pinches out the seeds; right, bean pods, in which sudden coiling of the two halves scatters the seeds. After Kerner

adaptations which effect the dispersal of seeds. Seeds are scattered by four principal means: by contrivances which shoot the seed to a distance, by wind, by water, and by animals. In propulsive contrivances a tension is set up in the ripening pod which finally produces an explosion, scattering the seed. The snapweed or touch-me-not is an amusing example. Violet pods suddenly and violently split into three parts throwing the seed to a distance of several feet (Fig. 20). The capsule of witch-hazel pinches out its two black seeds with such force as to send them twenty feet or more away. Many bean pods open by a sudden coiling of the two halves. The tropical sandbox tree has large woody pods, which explode with great violence, throwing out hard lens-shaped seeds half an inch in diameter, thereby endangering passers-by.

Just as many flowers rely on the wind to transport their pollen to receptive stigmas, so many plants depend on the same ubiquitous agency to scatter their seeds. Small seeds are carried long distances by the wind without special adaptations. In northern countries the migrations of late-maturing seeds are often aided by crust on the surface of snow over which they are borne with surprising velocity. In open country, plains, and prairies, tumbleweeds break away and roll before the wind, scattering their seeds as they go. The Russian thistle (which is really not a thistle, but a relation of the pigweed), an introduced annual now common in the northern part of the Great Plains, breaks off near the surface of the ground. The branches are light and stiff and the plant as a whole is globular in outline. These tumbleweeds roll across the plains in vast numbers, and have even been seen to chase an express train as they are carried along in the rush of wind behind the rear car. The light branching panicles of tickle grass and old witch grass break away and travel in the same way. Great piles of tumbleweeds may gather in windrows along fences and other obstructions.

Some fruits, such as those of the elm, maple, and ash, are winged (Fig. 21). The very thin pod of the redbud and the bract on the stem of the little fruit of the linden serve as wings; and the thin seed of the catalpa is surrounded by a light wing. Winged fruits and seeds are more common to trees, from which they get a good start for their aerial voyages, than to herbs. But a vast number of fruits and seeds of both trees and herbs have tufts or tails of woolly or silky hairs. The willows and poplars, the clematis or virgin's-bower, milkweeds, willow herbs, dandelions, lettuces, and thistles are all carried on the wind by such devices.

Some fruits, such as those of the balloonvine, bladdernut, and groundcherry, are carried in little balloons that roll before the wind.

Water is the means of dispersal for many plants that live in or near it. In order to take advantage of water

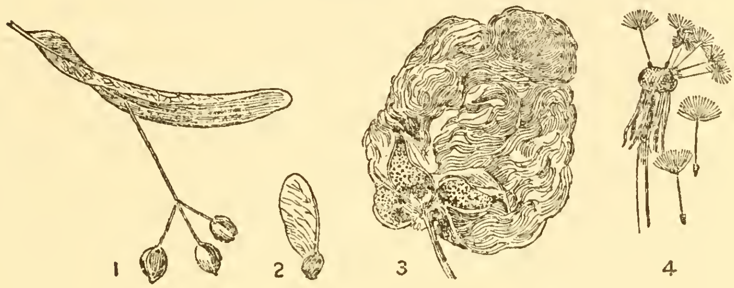


FIG. 21. Dispersal of seeds by wind. 1, fruit cluster of basswood with winged supporting bract; 2, winged fruit of the maple; 3, cotton, which has hairs attached to the seeds; 4, dandelion, whose fruits bear parachutelike tufts of hair. After Kerner

currents the fruits or seeds must be able to float, must remain uninjured by the water, and must be capable of germinating and establishing themselves in the situations in which they are deposited. To secure sufficient lightness the surrounding tissues are in many cases spongy or bladdery. Strand plants (plants of sandy seashores) are distributed largely by ocean currents; this agency may carry seeds great distances, even thousands of miles (see page 85).

Some of the most interesting adaptations for dispersal are found in fruits scattered largely through the agency of animals. The sandbur (*Cenchrus*), cocklebur (*Xanthium*), Spanish needles (*Bidens*), stickseeds, and a host of other plants bear appendanges by which they are easily attached to the hair or fur (Fig. 22). This method of stealing rides is a favorite one with weeds such as are common in old fields and weedy waysides. A walk through lowland woods or meadows in the autumn is sure to result in a fine collection of such fruits on the clothing. The seeds of rib grass, or plantain, are mucilaginous when wet and stick to animals or even to dry leaves; in the latter event they are carried by the wind.

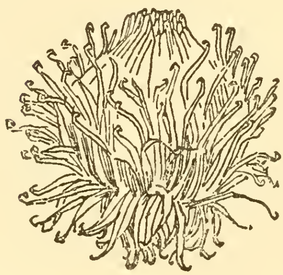


Fig. 22. Fruit of the burdock. The hooked bracts of the bur catch on the hair of animals. After Ganong

Fleshy and juicy fruits do not steal transportation but pay their way handsomely, for nearly all of them are eaten by some kind of bird or beast. The smaller fruits are eaten entire and the seeds pass through the digestive tract—unharmed because of their impervious seedcoat—and are dropped at a distance, sometimes of miles, from the place where they were eaten. The brambles and redcedar so common along fencerows were planted by birds as they sat on the fence. Incidentally, birds are to dispersal of plants almost what insects are to cross-fertilization. Nuts and acorns are buried in the earth by squirrels, chipmunks, and other rodents, and the greater number are left there.

We must not forget that man is a part of nature and has been for ages. In his migrations he has unintentionally carried with him from one place to another a vast number of plants not cultivated—weeds like weedy bromes, dandelions, and many others. But, far more important, he has also taken along with him the seeds of those plants we are pleased to call cultivated, and he has scattered these seeds far and wide through the channels of commerce.

The observer who finds pleasure in wandering through fields and woods may find much amusement and interest in studying the methods of seed dispersal in the plants of his vicinity. He will note many curious adaptations, for strange and curious things need not be sought in foreign parts; they are all about for those who have eyes to see.

Germination of Seeds

When seeds are surrounded by the proper conditions they germinate, that is, the embryo resumes its growth. The first stage in this process is the absorption of moisture. Through the action of enzymes the nourishment stored in the seed (either around the embryo or in its thickened cotyledons), is converted into a liquid form and is absorbed by the growing embryo. The first visible change is usually the protrusion of the primary root, which may grow to considerable length and be covered with root hairs (see page 5) before any leaves appear.

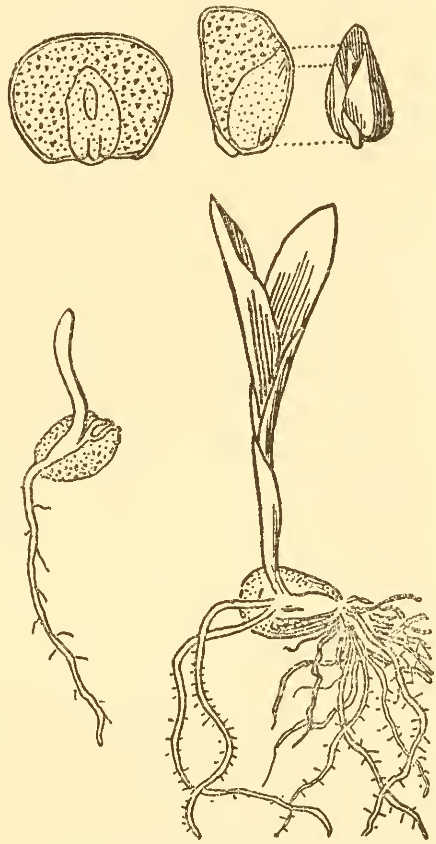


Fig. 23. Corn or maize. Cross and longitudinal sections of a grain, an embryo removed, and two stages of the germination. After Gray

There are two main classes of embryos: those with one seed leaf (monocotyledons), and those with two seed leaves (dicotyledons). The maize, or Indian corn (Fig. 23), is an example of the first group. The embryo of this plant can easily be seen by cutting longitudinally through the middle of the grain or kernel. During germination the seed leaf, or cotyledon, remains within the seed coat, but the first growing leaf elongates and breaks out of the seed coat though its tip remains closed over the other leaves within. If the seed is covered with earth this first growing leaf pushes through the particles without damage until it reaches the surface; then the next leaf breaks through, soon turns green, and the plantlet is established. If the grain of corn is buried too deeply the little leaf, or protecting sheath, can not reach the surface; if the grain lies on the surface the protecting leaf bursts very soon after emerging from the seed coat and lets out the other leaves. Not all monocotyledons germinate in the way described, but this way is characteristic of the grasses.

There are three general types of germination among the dicotyledons: In one type, the cotyledons remain in the seed coat; in a second they emerge, but function only as storehouses for plant food; in a third, they may spread out and function as foliage leaves.

The garden pea illustrates the type in which the cotyledons (the two halves of the pea) remain in the seed coat (Fig. 24, center). Soon after the root pushes out, the little bud (plumule) between the two cotyledons grows toward the surface (if the seed is covered by soil); but the growing part is bent just below the tip so that it is not the tender growing summit which is forcing the soil particles aside but a little bend in the stem. When the surface is reached the tip straightens out and spreads its leaves. The oak is another example of this same type (Fig. 24, right); the fat cotyledons of the acorn remain in the shell while the root and stem protrude.

The garden bean furnishes an example of the second type of germination (Fig. 24, left). The little stem between the two thick cotyledons sends out a root at the lower end and elongates above. If the seed is covered by soil the upper end forms a bend, backs up, and draws the cotyledons out of the seed coat. Thus it is not the cotyledons which first appear above the surface, but this bend. As soon as the cotyledons are drawn out (leaving the seed

FIG. 24. Left, seed (embryo) from which the seed coat has been removed, and two stages of the germination of the garden bean; center, embryo and seedling of the garden pea; right, section of acorn and a seedling of the oak. After Gray

coat in the ground) the stem straightens, the cotyledons spread but do not grow, and the second pair of leaves spread rapidly, grow much longer, and turn green; the young plant is thus established.

In the great majority of dicotyledonous plants the third type of germination prevails. This differs from the second type only in that the cotyledons enlarge, turn green, and function as leaves, though they are usually different in shape from the leaves that follow. If buried in the soil the cotyledons are drawn out of the ground by a bend in the stem, leaving the seed coat in the ground. Germination in the morning-glory and in the maple is of this type (Fig. 25).

The bending that occurs in stems of all types of dicotyledons when the seed is below the soil surface would

FIG. 25. Germination of the red maple. The winged fruit with the seed in one end, the seed cut through exposing the embryo, the embryo removed, the embryo unfolded, and the seedling in three stages of growth. After Gray

appear to be due to a sort of uncanny instinct; as a matter of fact it is merely the result of growth that takes place below the summit. If the seed is above ground, the growth of the stem pushes the tip forward and there is no bend; if below ground, the tip can not be pushed through the soil; as a result the stem forms a loop and so pulls it out.

The seeds of the pumpkin, squash, watermelon, and others of the gourd family overcome a difficulty in germinating in a way that suggests intelligence. The seed coat splits a little at the pointed end as the root pushes out. But the expanse of the firm coat in these large flat seeds is great in proportion to the plantlet within, and the coat presses on the cotyledons so hard that they could not emerge were it not for an unusual contrivance. The young stem forms a shoulder just under one cotyledon; this shoulder grips one side of the seed coat and holds fast while the stem above elongates, pulling the cotyledons from the firm seed coat. In effect the embryo seizes one jaw of the firm seed coat and pushes the mouth open while the cotyledons are drawn out.

It is common knowledge that the root of a seedling grows downward and the stem upward when the seed germinates, and that plants in general send their roots down and their stems up. What causes this growth in opposite directions? It has been shown experimentally that the cause is gravity. If seeds are germinated on a vertically revolving wheel, turning slowly, gravity is neutralized and the roots and stem grow in the directions in which they emerge from the seed. If the wheel revolves rapidly, the roots grow away from the center of the wheel and the stems toward the center. Centrifugal force has been substituted for gravity. This response is called geotropism.

Vegetative Propagation

Whereas seeds—the offspring usually of two parents—perpetuate the species, many plants perpetuate themselves individually by vegetative means. Seeds spread the species far and wide; vegetative reproduction enables an individual to occupy adjacent territory quickly. All vegetative reproduction is the division of an individual into two or more individuals. The progeny are all parts of the original plant and possess the same characteristics, just as the branches of one side of a tree are similar to those of the opposite side. The different trees of the Ben

Davis apple are as much alike (barring the effects of climate and other environmental factors) as are the different branches of the original tree from which they all sprang. But different varieties of the apple show distinct differences, though they may all belong to the same soecies.

Plants propagate vegetatively in nature by the formation of creeping underground stems (rootstocks or rhi-

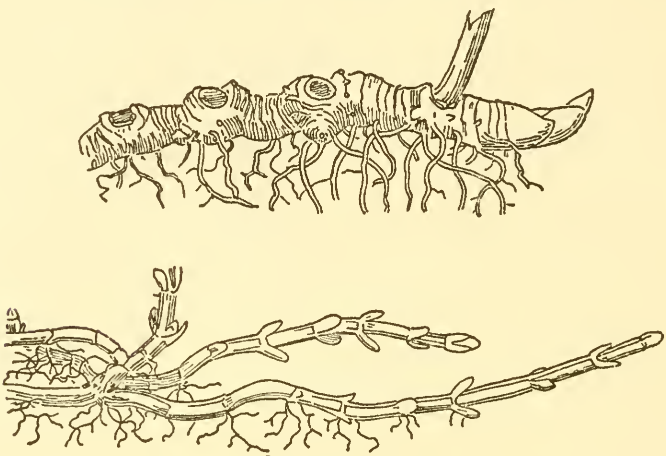


Fig. 26. Rootstocks or rhizomes. Upper, four-year-old fleshy rootstock of the Solomon's-seal, which produces one stem each year; lower, slender creeping rootstock of peppermint, which produces several stems each year. After Gray

zomes); by creeping propagating roots; by stolons; by tubers, corms, and bulbs; and by offsets. The rootstock may be thick and fleshy—as it is in the Solomon's seal and the iris—or it may be slender—as it is in quack grass and the hedge bindweed (Fig. 26). Slender rootstocks send up shoots from the nodes. Plants with vigorous slender rhizomes grow in colonies, forming dense sod or masses; often—as illustrated by the zones of grasses, sedges, and reeds around ponds, and in the saline marshes along our seacoasts—they grow so densely as to exclude other plants.

Propagating roots resemble rootstocks but differ in having no reduced leaves (scales) as do rootstocks, which are true stems. Buds form on the propagating roots at irregular intervals and grow up into shoots. Some trees, such as the silver poplar, the wild plum, and the black locust, form thickets of "suckers," produced from propa-

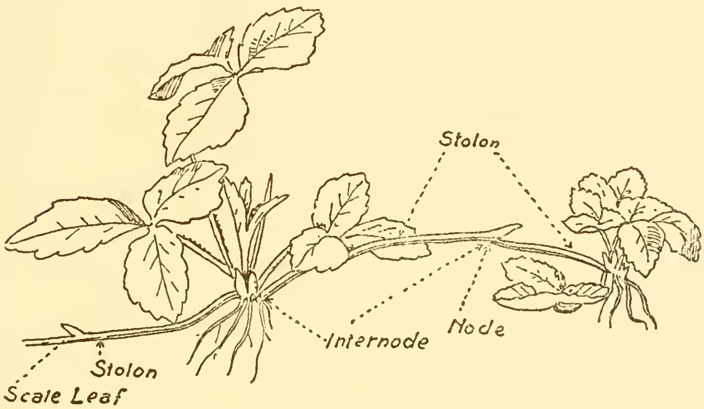


FIG. 27. Runner or stolon of the strawberry. A plant is produced at each node. After Gray

gating roots. Some of our troublesome weeds, for example, the Canada thistle and the field bindweed (*Convolvulus arvensis*), produce propagating roots which are exceedingly difficult to eradicate. The common dandelion, although it does not have creeping propagating roots, is able to produce adventitious buds upon the thick tap root, especially when this is injured. For this reason it is futile to attempt to destroy the dandelion by cutting through the tap root below the crown, as is often done to remove the weed from lawns. Buds form on the upper end of the cut root and where there was one dandelion before, two or three may take its place. Of course, repeated cutting at short intervals will exhaust the tap root, but it is better to dig up the whole plant, root and all.

The runner is a creeping propagating stem, which grows above ground and at intervals takes root and forms a new plant (Fig. 27). The strawberry has such runners and the varieties are propagated commercially by the new plants

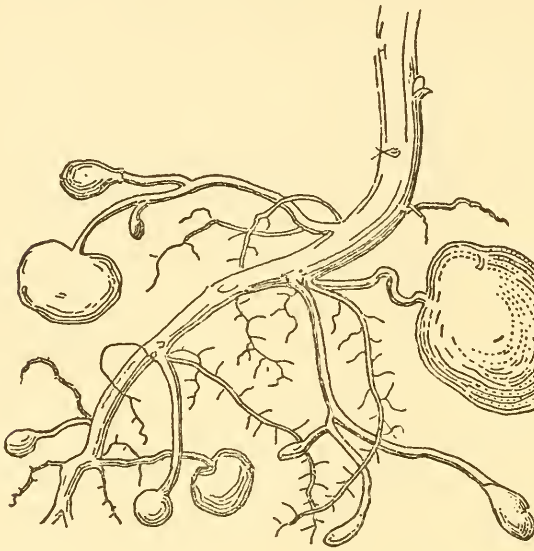


FIG. 28. Tubers of the potato. A slender rootstock swells at the end into a tuber. After Gray

formed. Bermuda grass produces rootstocks below ground and runners or stolons above ground. The grass is often propagated by planting pieces of the runner or rootstocks at suitable intervals in prepared soil. Each piece becomes a new plant and a field is thus soon covered. A modification of the runner is seen in the black raspberry in which a stem or cane bends over and takes root at the tip. The walking fern does the same thing. The sugarcane is propagated commercially by cutting up the canes into pieces and planting them; each piece must have a node on it because this has the bud from which a new shoot springs.

The common white potato (the so-called Irish potato) produces typical tubers (Fig. 28). The slender rootstocks which first appear finally enlarge at the ends, thus producing the edible potato. The "eyes" of the tuber are buds from which the shoots grow. Below each bud or eye (towards the base where the old rootstock is seen) there is a little scale or rudimentary leaf. When the potatoes are stored in bins, they are likely to "sprout" toward spring, the shoots remaining white or tawny (etiolated) if they are in darkness. In time the substance of the tuber, mostly starch, is transferred to the shoots and the tuber becomes shriveled. When the tubers are used for propagation they are cut into pieces, as is well known, but each piece (so-called seed) must have at least one eye, otherwise no shoots could be produced. As soon as the shoots reach the light they turn green through the formation of chlorophyll. The potato (at least, many varieties of it) may produce whitish or bluish flowers, followed, less often, by berries or little balls containing small seeds. The seeds will produce potato plants, but not the particular variety from which they came; new varieties are produced in this way, but to perpetuate the variety the tuber must be used for propagation. If a tuber is exposed to the sun it turns green (due to chlorophyll) and begins to manufacture the same bitter substances that are found in the normal stems and foliage.

In contrast to the tuber of the white potato we have the fleshy root of the sweet potato, which, although it resembles the white potato in that it stores nourishment and becomes fleshy, is a true root with no eyes. When the sweet potato is placed in soil under proper conditions it produces new shoots; it is these shoots that are set out to propagate the plant. The shoots come, however, from adventitious buds.

Perennial herbs often produce at the base a series of branches or shoots called offsets, or suckers. These may be utilized in horticultural practice to propagate the species. Some kinds of century plants and yuccas, the banana, and the pineapple, are propagated in this manner. Other perennials that form a crown of upright shoots are propagated by dividing this crown, a method known as division of the roots.

Bulbs—such as the onion, tulip, narcissus, and many lilies—and corms—like the crocus and gladiolus—propagate by daughter bulbs and corms (Fig. 29). A bulb is made up of fleshy leaves, or scales, on a short supporting stem, or button, at the base. The garden onion produces also little bulbs at the top of the plant in the place of flowers, and the tiger lily produces bulblets in the axils of the leaves. These bulblets are used to propagate the plant. A corm differs from a bulb in being solid, the stem having developed at the expense of the leaves, which are reduced to scales upon the surface.

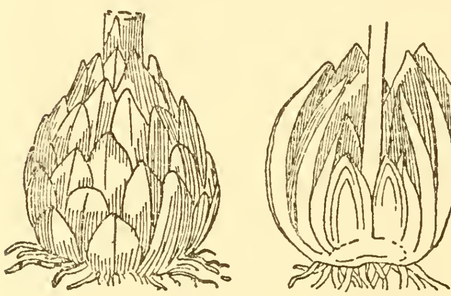


Fig. 29. Bulb of a lily. This is made up of a series of overlapping fleshy leaves borne upon a buttonlike stem, as shown in the section. After Gray

The methods of propagation mentioned so far are those found in nature or which have been adapted directly from nature. Man has invented a few other methods, such as propagation by cuttings, by budding, and by grafting.

Propagation by cuttings is a simple matter, theoretically. A twig or branch is cut off and placed in a rooting medium, such as soil, sand, or water. In time roots are produced at the lower end and the buds develop to produce shoots. Some trees root so easily that a twig or even a small log will send out roots. The willow and poplar and many herbs grow readily from cuttings, and among house plants the geranium is a familiar example of those that can be thus reproduced, the cuttings being often called "slips." On the other hand, some plants are grown with difficulty from cuttings, but in most of these the difficulty arises from lack of knowledge as to the most favorable time of year to take the cuttings, the best part of the plant for the purpose, and the conditions most favorable for the production of roots.

Budding is the process of removing a bud from one plant and setting it into the bark of another (Fig. 30, right). The peach is commonly propagated in this manner. A bud is cut out so as to carry a narrow slice of the bark of the twig and deep enough to include the cambium layer. A slit just to the cambium is made in the young bark of the plant to be budded, and under this the bud is slipped and bound in place. The cambiums being in contact the bud becomes a part of the twig. The twig above the bud is cut off and the bud continues the growth in its place. In practice a seedling of the peach is used for the stock and to it when young the bud from the desired variety is transferred. Hence the mature tree is of the variety wished but the root system is that of the seedling.

The third process of artificial propagation is grafting (Fig. 30, left). It differs from budding in that a whole twig (the scion) of the variety to be propagated is united with some hardy but otherwise undesirable plant (the stock). A common method of grafting where the stock and scion are the same size, is to cut each slantingly and place them together. A little tongue is cut in each surface to aid in keeping the scion in place. The junction is then bound securely and sometimes covered with wax. The cambiums unite and the scion becomes a part of the stock. There are many kinds of grafts but in all of them the cambium of the scion is placed in contact with that of the stock and the joint bound and protected until union takes place. In root grafting the stock is a piece of the root of a seedling. In top grafting the scion is grafted into the top of a tree. Many varieties of fruit, ripening at different times, may be made to grow on a single tree.

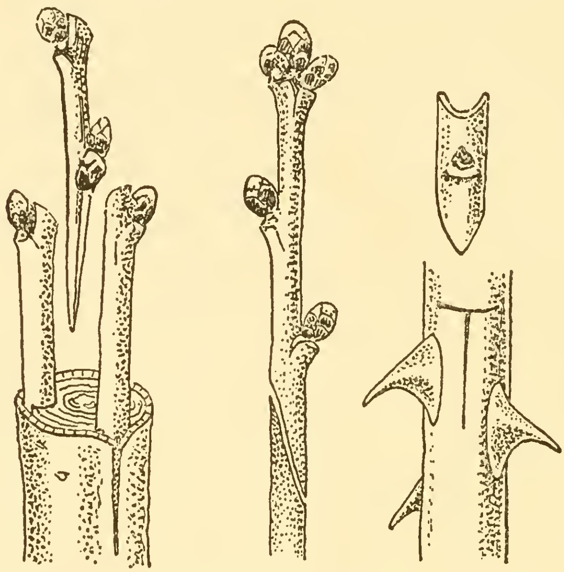


Fig. 30. Grafting and budding. Left, three small scions being grafted on a large stock; center, grafting of a scion on stock of the same size; right, a bud ready for insertion in the stock. After Strasburger

Furthermore, scions of one species may be grafted on stocks of other species of the same genus or even of related genera. Almonds, peaches, apricots, and plums may be grafted on one another; so also with quinces, apples, pears, and hawthorns. The gardener often is able to grow a desirable variety on the roots of a hardy species under conditions which this variety would not withstand on its own roots.

Through grafting and budding man has been able greatly to extend and to diversify his cultivation of useful plants. These processes come down to us from prehistoric times. One illustration will suffice to show how useful the processes have been to man. At one time the grape industry of France and of some other European countries was threatened with extinction because of the introduction from America of the root louse (*Phylloxera*). The industry was saved by grafting the European grape (the wine grape, *Vitis vinifera*) on the roots of native American species that were immune to the attacks of the insect.

CHAPTER IV

PLANT MOVEMENTS AND CARNIVOROUS PLANTS

In the first chapter we stated that plants have no nervous system. Nevertheless, they do possess to a limited degree the power of motion. Very rapid movements are exhibited by the motile spores of algae. These spores swim about by means of fine hairs or cilia which vibrate so rapidly that they can not be followed by the eye when viewed through the microscope. These movements are autonomous; that is, they are due to some internal stimulus.

Movements in response to gravity and light, and the movements of twining stems and tendrils have been mentioned; there are movements in the opening and closing of flowers, and various movements in connection with pollination and with dissemination; there are the "sleep" movements that cause the leaflets of the oxalis and of the pinnate leaves of many plants, especially of the Leguminosae, to come together at night. Movements of leaflets are caused by the unequal turgidity of little swellings (pulvini) at the base. Under the influence of a stimulus (light, heat, touch), the upper part of a pulvinus absorbs water from neighboring tissue and becomes more turgid, while the lower part of the pulvinus becomes less turgid. This moves the organ downward. The reverse process moves the organ upward. Such movements are usually rather slow, but in a few plants they are so rapid as to give the impression of nervous reaction.

The sensitive plant (*Mimosa pudica*), a native of the Tropics that is often grown in northern greenhouses, is

PLATE 12

Venus's-flytrap. Most of the traps are open but some have closed upon insects. The plants are about six inches high. Modified from Kerner

highly responsive to the touch (Fig. 31). The leaves are twice pinnate—that is, the paired main divisions have

Fig. 31. Sensitive plant (*Mimosa pudica*). Left, leaves in normal position; right, leaves after being touched or shocked. After Kerner

paired subdivisions; the main petiole is an inch or two long and has a pulvinus at the base; on the main petiole there are four main divisions, each about as long as the petiole and each with a pulvinus at the base; each division has numerous small leaflets and each of these has a pulvinus at the base. If the leaf is touched the main petiole reflexes quickly, the four divisions fall toward each other, and the small leaflets close together upwards. In warm sunlight these movements are almost instantaneous. If one pinches the end leaflet of a division without disturbing the rest of the leaf, the stimulus travels down the division, closing one pair of leaflets after another, then the four divisions come together, and finally the main petiole droops. If one hits a single leaf carefully without shaking the stem, this leaf will reflex and in a few moments the leaf above and the one below will do the same, and so on until the stimulus dies out. The leaves return slowly to their normal position in a few moments. It is evident that there exists a channel by which the stimulus is carried through the leaf and through the stem. There appears to be here a rudimentary nervous system.

The Venus's-flytrap is another plant that responds to a stimulus in an almost instantaneous manner (Plate 12). This plant grows in bogs in eastern North Carolina. The leaves have at their ends a nearly circular, flat "trap" about an inch in diameter, through the middle of which runs the midrib of the leaf. The edge of the trap has a number of long, sharp teeth and in the central part of each half are three little spines shorter than the marginal teeth. When an insect strikes one of these spines the trap snaps shut quickly enough to catch the intruder. The trap at once exudes a juice over the insect and the soluble parts are digested and absorbed by the plant. It is curious that if the spines are touched, say, by the end of a pencil, the trap closes but soon opens again, whereas if an insect is caught the trap remains closed several days until the nitrogenous food is digested.

Other plants besides the Venus's-flytrap have special structures by which they can catch small insects. Such plants have been called carnivorous, because they not only catch insects but digest them with the aid of a special secretion and absorb the nourishment. On the other hand some plants secrete sticky fluids on their stems or leaves, which may catch insects, but the plants do not digest and absorb their victims. For example, the catchfly secretes, at the time of flowering, a sticky substance in a zone on the internodes, the purpose of which appears to be to prevent ants from climbing the stems to the flowers, where they would steal nectar intended for insects that aid in pollination. Incidentally in this connection, we find that plants are protected from animals in various ways. Thorns, spines, and prickles all serve a protective purpose, as seemingly do the stinging hairs of nettles and some other plants. Unpalatable substances in the foliage protect against grazing animals, and a few plants have an active substance that poisons when the foliage is touched. The common poison ivy and poison oak belong to this class. The deadly upas tree of the East Indies yields an active poison from its milky juice, but the stories that it destroys all life within a radius of fifteen or more meters are pure invention. Equally without foundation are the hair-raising tales of a plant (from some little-known tropical country, of course) that has long tentacles by which it grasps stray victims and sucks their blood.

The best known carnivorous plants, aside from the Venus's-flytrap, are the bladderwort (*Utricularia*), the sundew (*Drosera*), and the pitcherplants (*Sarracenia* and *Nepenthes*). The bladderwort floats in the still waters of ponds by means of numerous small bladders each about the size of the head of a pin. Each bladder has a small entrance guarded by a trap door, through which minute water animals can enter but can not escape. The animalcules soon perish and the organic substances of their bodies are absorbed.

Numerous stalked glands on the surface of the leaves of the sundew exude a sticky substance by which insects are caught. The glands glisten in the sunlight and suggest the plant's name—sundew. If an insect touches the sticky surface it remains stuck unless it is powerful enough to free itself. Small flies can not get away. Very soon the stalked glands, or tentacles, close down on the victim and, if it is not already there, gradually move it towards the center where it will be covered with the greatest number of glands. It is to be noted that not only the tentacles in contact with the insect turn down, but finally all the tentacles (of species like *D. rotundifolia*) bend over to come in contact with it. A digestive fluid is then secreted and the substance of the victim is absorbed. It is significant that rain and wind will not cause the tentacles to act, and inert bodies like grains of sand, or even non-nitrogenous organic substances such as sugar, cause only a slight disturbance; but a living insect or a piece of meat sets up the characteristic action.

Pitcher plants are so called because the leaves have the form of a cup or pitcher and are more or less upright. The structure is such that insects can easily crawl into the pitcher but are prevented from escaping by stiff hairs directed downward around the mouth of the pitcher, and by the slick inner surface. It appears that the leaves extract nourishment from the macerated and decaying animals.

As all the carnivorous plants live in bogs or moist soil in which there is a deficiency of nitrogen, it is thought that this peculiar carnivorous habit may be beneficial in supplying the needed element.

CHAPTER V

PLANT SOCIETIES

The earth, except in regions of perpetual snow or extreme desert, is now covered with plants. The conditions under which these plants grow, of course, differ widely in different quarters of the globe; plants found in the Tropics could not exist in Arctic regions; plants of the seashore would fail upon mountain tops; swamp plants would succumb to desert conditions. It is evident to the most casual observer that under a certain set of conditions—those found in a marsh, for example—there grow a certain group of plants that do not grow elsewhere. The seeds of plants are scattered far and wide and are produced in quantities far exceeding what could possibly find space to grow. There is always strenuous competition, first for a place to germinate, and then for soil, air, water, and light to bring seedlings to maturity. The Great Teacher was familiar with this law, as is shown by the parable of the sower (Luke 8:5–8). Much of the seed sowed by the sower failed to survive, but a part, falling on good ground, "bare fruit an hundredfold." There is in nature a constant "struggle for existence" which, broadly speaking, results in the "survival of the fittest." Each species must compete with all other species adapted to a particular set of conditions; the individual must compete with other individuals of the same species—the severest competition of all.

Furthermore, plants in possession resist displacement. In fact, the spread of species often depends upon the opening of soil by some catastrophe. Virgin forest may remain indefinitely, excluding all aliens even of the same species, until a hurricane sweeps through or a giant tree overturns, making a place for seed. Prairie sod may continue unbroken except here and there by gophers and prairie dogs, by the tramping and pawing of buffalo or cattle, or by some other casual circumstance, for hundreds or even thousands of years.

Each type of environment found on the earth—whether it be rocks or forest, seashore, plain, or marsh—supports the plants suited to it. Some plants found in a certain situation could grow under other conditions, though they might not be able to compete with other species. Thus the bald cypress is found growing naturally in swamps—"cypress swamps"—but it thrives also when cultivated in ordinary soil in parks. Man's crop plants are soon exterminated by the encroachment of native species if he does not protect them.

The study of the adaptation of plants to their surroundings is known as ecology. In a broad way, plants may be classified on the basis of environment into four groups: Hydrophytes, xerophytes, halophytes, and mesophytes. The first group (hydrophytes), adapted to an excess of water, are found in water or in wet places; they may be submerged, or their leaves may float; or they may be emersed but have their roots in a saturated soil. It might be supposed that hydrophytes would have no difficulty in getting water; nevertheless they are often provided with leaf structures like those found in some desert plants to enable them to resist evaporation. For example, the sweet flag and the cat tail have thickish vertical leaves exposing a comparatively small surface. It so happens that in the early part of the season the leaves of these plants are subjected to evaporation at a time when the roots are surrounded by water so cold that it can not be readily absorbed. Consequently, in spite of the abundance of water, the leaves—were they not protected by a special structure—might wilt because of the inactivity of the roots.

The second group (xerophytes) grow on soil in which there is too little water; for example, sandy soil, which will not hold water; the soil of arid regions, which suffers from a deficiency in rainfall; or rocks, which shed water rapidly. The group includes most epiphytes—plants that grow upon the surface of other plants, especially trees, but are not parasitic upon them (Plate 13). The problems for xerophytes are to prevent too great a loss of water through evaporation, and to store water during a favorable season to last them through a period of drought. They meet these problems by a variety of structures and adaptations such as a thick epidermis to the leaf-blades, waxy, sticky, or hairy leaf surfaces, mucilaginous juice, great reduction of leaf surface—as in the cactus—rolling of the blades so that the breathing pores (stomata) are on the inner surface, and fleshy underground stems, bulbs, and fleshy roots that store water beneath the surface of the soil. All these contrivances are adaptations to a small water supply.

The third group (halophytes) are adapted to soil with an excess of mineral salts. (The excess mineral matter in soils supporting halophytes is usually salt or soda, but there may be an excess of other mineral constituents.) Halophytes are found along the seacoast, in the coastal marshes, and around salt lakes or springs. Undrained basins accumulate mineral constituents at the surface of the soil by evaporation. The problem for halophytes is to obtain sufficient water without committing suicide by taking in an excess of mineral matter. Consequently such plants have many of the structures found in xerophytes to reduce evaporation. The leaf surface is reduced, the plant is fleshy, the juice is mucilaginous, or the leaf-blades are hard and fibrous. Bulbs and fleshy rootstocks or roots are not common as there is usually no need for storage against drought or aridity.

The fourth group (mesophytes) include plants having a sufficient but not excessive supply of water; they grow under medium conditions. Typical mesophytes such as are found in tropical rain-forests have broad, thin leaf-blades through which the water in the plants readily evaporates; and they lack special structures to resist evaporation or to store water. However, many plants that are classed as mesophytes are subjected to xerophytic conditions during a part of the year and possess adaptations to meet them. For example, the deciduous trees of the temperate zone drop their leaves for the winter season, when it is difficult for the plant to obtain water, and evergreen trees meet winter conditions by a reduction of foliage and by having resinous sap.

Of course, the lines are not sharply drawn between the four groups mentioned but the classification serves as a basis for study.

During the long period that plants have existed upon the earth physical conditions have gradually changed and plants have had to adapt themselves to the changes or—as fossil records show—they have been exterminated.

The Geographical Distribution of Plants

Plants, as we have said, cover the earth except in regions of perpetual snow or extreme desert. Lack of water precludes vegetable growth, but such lack is rarely or never permanent for any region of the earth; the most arid regions receive rain occasionally though it may be—as on the coast of northern Chile—after periods of drought lasting several years. After these rare rains vegetation springs forth with astonishing quickness and in unexpected abundance; the vegetation may last possibly only a few weeks, but within this time it matures seed which lies dormant until the next rain. Thus it is that land plants are found from sea level to the edge of perpetual snow on the highest mountains, and from the equator to perpetual snow around the poles. Even the sea supports abundant vegetation along much of its margin as far below the surface as light will penetrate; and even far out from land it supports near the surface a floating population of microscopic plants (diatoms) in unbelievable numbers, these plants forming in the last analysis the basis of sustenance for most of the animals of the sea.

The theory of evolution, to which all modern botanists subscribe, holds that all species of plants of the present are derived from other but related species of plants of the past, and that all plants are genetically connected, though the lines of descent may have begun to diverge millions of years ago. If this is so, why do we find such an intricate mixture of kinds of plants in any area of vegetation that we may select? Why do we find in any given locality plants growing together, cheek by jowl, that may represent all the chief divisions of plant life? Our answer might be that in the evolutionary development of species the lines of descent from remote ancestors have, through repeated divergence, become entangled. The case is not so simple. We find closely related plants growing in regions remote from one another; we find a close relationship between the plants of Japan and those of the northeastern part of the United States; we find individuals of the same species on widely separated mountain tops with no representation between; certain groups of plants may be represented in South Africa and South America. How are these gaps to be explained?

The distribution of plants within a single area of uniform conditions may be explained by the methods of seed dispersal already discussed (see page 55). The wind will blow fluffy or winged seeds to a considerable distance; animals may carry burs from one point to another; water courses may carry seeds down stream. These factors will account for much of the local intermingling of species and indeed will result in a slow migration of species. But to explain the present geographical distribution of plants over the earth's surface, we must look for causes operating over wide areas and over long periods of time.

Some of these causes may be effecting changes at the present time; some have effected fundamental changes in past geological epochs.

One of the causes operating at the present time is the introduction, mostly unintentional, of the plants of one country into another through the agency of man. The extensive interchange of products between remote countries makes the accidental transportation of seeds comparatively easy. Alfalfa seed grown in Europe and imported for use in Kansas may bring with it seeds of European weeds. Wool from Argentina may carry seed to Germany, and some of it may acquire a foothold. A summary of the flowering plants in Gray's *Manual of Botany of the Northeastern United States* shows that of about 4,000 species, 666 are introduced. Certain species of introduced grasses (bromes, wild oats, barley grasses) have driven out native species from large areas in the valleys and foothills of California. Introduced species have so thoroughly displaced the original flora in the vicinity of Honolulu that it is difficult now to find a native species—except for certain strand plants—within many miles of the city. A visitor unfamiliar with the history of the Hawaiian flora would think that the guava, the lantana, and Hilo grass (*Paspalum conjugatum*) were native plants, so widespread and abundant are they. Modern methods of transportation have accentuated this mixing of floras, but for thousands of years plants have been carried along the ancient trade routes.

Botanists have noted the wide distribution of the typical plants of fresh-water ponds and marshes. This is chiefly due, no doubt, to the dispersal of the seeds of these plants by migrating water fowl; the seeds are carried in mud upon the feet of the birds or to a less extent upon the feathers. This method of dispersal is especially efficacious because the seeds are deposited in places suited to their germination and subsequent growth.

Plants tend to migrate slowly from one region to an-

PLATE 13

Live oak with epiphytic Spanish moss hanging from its branches. The moss does the tree no harm except that it may interfere with the functioning of the leaves. Courtesy of the U. S. Forest Service

PLATE 14

Silver-sword, a very rare xerophytic plant growing in lava in a volcanic crater, Hawaiian Islands.
Photograph by Hitchcock

other over the land surface where there are no barriers such as high mountain ranges or arid wastes. This gradual spreading has been going on for untold ages. But it is apt to meet with obstacles, causing great changes in the composition of floras, for we know that the topography of the earth has undergone many alterations in times past; land areas have risen or fallen in relation to sea level; certain lands now separated by wide stretches of water are known to have been connected in former epochs, when migration, which is impossible now, could have progressed freely. We have material evidence in the fossil remains of plants preserved in the rocks that great changes have taken place in the composition of floras. It is easy to see how they must have come about. The alterations in topography effected changes in the climate, just as a diversion of the Gulf Stream through a channel in the region of Panama would profoundly affect the climate of the British Isles; such a change of climate would, of course, alter the flora.

Preceding the last Glacial epoch when the ice cap extended far down into temperate regions—for example, as far south as Iowa and northeastern Kansas in America—a mild climate prevailed in Arctic regions, as shown by fossil remains of palms and other plants typical of warm regions. As the Glacial epoch developed, these plants were gradually driven southward. Had the conditions along the parallels of latitude been uniform, the plants would have followed the meridians of longitude. The conditions, however, were very diverse. In the southward movement species were extinguished except as they encountered favorable conditions. Thus it came about that certain species that had enjoyed a continuous area of distribution in high altitudes before the Glacial epoch divided as they were driven southward, part following the east Asiatic coastal region and another part following the east American coastal region. Only in these regions did these species find suitable conditions; elsewhere they were exterminated. The migration was so slow that the part pushed into eastern Asia had time to differentiate somewhat from the part pushed into eastern America. Nevertheless, at present the flora of Japan and northeastern Asia is evidently closely related to that of northeastern America—much more closely related than it is to the flora of the Pacific Coast of America. There are many genera of plants in which some of the species are found in northeastern America and some in northeastern Asia but none in any other part of the world.

Another result of the southward push of the great ice cap is the small number of species in the present flora of Greenland as compared with the flora of that part of North America in the same latitude. On the continent the ice cap drove the plants southward over the land, so that on the retreat of the ice they gradually followed northward; but in Greenland the plants had, as it were, been driven into the sea so that there were none to follow the ice back. The present flora is in the main the result of accidental introductions since the Glacial epoch.

Still a third result of the descent of the ice sheet is the occurrence of many Arctic species on the tops of high mountains in temperate regions. Species driven to these peaks by the ice were unable to follow the retreating glaciers back, because in descending the mountains they came into contact with a temperate flora, which they could not dislodge. A certain grass (*Trisetum spicatum*), common at low altitudes in Arctic regions and circumpolar in its distribution, extends southward along the mountain ranges that run north and south. It is found on the summits of the White Mountains, of the Adirondacks, and of Roan Mountain (North Carolina), in the alpine regions of the Rocky Mountains, of the Sierra Nevada, and of the high mountains of Mexico and the Andes, and descends to low altitudes again in the Antarctic regions. It is also found in the Himalayas and other high mountains of the eastern hemisphere, including those of New Zealand and Australia.

One other factor in the world-wide distribution of plants is transportation by ocean currents. Much information on ocean currents has been obtained by consigning bottles to the waves at various places, with instructions for their return when picked up. Many such bottles have been recovered at long distances from the point whence they started. Botanists (notably H. B. Guppy) have investigated the transportation of seeds and fruits by these currents. Plants can profit by the ocean currents only when their seeds (or fruits) are able to float for a long time, are not injured by the seawater, and find favorable conditions for germination and growth in the places where they are deposited. Seeds of West Indian plants have been found on the coasts of Norway, of England, and even of countries as far south as Morocco and the Cape Verde Islands; they were transported to all these places by the Gulf Stream.

It is probable that ocean currents constitute the chief factor in the distribution of strand plants. The south equatorial current readily brings seeds from the coast of Africa to Brazil, thus partly accounting for the similarity of the strand plants of the two regions. The flow of ocean currents in past ages may account for what seems at present to be an anomalous distribution of certain strand plants. For it must be recalled that, because of different configurations of the land surfaces, the ocean currents in past geological ages flowed differently from what they do at present.

When it is remembered that the factors controlling the distribution of plants have for the most part acted for millions of years and under conditions known to us only in part, that through all these ages the evolution of plants has been going on, and that an indefinite number of connecting links have disappeared, the present complexity of distribution is not so surprising.

CHAPTER VI

HOW PLANTS ARE RELATED

The plants inhabiting the earth today are the surviving descendants of countless generations. To determine how they are related to each other is one of the fundamental problems of botany. The classification of plants is an attempt to show this natural relationship—an attempt based on the study of the relatively very small part of the vegetable kingdom living today, and of the still smaller part represented by fossils. The present flora of the world is a cross-section of the lines of descent that extend far back for untold generations. Some of the extinct links are revealed to us in the fossil remains in the rocks, but most of them are lost. We are forced to base our classification on similarities.

Herbert Spencer stated in his somewhat stilted language that "organisms are classified according to the totality of their morphological resemblances." The relationship between some plants is evident, so evident that observant mankind has recognized certain groups since time immemorial. The palms, the pines, the oaks, the legumes, the crucifers, and the composites, the grasses, the ferns, and the mosses have always been recognized as groups each containing related kinds of plants. But there are many plants whose relationships are not at all clear. These are placed provisionally at certain points in our classification but with the understanding that on further study they may be placed elsewhere.

Plants in general fall naturally into four great groups: the thallus plants, the mosses, the ferns, and the seed plants.

Thallus Plants (*Thallophyta*)

The thallus plants, the lowest group, consist of kinds which are not divided into stem and leaf. In the simplest forms the plant body is made up of single cells, or of simple or branched filaments; in the higher forms the plant body may become rather complex but still not be differentiated into a stem and leaves.

There are two main groups—algae and fungi—based on the presence or absence of chlorophyll. The algae possess chlorophyll, though it may be masked by a red or brown coloring matter. The fungi are devoid of chlorophyll.

Algae

The algae (see Part III, page 165) are confined almost entirely to water or wet places. The forms that live in the ocean, usually called seaweeds, may be green, brown, or red, whereas most of the fresh-water algae are green or bluish-green. The green coating sometimes found on the north sides of brick buildings and of tree trunks, near the ground, is made up of microscopic one-celled or simple forms of green algae. The fresh-water and marine plants called diatoms are one-celled, yellowish algae, which are peculiar in having a siliceous cell wall; under the microscope this wall is seen to be beautifully figured and ornamented. Because of the silica in the cell wall, diatoms retain their shape after the death of the cell contents. These minute plants exist in enormous numbers in the sea, where they float unattached and are shifted about by the currents. Directly or indirectly they are the basic support of most of the animal life of the sea. Diatoms are also widely distributed in fresh water and compose the slimy coating commonly found on sticks and logs in streams, ponds, and ditches. In past ages these minute algae have existed in such numbers that their siliceous remains have formed great beds of diatomaceous earth on the sea bottom. In the course of ages geologic changes have lifted many of these beds above sea level and made them accessible to commercial exploitation. For example, the material is mixed with nitroglycerin and used in making certain grades of dynamite. Some beds are several hundred feet in thickness and an idea of the enormous numbers of diatoms composing them may be obtained when it is realized that one cubic centimeter may contain more than two and a half million diatom shells.

Some of the filamentous algae form the green scum (pond scum) often seen on stagnant water in bright weather. The bubbles of oxygen formed during photosynthesis are quite evident and tend to float the felty mass. At night the filaments sink below the surface. Duckweeds also form a scum on the surface of stagnant water (see page 113), but these plants have a small flat plant body and are not made up of filaments or felty masses.

The seaweeds are found chiefly along rocky seashores between tide limits, though sometimes they may occur as much as six hundred feet below the surface. They have rootlike processes by which they hold fast to an anchorage, but these holdfasts do not absorb nourishment and do not have the structure of roots. The large brown seaweeds are usually called kelps. The giant kelp of the Pacific Coast may attain a length of 500 feet. Certain kelps that look like rubber tubing with large bladder-like swellings are commonly washed up on our western shores. Seaweeds exposed to the air during low tide are protected from drying out by being tough and mucilaginous. A mass of the seaweed sargassum (Fig. 32) floats in an immense eddy of the Atlantic Ocean northeast of the West Indies; it covers an area of probably two hundred thousand square miles, which is known as the Sargasso Sea. The floating seaweed propagates vegetatively. The little berrylike bodies on the alga are not fruits of the plant but bladders by which it floats. The plant body consists of a central axis with expanded branches which

. Wheat showing stems and leaves infected with the black rust.
Courtesy of the U. S. Bureau of Plant Industry

Plump healthy kernels of wheat (upper) and kernels shriveled by wheat rust (lower.) Courtesy of the U. S. Bureau of Plant Industry superficially simulate the stems and leaves of higher plants. Sargassum in small masses is frequently seen from the decks of transatlantic steamers.

Certain seaweeds are edible — among them the species from which is obtained agar, or agar-agar, a substance much used in laboratories for growing bacteria in artificial cultures.

FIG. 32. Sargassum. The globular objects are bladderlike floating organs. After Kerner

Fungi

Possessing no chlorophyll, the fungi must obtain their sustenance from living or dead organic matter. If they derive their nourishment from living plants or animals they are parasites; if from dead material, they are saprophytes. The simplest forms of fungi, the bacteria, are of interest to us because they cause fermentation, putrefaction, nitrogen fixation in the soil (see page 27), and especially because they cause many of the serious diseases of the human race, and of domestic animals and cultivated plants. Among human diseases caused by bacteria are cholera, diphtheria, lockjaw, pneumonia, tuberculosis, and typhoid fever; among the diseases of domestic animals, anthrax, black-leg, and chicken cholera; and among the diseases of plants, the soft rots of vegetables and the blights of cucumber and potato. The quick action of bacteria in producing fermentations, diseases, and so on, is due to their rapid multiplication, some kinds dividing as often as once every twenty minutes. Incidentally, some contagious diseases are caused by protozoans, a simply constructed group of the animal kingdom.

Until within the lifetime of many now living, putrefaction was thought to be due to "spontaneous generation." If a decoction of hay or of meat was exposed to the air for a short time, it decomposed and bacteria appeared. As nothing had been added to or had been seen to enter the liquid, the natural supposition was that the organisms found in the decomposing material must have originated spontaneously. Then in 1864, Pasteur, the great French scientist, showed conclusively that putrefaction could not take place if certain precautions were taken to exclude germs floating in the air. He placed boiled decoctions in two test tubes, leaving one open and protecting the other by a plug of cotton which would not exclude the air. The first decomposed; the second did not, because the minute germs in the air had been filtered out. He had great difficulty in overcoming the prejudice of ages, but the younger men were won over to his views. The life of Pasteur reads like a novel. He was the first to show that rabies was carried by a germ and he invented a cure, consisting of antitoxic serum, for this dreaded disease. Again he had to fight the prejudices of his colleagues. How he saved the life of a child that had been bitten by a mad dog is certainly one of the romances of science.

The active part of baker's yeast is a microscopic plant similar to bacteria. The single-celled individuals propagate by budding instead of by division. One side of the cell bulges out to form a "bud" which soon becomes as large as the original or mother cell. The new cells may remain attached as a colony or may separate. During metabolism, the yeast plant gives off carbon dioxide. It is this gas which makes the bubbles in dough and causes it to "rise."

The higher fungi are responsible for many of the maladies of plants, and constitute a serious drain on our agriculture. One author estimates that the reduction in the yield of cereals in the United States due to smuts (Plates 15 and 16) alone amounted during one recent year to

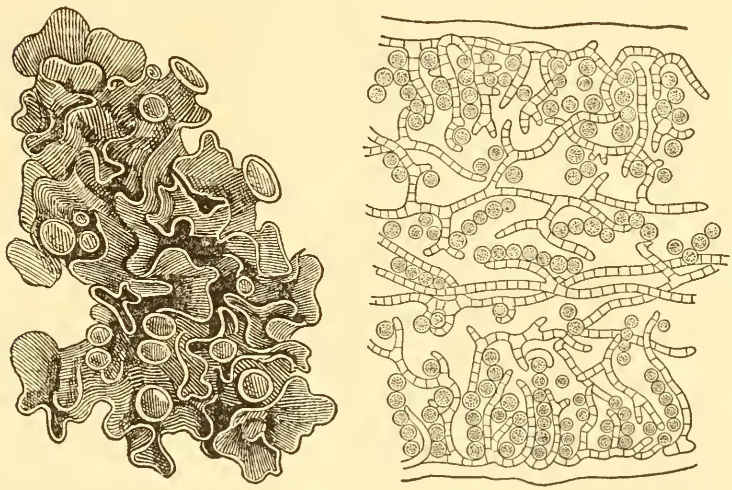


FIG. 33. Left, lichen of the leafy sort growing on rocks (the cups contain the spores); right, cross section of a leafy lichen (the filaments belong to the fungus). After Kerner

160,735,000 bushels. Other fungi also take their toll. The more common fungous diseases are smuts, rusts, and parasitic mildews such as the potato mildew and the grape mildew. The filaments of the fungus penetrate the cells of the host plant or spread over the surface and send down little sucking processes into the cells. The spores are the more conspicuous part and are usually formed on the surface where they can be scattered by the wind. Wheat rust and corn smut are familiar examples.

Another series of fungi—often referred to loosely as fleshy fungi—include mushrooms, toadstools, puffballs, bracket fungi, and their allies. The conspicuous part of the fungus is the spore-bearing body, whereas the mycelium, or threads, of the plant body penetrate the support on which they grow. If the cap of a toadstool is cut off and laid, under side down, on black paper for a few hours, the spores will drop from the gills and form a print of the gills upon the paper. Most of these fleshy fungi are saprophytic. The common mushroom, cultivated for food in dark cellars, illustrates the manner in which saprophytes live. Upon a prepared bed of decomposed organic matter is planted the spawn, or mycelium, of the mushroom, a felty mass of white threads. After a time the spore bodies of the fungus make their appearance and are gathered for sale.

Fig. 34. A moss. The capsules at the summit contain the spores. After Schimper

To be considered along with the fungi is a group of very remarkable plants, the lichens. A lichen consists of a combination of a species of fungus with a species of alga (Fig. 33). The combination (for life) is called symbiosis because it is mutually beneficial. The fungus surrounds and protects the alga and supplies it with water and mineral salts; at the same time it feeds upon the alga, absorbing its excess nutriment. Although parasitic on the alga, the latter is not destroyed by the fungus but remains in good condition. The relation is somewhat like that between man and dairy cattle.

Lichens are common. They form the grayish-green leafy coatings on the bark of trees, the red, yellow, and black stains on rocks, and the flat or curly thallus on the ground. The so-called reindeer moss of northern regions which furnishes so much food to caribou and reindeer is a lichen, and so is the Iceland moss once widely used in pulmonary diseases.

Mosses (*Bryophyta*)

The second great group of plants, the mosses (Fig. 34), are familiar to all who roam the woods. They have a stem and leaves but no distinct vascular system. They absorb moisture through the roots when these are well developed, and also directly through the leaves when these come in contact with dew or other moisture. The spore bodies are in the little capsules at the summits of the stems.

In general the mosses are of little use to man. The sphagnum moss, which forms great bogs (peat bogs) in northern regions, is used for packing and in the nursery trade for potting plants. Also, the disintegrated vegetation of old bogs, consisting largely of sphagnum, gives us peat, which in some countries is an important fuel.

Ferns (*Pteridophyta*)

The ordinary ferns (the third plant group), are common undergrowth plants of the forest, being especially numerous in the wet forests of the Tropics, and some kinds are found on rocks and on trees (Fig. 35). In warm regions ferns may become trees, resembling palms and possessing distinct trunks and great crowns of spreading fronds. The fern group differs from the preceding two large groups in having a distinct vascular system. The spores are borne for the most part in lines or dots on the under sides of the leaves or fronds (Plate 17).

Allied to the true ferns are the club mosses—which include the ground pine, and the selaginella, the mosslike decorative plant of our greenhouses—and the horsetails, or scouring rushes, with stiff, jointed, leafless, green stems, which are harsh because of the silica contained in the tissue. The ferns have also some other less common allies. The fossil evidence shows that in past ages, especially in the Carboniferous Period, the fern group dominated the vegetation of the earth.

FIG. 35. A fern. The leaves or fronds have a peculiar coiled form when young. After Strasburger

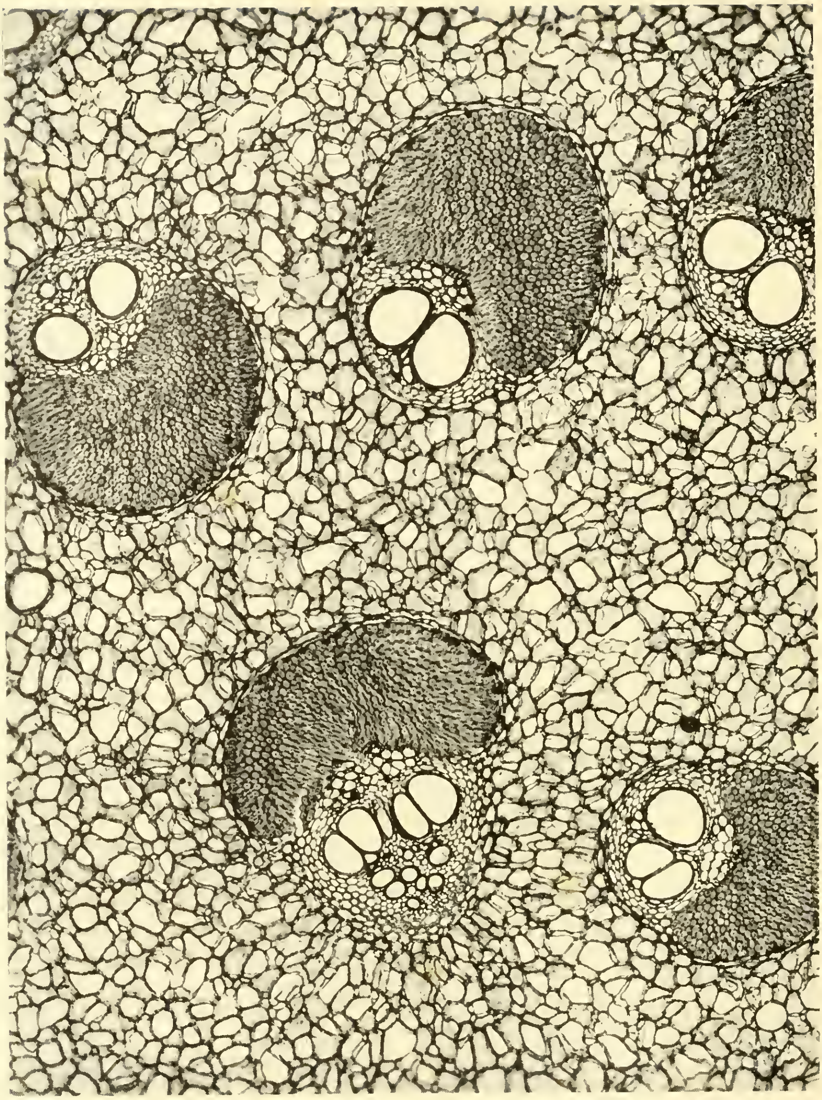
SEED PLANTS (*Spermatophyta*)

This, the fourth and highest group of plants, includes most of the ordinary conspicuous plants with which we are familiar. It is distinguished from the three preceding groups in that its members form seeds with an embryo. There are two distinct subdivisions of the seed plants—the gymnosperms and the angiosperms.

Gymnospermae

The gymnosperms (meaning naked seeds) are also loosely called conifers because many of them bear cones in which are the seeds; and in northern regions they are often called evergreens because most of them remain

Under side of a fern leaf, showing spores; much enlarged. In this species the spore cases are partly hidden by a thin membrane



Part of cross section of a palm stem as seen under a microscope, showing the vascular bundles distributed through the pith. Courtesy of the U. S. Forest Products Laboratory green through the winter, whereas other trees are deciduous. This difference does not hold good farther south, where many other kinds of trees are evergreen. To the gymnosperms belong the pines, spruces, firs, larches, the yew, junipers, sequoias (redwood and big tree), and many others, including the cycads which resemble palms and have a stout, short trunk and a tuft of large leaves with numerous slender leaflets. The cycads are thought to be the most primitive of the gymnosperms and were abundant in earlier geologic ages.

The flowers of the gymnosperms differ from those of the angiosperms in that the ovule is not inclosed in an ovary, but lies naked, though usually protected by surrounding scales. The pollen does not have to grow through the tissues of a style and ovary to reach the ovule but can penetrate the ovule directly. The leaves of most kinds are needlelike, as in the pines, or scalelike, as in the red cedar (a kind of juniper).

Angiospermae

The angiosperms (meaning inclosed seeds) are the ordinary flowering plants, the ovules of which are borne within a closed ovary. This group is split into two large subdivisions according to the number of cotyledons of the embryo: the monocotyledons and the dicotyledons.

The structure of the embryo of the maize, already described (see page 59), is characteristic of the monocotyledons in so far as the single cotyledon is concerned. The parts of the flower (sepals, petals, stamens, and stigmas) in the monocotyledons are usually in threes or sixes, and the usually parallel-veined leaves are entire (that is, the edges are not notched or lobed). The structure of the stem differs from that of the dicotyledons. The bundles of conducting tissue are not distributed in a definite ring with a central pith but are arranged irregularly through the pith (Plate 18). The maize (corn) stem shows this distribution characteristically, but the wheat and other hollow-stemmed grasses appear to depart from it because the central part shrivels at an early period of growth and the bundles are forced into an annular zone; however, within this zone they are irregularly distributed, as may be observed with a good lens. Furthermore, the stems (with rare exceptions) have no cambium and therefore can not increase in diameter after the tissues of the stem have reached the mature form. Thus the palms, at the base of their cluster of leaves, slowly form a trunk which, when it emerges above ground, is as large as it ever will be at that point.

The embryo of dicotyledons has two cotyledons, as described on page 60. To this group belong all our northern forest trees except the conifers, and, so far as the number of species is concerned, probably two-thirds of the herbaceous plants. The flower parts are usually in fours or fives and the leaves are usually net-veined. The vascular bundles are distributed in a ring around a central pith. Since there is an actual or potential cambium in the bundles, the stems of dicotyledons can grow in diameter as described on page 14.

In their system of classification Engler and Prantl number 280 families of flowering plants. The list appears on paper in lineal sequence; the evolution of plants, however, has not developed along a single line but in many directions. The dicotyledons follow the monocotyledons, but the highest group of the latter—the orchids—are much more complex than the lower groups of the dicotyledons. Relationships are revealed also in the structure of the plant body itself, but the flowers are less subject than is the plant body to modification as a result of environment, and so are the best key to genetic relationships.

The relationships of the better-known flowering plants, particularly those of the temperate zone, are given in more detail than we have room for here in an Appendix at the end of this Part (see page 112). The amateur gardener may discover in it some rather unexpected affinities between the plants with which he is empirically familiar.

CHAPTER VII

HOW PLANTS ARE USED BY MAN

Mankind is absolutely dependent for his existence upon plants. He utilizes animals, but they in turn are dependent upon plants. In the story of creation plants appeared on the third day, whereas animals were not created until the fifth day, and man himself not until the sixth. So early was it recognized that man and other animals could not live without plants.

Man has used plants since he appeared on earth, of course, but at first he took them as he found them, eating such roots and fruits as were edible. Very early in his career, however, he began to adapt plants to his use in ways that other animals have never learned, an achievement that distinguishes him from these animals and to which in the last analysis he owes his dominant place in the animal kingdom. Long before the dawn of history man had learned to gather and store seeds, and to cultivate many plants, thus securing a larger supply of more-palatable food. He somehow learned to burn wood, a tremendous advance in his career. He clothed his hairless body with skins of animals mostly, but very early he devised ways to make cloth out of bark and to weave the fiber beaten out of certain stems.

The most primitive races today utilize plants in many ways that require intelligent preparation. In fact, savage races show a surprising knowledge of their native plants and of the uses to which they may be put.

It is an interesting fact that nearly all the important and widely cultivated economic plants of today have been in cultivation since prehistoric times. Aside from forage plants and ornamentals, very few important economic plants have been brought into cultivation within historic times.

Foods

The staple foods, with the exception of the legumes—in which there is a considerable proportion of protein (nitrogen-containing material)—are largely starch; these are parts of plants in which the plant itself has stored carbohydrates for its own use. By far the most important staple foods are the grains—wheat, rice, maize, barley, and the sorghums, all of which belong to the grass family and are discussed in Part IV of this volume (page 207). Aside from the grains, probably the most important starchy food plant, at least for the white race, is the white potato (miscalled Irish potato, for it came from America). The white potato is not a root but a stem (see page 67). The sweet potato (also from America), widely cultivated in warm regions, is a true root.

Because they contain protein, the beans (legume family) are extensively used. Numerous varieties of the navy, or kidney, bean, the lima bean, originally from South America, the broad bean of Europe, and the soy bean of China and Japan, are staples over the greater part of the world. Other leguminous seeds widely used in eastern countries, though not in especial favor with us, are the chick pea, pigeon pea, and lentils. It was for a pottage of lentils that the hungry Esau sold his birthright to Jacob.

The cassava (manioc, mandioc), originally from Brazil where it is a staple food today, is now widely cultivated for its fleshy roots. The refined starch obtained from cassava is the tapioca of commerce. The fleshy underground parts (corms or tubers) of the taro or dasheen, a relative of the calla lily, also provide a commercially important starch, and from them the Hawaiians make their "poi." The breadfruit is a staple food in the East Indies and the South Sea Islands. When cooked the large spherical fruit tastes like fresh steamed bread. The trunk of the sago palm furnishes a starchy pith used by the natives of the South Sea Islands, and the refined product comes into commerce as sago. Bananas and plantains furnish food for millions of people in the Tropics, especially for the natives of Africa. The fruit is cooked and eaten direct, or dried and ground into flour. In Arabia and north Africa the date is a basic food, and the fig, fresh or dried, is a food plant in the Mediterranean region.

The garden vegetables used for food are so numerous that only the more important ones can be mentioned here. The fleshy root of the beet, carrot, parsnip, radish, and turnip, the bulb of the onion, the young stems of the asparagus, the leaves of the cabbage, Brussels sprouts, kale, and spinach, and the stem and undeveloped inflorescence of cauliflower, the seed of the garden pea, kidney, lima, scarlet runner and other beans, and the edible pods of the kidney bean (string bean), are commonly used in cool regions. The fruits of the eggplant, tomato, squash, pumpkin, and cucumber may be classed as vegetables with regard to culinary use. The juicy petioles of the rhubarb or pieplant furnish luscious pies in spring. The leaves of lettuce, celery, and cress are used for salad.

Edible fruits have been used for supplementary food since the earliest times. In cool climates we have the apple, pear, quince, peach, apricot, plum, cherry, grape (raisins are dried grapes, currants are small seedless raisins), raspberry, blackberry, strawberry (the fleshy receptacle), gooseberry, currant, blueberry, cranberry, watermelon, and muskmelon. Several important fruits are now shipped to us from warmer regions, the pineapple, the banana, the citrous fruits (orange, tangerine, lemon, grapefruit, and lime), dates and figs (mostly dried). There are many more in tropical regions.

Certain plant products might be called accessory foods.

Many nuts and dried fruits are much in evidence about Christmas time. The commoner nuts are the English walnut, filbert, pecan, and peanut (a legume rather than a nut), and Brazil nut. All of these are cultivated except the Brazil nut, which comes from the Amazon basin. The fruit of this is a hard globular object containing several angular seeds, the nuts of commerce.

A few plant products are used as flavors or relishes rather than strictly as food. Such are the fleshy root of the radish and horse-radish, and the spices—black pepper (fruit), clove (flower bud), allspice (fruit), nutmeg (seed), cinnamon (bark), red, or cayenne, pepper (fruit), ginger (root), and mustard (seed).

The vanilla, a favorite flavoring material, comes from the pod of a climbing orchid. Several flowers and fruits furnish essential oils used in flavoring or in perfumery. One of the best-known perfumes is attar of roses, made from rose petals. Peppermint and pennyroyal are examples of essential oils from the mint family. Wintergreen comes from the blueberry family.

The chief vegetable oils used in the preparation of food come from corn, olive, peanut, coconut, and cottonseed.

Drugs

Many powerful vegetable drugs owe their efficacy to an alkaloid. Morphine, long known as a reliever of pain, is the alkaloid of opium, which is produced from the milky juice of the poppy. Cocaine comes from the leaves of the coca plant, a shrub grown on the hillsides of Peru and Bolivia. The natives of the Andes chew the leaves mixed with a paste of ashes. The released alkaloid acts as a stimulant. Quinine, a specific against malaria, comes from the bark of the cinchona tree, a native of Peru, but now widely cultivated in Ceylon, Java, and neighboring countries. Strychnine, a violent poison, comes from the seed (*nux vomica*) of an Asiatic tree.

Some other common drugs are atropine (active principle of belladonna) which comes from the roots and leaves of the deadly nightshade; senna, from the leaves of the cassia (legume family); aloes, from the juice of *Aloe* (lily family); ipecac, from the root of a South American vine; eucalyptus oil, from the Australian eucalyptus tree; digitalis, from the leaves of the foxglove; sarsaparilla, from the roots of a tropical American species of greenbriar (*Smilax*); sassafras, a common domestic remedy, from the bark of the roots of the sassafras tree (eastern United States); aconite, from the leaves of the monkshood. Caffeine is the active principle of coffee, tea, and the kolanut. Castor oil, the bane of our childhood, comes from the seeds of the castor bean. Camphor is distilled from the twigs and wood of an Asiatic tree. Hashish, or Indian hemp, is a drug produced from the seed of the same plant that produces hemp fiber. Chaulmoogra oil, from the seeds of a Burmese tree, has come into prominence recently because it is beneficial in the treatment of leprosy. Dr. Joseph Rock's search for the seed in its native habitat is a botanical romance, because of the difficulties and dangers involved. The tree is now being cultivated and the oil will soon be widely available.

Beverages

The three common beverages that come directly from plants are: tea, the leaves of a shrub cultivated in China, Japan, and India; coffee, the seeds of a small tree grown in cool mountain regions of the Tropics of both hemispheres; and cocoa, from the seed of a tree originating in South America, but now widely cultivated. Maté, or Paraguay tea, the leaves of a shrub, is much used in southern South America. Alcoholic beverages are all indirect products of plants.

Fibers

By far the most important fiber plant of the world is the cotton, the commercial product being obtained from the slender fibers that grow on the seed. The four other important fiber plants are the flax, hemp, jute (all of which furnish fiber from the stem), and the abacá (Manila hemp), which furnishes fiber from the sheathing leaf-stalks. Flax supplies a fine fiber from which linen is made; the others supply coarse fibers used for cordage and coarse cloth. The sisal, or sisal hemp, which is used for binding twine for the harvesting of grain, is produced from the leaves of a century plant grown in Yucatan. There are many other fibers of less importance.

One of the most important inventions of modern times is paper, for upon it is based the manufacture of books, which has brought about the wide diffusion of knowledge. The basis of paper is the cellulose of plants—obtained from linen and cotton fibers and in recent years from wood pulp, straw, and other materials. Rayon, or artificial silk, is also a product of wood and other cellulose-containing substances.

In ancient times one of the writing materials was made from papyrus, a tall sedge growing in shallow water.

Woods

Our forests furnish a great variety of lumber for building, for furniture, and for other purposes. The conifers are of prime importance as sources of lumber. White pine, formerly much used, is becoming scarce and other kinds are replacing this valuable species. Douglas fir and redwood, of the Pacific Coast, are now shipped to all parts of the world. For cabinet making the black walnut, maple, oak, birch, and others are used because they take a high polish. The tulip-tree furnishes a soft wood called by cabinet makers yellow poplar, though it is not at all allied to the poplars. Special purposes require special woods, such as the ash and hickory.

Many tropical trees, such as the mahogany, ebony, rosewood, and sandalwood, furnish hard dense wood which takes a high polish. The greenheart from British Guiana is used for piles in wharves and docks at seaports because it resists the action of the teredo, or shipworm. Rattan, a climbing palm, is used in making furniture, and the split canes are used for the seats of chairs.

Dyes

Formerly vegetable dyes were much in use, but in recent years they have been gradually supplanted by the artificial product. Indigo comes from the stems and leaves of a leguminous plant grown in India; saffron from the stigmas of a kind of crocus. The extract of the wood of logwood, a tree of the American Tropics, furnishes a basis for several dyes, especially blacks. Madder is made from the root of an herbaceous plant. A common dye is obtained from the extract of the heartwood of Brazilwood.

Miscellaneous Uses

Tanning material is derived from oak bark, from the mangrove, and from several other trees and bushes.

Rubber is made from the milky juice of several trees, the most important of which is the Pará rubber tree, originally from Brazil. Some years ago rubber was produced only from the wild trees, but later the species was brought into cultivation in the Malay States, Java, and other places in the East. In America attempts are being made to produce rubber from a desert bush, the guayule. Two allied substances are gutta-percha—from the milky juice of a Malayan tree—and chicle, the basis of chewing gum—from the bully tree of Central America.

Tobacco, from the leaves of an American plant (*Nicotiana*) of the nightshade family, owes its effect to an alkaloid—nicotine.

There are a few vegetable oils, especially olive oil (from the fruit of the olive), that are used extensively in soap making, in cookery, and as adulterants of other oils. The meat of the coconut, when dried, is called copra, from which is obtained coconut oil. Palm oil comes from the African oil palm. Peanut oil and cottonseed oil have been mentioned in previous paragraphs. They are among our most important vegetable oils and are used for a variety of purposes.

There are several plant products of commercial importance that are classed in general as gums, balsams, and resins. Gum arabic comes from the juice of an Egyptian tree. When distilled, turpentine, from the sap of pine trees, gives turpentine oil or spirits of turpentine; the residue yields common rosin. Canada balsam comes from the balsam fir. Amber is a fossil resin.

Coal is a plant product of past ages and we may therefore classify as plant products the great array of materials that are derived from coal, such as gas, tar, and the numerous coal-tar derivitives, including artificial dyes and synthetic drugs.

Forage plants are indispensable to man since they serve to feed domestic animals. The cultivated forage plants belong chiefly to the grass family (see page 199) and to the legume family. The cultivated forage legumes are the clover and alfalfa, soy bean, velvet bean, the broad bean, and several allied plants.

The more important economic plants, with the family to which each belongs, the part used, and the hemisphere in which each originated are given in the following table:

NAME	FAMILY	PART USED	ORIGIN[1]
STAPLE FOODS			
Wheat	Grass	Grain	
Rice	do.	do.	
Maize	do.	do.	A

[1] Those marked "A" are originally from the Western Hemisphere (America). The others are from the Eastern Hemisphere. Certain species of certain groups, such as the plums and grapes, originated in one hemisphere, whereas other species of the same groups originated in the other hemisphere. These groups are marked in the Origin column "A (in part)."

NAME	FAMILY	PART USED	ORIGIN
Barley	Grass	Grain	
Rye	do.	do.	
Oats	do.	do.	
Sorghum	do.	do.	
Potato	Nightshade	Tuber	A
Sweet-potato	Morning-glory	Fleshy root	A
Kidney bean	Pea	Seed	A
Lima bean	do.	do.	A
Soy bean	do.	do.	
Cassava	Spurge	Fleshy root	A
Taro (dasheen)	Aroid	Tuber	
Yam	Yam	Fleshy root	
Breadfruit	Mulberry	Fruit	
Sago	Palm	Starchy pith of stem	
Banana	Banana	Fruit	
Plantain	do.	do.	
Date	Palm	do.	
Fig	Mulberry	do.	
VEGETABLES			
Pea	Pea	Seed	
Kidney bean	do.	do.	A
Lima bean	do.	do.	A
Scarlet runner	do.	do.	A
String bean	do.	Pod and seed	A
Beet	Goosefoot	Fleshy root	
Carrot	Parsley	do.	
Parsnip	do.	do.	
Turnip	Mustard	do.	
Cabbage	do.	Leaves	

NAME	FAMILY	PART USED	ORIGIN
Brussels sprouts	Mustard	Leaves	
Cauliflower	do.	Stem and undeveloped inflorescence	
Onion	Lily	Bulb	
Asparagus	do.	Young stems	
Spinach	Goosefoot	Leaves	
Eggplant	Nightshade	Fruit	
Squash	Gourd	do.	
Pumpkin	do.	do.	A
Cucumber	do.	do.	
Tomato	Nightshade	do.	A
Rhubarb	Buckwheat	Juicy petioles	
FRUITS			
Apple	Rose	Fruit	
Pear	do.	do.	
Quince	do.	do.	
Peach	do.	do.	
Plum	do.	do.	A (in part)
Apricot	do.	do.	
Cherry	do.	do.	
Raspberry	do.	do.	A (in part
Blackberry	do.	do.	A
Strawberry	do.	Fleshy receptacle of fruit	A (in part)
Grape	Vine	Fruit	A (in part)
Gooseberry	Saxifrage	do.	A (in part)
Currant	do.	do.	
Blueberry	Heath	do.	A
Cranberry	do.	do.	A

NAME	FAMILY	PART USED	ORIGIN
Pineapple	Pineapple	Fruit	A
Orange	Rue	do.	
Tangerine	do.	do.	
Lemon	do.	do.	
Grapefruit	do.	do.	
Lime	do.	do.	
Watermelon	Gourd	do.	
Muskmelon	do.	do.	
Mango	Cashew	do.	
Avocado	Laurel	do.	A
Banana	Banana	do.	
SALADS, SPICES			
Radish	Mustard	Fleshy root	
Celery	Parsley	Petioles	
Lettuce	Aster	Leaves	
Horse-radish	Mustard	Fleshy root	
Black pepper	Pepper	Fruit	
Allspice	Myrtle	do.	
Clove	do.	Flower buds	
Cinnamon	Laurel	Bark	
Nutmeg	Nutmeg	Seed	
Red pepper	Nightshade	Fruit	A
Mustard	Mustard	Seed	
Ginger	Ginger	Root	
Vanilla	Orchid	Pod	A
SUGARS			
Cane	Grass	Stem	
Beet	Goosefoot	Fleshy root	
Maple	Maple	Sap	A
Corn	Grass	Seed	A

NAME	FAMILY	PART USED	ORIGIN
NUTS			
English walnut	Walnut	Seed	
Pecan	do.	do.	A
Filbert	Birch	do.	
Peanut	Pea	do.	A
Brazil nut	Brazil nut	do.	A
Chestnut	Beech	do.	A (in part)
Almond	Rose	do.	
Cashew	Cashew	do.	A
DRUGS			
Opium	Poppy	Milky juice	
Morphine	do.	do.	
Cocaine	Coca	Leaves	A
Quinine	Madder	Bark	A
Ipecac	do.	Root	A
Strychnine	Logania	Seed	
Castor oil	Spurge	do.	
Chaulmoogra oil	Flacourtia	do.	
Camphor	Laurel	Wood	
Hashish	Mulberry	Seed	
Atropine	Nightshade	Roots and leaves	
Senna	Pea	Leaves	
Aloes	Lily	Juice	
Eucalyptus oil	Myrtle	Leaves	
Digitalis	Figwort	do.	
Sarsaparilla	Lily	Roots	A
Sassafras	Laurel	Bark of root	A
Aconite	Buttercup	Leaves	

NAME	FAMILY	PART USED	ORIGIN
BEVERAGES			
Coffee	Madder	Seed	
Tea	Tea	Leaves	
Cocoa	Sterculea	Seed	A
FIBERS			
Cotton	Mallow	Fiber of seed	A (in part)
Flax	Flax	do. of stem	
Hemp	Mulberry	do. do.	
Abacá	Banana	do. of petioles	
Sisal	Amaryllis	do. of leaves	A
CABINET WOODS			
Mahogany	Mahogany	Wood	A
Ebony	Ebony	do.	
Rosewood	Pea	do.	A
Sandalwood	Sandalwood	do.	
Rattan	Palm	Stem	
DYES			
Indigo	Pea	Stem and leaves	
Saffron	Iris	Stigmas	
Logwood	Pea	Wood	A
Madder	Madder	Root	
Brazilwood	Pea	Wood	A
OILS			
Olive	Olive	Fruit	
Corn	Grass	Seed	A
Coconut	Palm	do.	

NAME	FAMILY	PART USED	ORIGIN
Palm	Palm	Seed	
Peanut	Pea	do.	A
Cottonseed	Mallow	do.	A (in part)
MISCELLANEOUS			
Rubber	Spurge	Milky juice	A
Gutta-percha	Sapodilla	do.	
Chicle	do.	do.	A
Tobacco	Nightshade	Leaves	A
Gum arabic	Pea	Juice	
Turpentine	Pine	Sap	A (in part)
Resin	do.	do.	A (in part)

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APPENDIX

GROUPING OF SOME BETTER-KNOWN PLANTS BY FAMILIES

I. Monocotyledons

The lowermost families of the monocotyledons are the cat-tail family, the pondweed family (with submerged stems and leaves—but also often with floating leaves—and small greenish inconspicuous flowers), the arrowhead family (common marsh plants with arrow-shaped leaves and white flowers), and the frogbit family (containing the tape grass, with submerged tapelike leaves, common in sluggish streams).

The grass family is rather simple in structure but is made up of reduced (derived by evolutionary reduction from more complex groups) rather than primitive forms (see Part IV, page 199). An allied family includes the sedges, which resemble grasses but differ in the floral structure and in having three-ranked leaves and often three-angled stems. The sedges are commonly found in marshes, where they may form distinct zones of vegetation. This family, although large, includes few economic species. The umbrella-sedge of greenhouses and the papyrus of the Egyptians are examples. From the papyrus an early kind of paper was made. The so-called grass or "Crex" rugs are made from Carex, a kind of sedge.

The beautiful and graceful palms constitute a family that has been recognized as a natural group since history began. They are characteristic trees and shrubs of tropical regions, though several species, as the cabbage palmetto of our Southern States, extend into warm-temperate countries, and fossil palms are found in Alaska. The date palm of Arabia and North Africa, now grown in California and Arizona, was early brought into cultivation for its fruit, which is a staple food in the oases of North Africa. The seed of the oil palm of Africa furnishes much of the oil used in making soap. Probably the best known palm is the coconut, familiar to the traveler in tropical countries and to the would-be traveler, who is beguiled by its presence in all advertising matter depicting the delights of warmer climes. Besides being a beautiful tree it is one of the most useful of plants. Its leaves and wood as well as its fruit serve a great variety of purposes. The "milk" of the coconut is a most delicious drink. The dried meat (copra) of the ripe nut is largely exported from tropical countries for its oil, which is used for making soap and for many other purposes. The rattan of commerce is the stem of a climbing palm. The starchy pith of the sago palm is a staple food in the South Sea Islands.

The aroids are numerous in the tropics but infrequent in northern regions. The calla lily (see page 47) is probably the most familiar example of this family. The showy part is a specially modified leaf, inside of which, on the little fleshy shaft, are the minute flowers. Other representatives are the jack-in-the-pulpit, skunk-cabbage, sweetflag, elephant's-ear, and the curious climbing ceriman (*Monstera deliciosa*) of greenhouses, which has large leaves perforated with great holes.

The smallest and simplest of flowering plants are the duckweeds, which are allied to the aroids. As they rarely flower, their relationship to the aroids would not ordinarily be apparent. They are stemless plants from one-twenty-fifth to two-fifths of an inch in diameter and float free on the surface of still water. In summer and autumn these plants may entirely cover the surface of ponds and ditches. They propagate vegetatively, that is, by the budding of one plant from another.

The pineapple family—the bromeliads—includes many epiphytes or air plants. One of these is the long, or Spanish, moss, which hangs thickly from the live oak and other trees of our Southern States. The pineapple originated in America but is now cultivated in all tropical regions.

The lily family and the amaryllis family are closely allied and may be considered together. Many of our ornamental perennial herbs belong here—the narcissus (including daffodil and jonquil), the lily-of-the-valley, the yucca, and the century plant, besides the many kinds of lilies and amaryllises. Members of these families among our garden vegetables are the onion and the allied leek and garlic, and the asparagus.

The yam family is important because it includes the yam, a staple food for millions of people in tropical regions. Its large starchy roots often weigh many pounds. In this country a variety of sweet potato, belonging to an entirely different family, is called yam.

The iris (blue flag) family is allied to the lilies, but the flowers have three instead of six stamens and the styles are quite remarkable, being split into three strap-shaped divisions bending over the three sepals. On the under side of each division is a lip, or flap, which is the true stigma. All this peculiar construction is to aid in pollination. A visiting insect—a bumblebee for example—pushes down under this style division; if there be pollen on the bee's back it is scraped off by the flap and then the bee gets more pollen from the anther just below the flap. To the iris family belong the crocus and the gladiolus.

A group of families allied to one another are the bananas, the gingers, the cannas, and the arrowroot. They all have irregular flowers and broad thin leaves with many side veins running from the midrib to the margin. The banana is a treelike herb, which after bearing a bunch of fruit dies to the ground, the stem being replaced by suckers. The plantain, widely used for food in tropical regions, is a close relative of the banana. Another ally, grown chiefly in the Philippines and neighboring countries, furnishes the fiber abacá, or Manila hemp. The canna, or Indian shot, is a familiar ornamental plant with red or yellow flowers. The ginger of commerce comes from the rootstock of a plant resembling the canna. Commercial arrowroot, an easily digested form of starch used as a food for invalids, comes from the rootstock of a similar plant.

The orchids are the most highly developed of the monocotyledons. The flowers are irregular and many of them very beautiful in shape and color. In number of species the orchids constitute one of the two largest of the plant families, though it is not usual to find large numbers of individuals together. The method of pollination (page 49) is usually complicated, and many species of orchids are so modified that each of them is dependent on a single species of insect for carrying its pollen. Not all the kinds have large and showy flowers, like the *Cattleya*, *Bulbophyllum*, *Dendrobium*, and others seen in our greenhouses; the greater number have small or inconspicuous flowers, some no larger than the head of a pin, but all of curious shape. Many of the vast number of orchid species are epiphytes, growing on the branches of trees in tropical regions; but there are many that are not epiphytes and that grow elsewhere than in the Tropics. In northeastern United States there are eighteen genera and sixty-eight species, all growing on the ground. The moccasin flowers, or lady's slippers, belonging to the genus *Cypripedium* (meaning Venus's shoe), have large saclike lips overarched and flanked by three narrow divisions of the perianth. These orchids—pink, yellow, and white—are found in moist hemlock or pine woods, in sandy bogs and swamps, and in rich woods. Several species of fringed orchids—purple, rich yellow, and white—the rose colored *Arethusa*, *Calopogon*, and *Pogonia*, all of which grow in bogs and swamps and wet woods, are exquisitely lovely in form and color. Many of our terrestrial orchids, however, have small white or greenish inconspicuous flowers. Only one of the great number of orchids has come into commercial use other than as ornamental plants; this is a species of *Vanilla*, a vine of the American Tropics, which furnishes the extract in common use for flavoring.

II. Dicotyledons

The well-marked willow family is made up of the willows and poplars, two groups that have been recognized for ages. The weeping willow (*Salix babylonica*), which has been introduced in our parks and cemeteries, grew by the waters of Babylon, where the homesick Hebrews came to bewail their captivity. The minute unisexual flowers are without corollas and are borne in catkins, so called from a fancied resemblance to a cat's tail. The little gray "pussies" that appear on some willows in early spring are the young catkins before blooming, the fur being the soft hairs on the numerous little bracts. Although the flowers are rather simple in structure they appear to be reduced forms of more highly developed families rather than truly primitive forms like the flowers of magnolias.

The willows and poplars are woody plants, ranging from large trees down to little heathlike forms only an inch or two high. They are easily propagated from cuttings, but it should be remembered that cuttings reproduce the sex, those from staminate trees producing plants with stamens only. If one wishes to propagate the common cottonwood (a poplar) and objects to the numerous cottony seeds of the pistillate tree, one should choose cuttings from a staminate tree.

The oaks form another natural group long recognized; the botanical name for the oak, *Quercus*, is the Latin name for these trees, which were often mentioned by Vergil. The oaks have acorns, a fruit unlike any other.

Related to the oaks are the chestnuts and beeches, which bear from one to four inconspicuous pistillate flowers directly on the twigs and staminate flowers in catkins. In the oak and beech the catkins are small and appear in spring just as the leaves are coming out, but in the chestnut they bloom in summer, forming stiff white fragrant fingers, conspicuous against the green leaves. Less closely allied to these trees are the walnuts and hickories, which have similar flowers and fruits, and the hazelnuts (including the filberts), birches, and alders. The two latter have minute winged nuts borne in conelike catkins. Each of these groups is a genus, the birches and alders form a family, and all the groups together form an order.

Another order includes several allied groups known to us as the elms, the mulberries, and the nettles. One of the mulberries furnishes food for the silkworm. The mulberry family includes the tropical breadfruit and the figs. There are many kinds of fig trees, but the most important is the one that produces the fig of commerce. The rubber plant of the hotel lobby with thick, smooth leaves is a kind of fig. The nettle family includes the stinging nettle, the bane of our childhood when exploring fence corners. The stinging hairs inject a poison under the skin. Allied to the nettles are the hop plant and the hemp.

The buckwheat family contains the grain from which our buckwheat cakes are made and the rhubarb or pie-plant whose juicy acid petioles furnish filling for pie. Several weeds (the smartweeds, docks, and sorrels) and the prince's-feather of our gardens belong here. The little fruits of many species of this family are shiny and triangular.

The amaranths (the pigweed family) and chenopods (the goosefoot family) are sister families in which the flowers are small and lack petals. They contain several common weeds (the pigweed and lamb's-quarters), and also the cockscomb of the garden. In some classifications the apetalous families are placed by themselves as a subdivision of the dicotyledons, but the tendency in modern classification is to distribute them among the petaliferous families to which they are allied. The four-o'clock, belonging to an allied family, has no petals, but the calyx is showy like a corolla. The bougainvillea, a common ornamental vine in warm regions, belongs to the same family, but in this plant it is bracts instead of petals that form the showy part of the inflorescence.

The pink family is well known through the pink and the greenhouse carnations, the bouncing-bet, and the little chickweeds.

The magnolias are thought by many botanists to be the most primitive family of the dicotyledons. There are several cultivated species brought from China and Japan, which bear a profusion of large white or pink flowers in the early spring before the leaves appear. The sepals, petals, stamens, and pistils range from several to numerous and are all separate from each other. The tulip-tree belongs to this family, though its sepals are only three and its petals six. The leaf of this tree is different from those of all others, its broad summit looking as if cut off with a pair of scissors.

The laurel family includes many woody plants with aromatic wood and bark, such as the camphor tree (from whose wood camphor is distilled), the cinnamon (whose bark furnishes the spice), and the sassafras. Another laurel, the avocado or alligator-pear tree, a native of tropical America, is cultivated in southern Florida and California, and its fruit is shipped to northern markets. The leaves of the laurel of southern Europe were used in Roman times to make crowns of victory.

A family allied to the laurel includes the nutmeg tree of the East Indies, whose seeds are the nutmegs of commerce; the mace of commerce is the pulpy covering of the seed. The seeds are dispersed by a kind of pigeon, which swallows the seed with its mace, digests the pulp, and voids the nutmeg uninjured.

The buttercups and their allies are herbs closely related to the magnolia. Their stamens and pistils are usually numerous, as in the common yellow buttercup. To the same family belong the clematis, the hepatica and wind-flower (anemone) of our eastern woods, the marshmarigold, columbine, monkshood, and larkspur.

The water-lilies of our ponds are an allied family, the flowers showing numerous parts, as in the magnolias. They are not lilies in the modern sense at all. Long before the Easter lily and its kind were named *Lilium*, the word was used for any particularly lovely flower.

The crucifers, or mustard family, are a more natural group than are many other plant families, because the structure of the flowers follows a quite definite plan. The group was recognized long before plants were classified in any modern way. They are herbs with pungent juice. The flowers, white or yellow (rarely pink), have four sepals, four petals, six stamens (two of them shorter than the others), and one pistil, which forms in fruit a two-celled pod. The four petals spread in the shape of a cross, hence the family name Cruciferae, or cross-bearers. To this family belong several of our garden vegetables: the cabbage and its derived forms—cauliflower, brussels sprouts, kale, and kohl-rabi, all of which originated from a wild cabbage; the turnip; the radish; the horse-radish; and the water cress. The mustard, peppergrass, and shepherd's-purse are common weeds. The mustard of commerce is made from the ground seeds of the cultivated white mustard and black mustard.

Belonging to distinct but allied families are the barberry and may-apple; the poppies and the bloodroot; the Dutchman's-breeches and bleeding-heart; the pitcher plants; the sundews and Venus's-flytrap.

The saxifrage family contains the currants and gooseberries and several ornamental shrubs, as the hydrangeas, the mock oranges, and the deutzias.

The rose family is familiar and important. The flowers of the common rose illustrate the structure. Inside the calyx and usually showy corolla are numerous stamens and (usually) numerous pistils, as in the more primitive magnolias; but the stamens and petals are attached to the calyx cup, showing a higher development. A comparison of the flowers of the strawberry, the blackberry, and the apple show such a close similarity that they are generally placed in this same family regardless of the differences in general appearance (herb, shrub, and tree). Many of our common fruits belong to this family—apple, pear, quince, peach, plum, cherry, apricot, strawberry, raspberry, and blackberry; also many ornamental plants, such as roses and spireas.

The pea or legume family is a large one, the members of which are easily recognized by the peculiar shape of the flower. The sweet pea, the garden pea, the bean (many kinds), the lentil, the clovers, and the alfalfa, the black locust, and the beautiful wisteria vine are familiar members of this family. An examination of the flowers will show a remarkable similarity throughout; for example, the single flower of a clover head will be seen to have essentially the same structure as the sweet-pea flower. The fruits also are similar (they are all pods), though differing in size. The peanut, much cultivated for its oil and known to us through the peanut stand, is peculiar in that the flower, which is formed above ground, buries itself so that the fruit develops underground. This burial, of course, is aided in cultivation. The pod contains one to three seeds —the "nuts" that we eat. The seed is very similar to that of a bean; when the two halves or cotyledons are spread apart, the little plumule or stemlet can be seen at the base.

Members of families allied to the legumes are the geranium, commonly grown as a house plant; the flax, from the fibrous stem of which linen is made and whose seeds (linseed) yield a valuable oil and a residue (oil cake), which is nutritious food for cattle; the oxalis and the wood sorrel, known for their acid, their cloverlike leaves, and for their pods that shoot when touched; and the nasturtium of the garden with curious peltate leaves (the stalk or petiole growing from the center of the round blades).

The rue family is important to us because it includes the citrous fruits. The Latin generic name, *Citrus*, has given us the adjective citrous. We have also citric acid, the acid of the citrous fruits, most abundant in the lime and lemon; and the citron, the fruit whose rind is candied. The citrous fruits common in our markets are the orange, tangerine, lemon, and grapefruit. The lime is less common but is grown in the West Indies for the production of lime juice and citric acid. The family is represented in the Eastern States by the prickly-ash and the hop-tree.

The spurge family contains many familiar species. The garden croton, with its curiously mottled and variously colored leaves often twisted in a spiral, is commonly cultivated in warm regions. The seeds of the castor-oil plant, which look absurdly like potato bugs, furnish the castor oil used in medicine and as a lubricant. The "gourd" that angered Jonah, because after coming up so quickly and giving him hopes of a bit of shade it withered and died in a night, has been identified as the castor-oil plant. It is still planted beside primitive huts in far corners of the world because it grows so quickly. The cassava (manihot, mandioca) is, next to the grains and the potato, one of the most important food plants of the world. The starchy, fleshy roots are the parts used. Some sorts contain hydrocyanic acid, a deadly poison; however, this is dissipated by cooking. The home of the cassava is Brazil, but it is now widely cultivated in all warm regions. The edible product of the plant comes into the American market in a purified form as tapioca. A Brazilian tree belonging to this family is the source of Pará rubber, now the most important rubber of commerce. It is cultivated extensively in the Malay region. Rubber is also obtained from plants of other families. Some spurges of arid regions resemble certain kinds of cactus. The Christ-thorn, or crown of thorns, which has small blood-red flowers and spiny stems, is a spurge. Many spurges have milky juice.

The sumacs come in the cashew family. The poison ivy and poison oak are two forms of the same species, the first climbing on tree trunks by rootlets, the second shrubby. The leaves have three leaflets, and the fruit is a cluster of dry white berries. The foliage contains an oil, which poisons the skin of many people who come in contact with it. The red-berried species are harmless. A resin (lacquer) commonly used in making varnish is obtained from a Japanese species of sumac. To this family belong the cashew nut, the pistachio nut, and the luscious mango.

Allied to the cashews is the ilex family, to which belong our Christmas holly and the Paraguay tea (a common beverage in South America); the maple family, including the maples, the buckeyes, and the horsechestnuts; and the balsam family, including the sultana and touch-me-not of our gardens and the wild jewel weeds of wet woods, all of which have succulent stems, irregular flowers, and explosive pods.

The vine family includes the Virginia creeper and the Boston vine, as well as the grapes. The grapes are a well-recognized genus characterized by their fruits and their tendrils. The Old World grape has been cultivated since prehistoric times. The wine grape of Europe and the imported table grapes belong to this species, which is also cultivated extensively in California. The grapes of the United States, except California, are varieties and hybrids of a few American species. The American grapes differ from the European in that the contents may be pinched out from the skin (hence sometimes called "slip-skins"). Because of the ravages of the phylloxera, a root louse introduced from America, the European grape is now grafted upon the roots of an American species that is immune to the attacks of the insect. Raisins are dried grapes of certain varieties and "currants" (originally imported from Corinth, Greece) are a small seedless variety of raisin.

The basswood, linden, or limetree, belongs to a family but poorly represented in the United States. The spokes of the "One-hoss Shay" that lasted a century, were made of basswood. Jute fiber used for bagging is obtained from an allied shrub of the East Indies.

The mallow family, of which the common hollyhock of the gardens is a good example, is distinguished by characteristic flowers. These are usually showy and have a mass of stamens arising as a conspicuous column from the center. Of this family is cotton, which, aside from the food plants, is probably the most important plant in the world. The cotton fiber, an outgrowth of the seed, is removed by a ginning machine. The seed itself furnishes the well-known cottonseed oil, and, after the oil is pressed out, a much-used fertilizer and cattle food (oil cake). The picking of the cotton has been done by hand and is a laborious process, but machines for picking are now coming into use. Some years ago a well-known scientist in the Bureau of Plant Industry, speaking at a meeting of scientists of the need of a machine for picking cotton, facetiously remarked that perhaps monkeys could be trained to do the work. Somehow a newspaper reporter heard of the remark and a fine story about monkeys as cotton pickers appeared in the press. The Bureau was soon bombarded with requests for further information as to where these trained monkeys could be obtained—all this much to the discomfiture of the scientist. To the mallow family belong the hibiscus—including the Chinese hibiscus (rose of China) and the shrub-althea (rose of Sharon)—and other ornamental trees and shrubs as well as okra, or gumbo, a vegetable popular in the South.

The ailanthus, or tree of heaven—a large graceful tree introduced from Asia—the cacao (*Theobroma*), which is the source of chocolate, and the kola nut belong to a family allied to the mallows. The cacao is a large tree and bears small fragrant white flowers from adventitious buds on the trunks and large branches. The fruit, borne directly on the trunk and branches, is fleshy and measures eight inches or more in length. Tea belongs to a family not far removed.

Several interesting families, mostly tropical, intervene between the foregoing and the violet family, of which *Viola*, with a hundred or more species in the United States, is the largest genus. The violets (which include the pansy) form a very distinct group, the flowers, though differing in size and color, all being readily recognized as of one pattern. In addition to the flowers we all love, which are pollinated by insects, very small short-stalked flowers without petals which never open and are close-pollinated, are produced by most of the species. These continue to appear all summer, circles of plump seed pods being found under the leaves or partly buried in the soil until fall. The pods when ripe burst violently, throwing the seeds in all directions.

Rather nearly related to the violets is the highly specialized family of passion flowers. These beautiful flowers, found growing in the wilds by the early padres, were pointed out to the Indians as showing forth the Lord's passion. To quote Lindley, "Thus the three nails—two for the hands, one for the feet—are represented by the stigmas; the five anthers indicate the five wounds; the rays of glory, or some say the crown of thorns, are represented by the rays of the corona; the parts of the perianth represent the Apostles, two of them absent—Peter who denied, and Judas who betrayed our Lord; and the wicked hands of his persecutors are seen in the digitate leaves of the plant, and the scourges in the tendrils." The passion flower is frequently used as a motif in ecclesiastical embroidery and decoration. Several species of passion flower grow in our Southern States, the large purple flowers beautifying the railway embankments of the Carolinas in places. The fruits of some species are edible.

The begonias, belonging to a small family of tropical and subtropical herbs, have fleshy stems, unsymmetrical leaves—often strikingly colored—and waxy flowers. They are favorite house plants, some of them being easily propagated from adventitious buds that develop on the leaves from incisions.

The cactus family is a striking group, of American origin, highly specialized and adapted to desert or semi-desert conditions. The stems are condensed into fleshy, succulent, usually very spiny columns, globes, or ovoid or thick flat joints. They are protected from evaporation by their reduced surface (most of them having no normal leaves), and from herbivorous animals by the abundant spines. The giant cactus of Arizona is a familiar component of the desert scenery, its columnar stems rising to heights sometimes as great as sixty feet. The barrel cactus is a source of water to the hard-pressed traveler in the desert. He cuts off the top, pounds up the pulp in the barrel-shaped body, strains out the juice and drinks it. The prickly-pears have thick flat joints with backwardly barbed spines, which stick in the flesh and are difficult to withdraw. Ranchmen of the Southwest singe off the spines with gasoline torches in order that cattle may eat the succulent joints, and even cultivate these plants, singeing enough for a feed each day. The cattle hear the torches and come running from all directions. No fences are needed, as the cattle can not touch the plants until they are singed. Spineless forms have been developed, but they must be fenced and cut for fodder. The fruit of some species—the "pear," or tuna—is used for food. Another species harbors the cochineal insect, which furnishes a red dye. The juice of the cactus, under the name of cactizona, is now coming into use for purifying boiler tubes. The early explorers found the various kinds of cactus so curious that they carried them back to Europe from the deserts of America. The prickly-pears (*Opuntia*), particularly, propagate so readily from the thick joints that they soon became established in congenial places throughout the Eastern Hemisphere. One species occupies great areas in the drier parts of the Mediterranean region, and prickly-pears are a serious pest today in Australia. The Indian fig, a species of *Opuntia*, is so characteristic a feature of the landscape of Palestine that in many old paintings portraying incidents in the life of Christ this plant is conspicuous, though it did not appear in that region till fifteen hundred years after the events pictured.

The families to which the pomegranate, the Brazil nut, and the mangrove belong, are allied groups. They are all related to the myrtle family, which comprises the eucalyptus trees (natives of Australia, but now grown in California, Brazil, and elsewhere), the guava, allspice, and cloves. Another relative of these groups is the evening primrose family. It contains the evening primrose, whose flowers are open during the night. Some of these flowers have corolla tubes as much as four inches in length and are pollinated by night-flying sphinx moths. Fuchsias (named for an early German herbalist, Leonard Fuchs), the beautiful house plants, belong to this family.

The parsley family (Umbelliferae) is one of the most natural families that we have. Its members are herbs that have furrowed, pithy stems, usually much divided leaves, and aromatic or acrid juice. The structure of the flowers and fruit is very similar throughout the group. The small flowers are borne in clusters on the ends of branches that start from about the same place, like the ribs of an umbrella, and make flat-topped inflorescences called umbels. Celery, carrot, parsnip, caraway, anise, coriander, and parsley, and also poison hemlock belong to this family.

Closely related is the aralia family, which contains English ivy, and ginseng and other medicinal plants. The dogwoods—a small family, mostly shrubs—have given us many ornamentals such as the flowering dogwood and cornelian cherry.

The heath family is the first in the large division of the dicotyledons in which the petals are united more or less into a cup. The common European heather, the azaleas, rhododendrons, and mountain laurel, which glorify our mountain slopes and our gardens in spring, as well as blueberries, huckleberries, and cranberries, belong to this family. The flowers of the heaths are highly specialized for insect pollination. In the mountain laurel and some others the stamens are set like a trigger so that, when released by the insect's tongue, they shoot the pollen over its body.

The cultivated primroses and cyclamen and our native shooting-star belong to a small family, composed mostly of herbs.

The ebony family, made up in the main of tropical trees and shrubs, is represented in the United States by the persimmon. Ebony wood is obtained from an allied species.

The olive family contains our ash trees, the cultivated lilac, and the olive. Allied families are those of the gentians and the milkweeds, both of which have many genera in the United States.

The morning-glory family is characterized by a flower in which the petals are completely united to form a cup or salver. The members of the family are mostly twining plants and include the cypress-vine and morning-glory, the bindweed, or wild morning-glory (a species of *Convolvulus*), and the sweet-potato (a species of *Ipomaea*). The sweet-potato, a native of Brazil, is now extensively grown in warm regions throughout the world. A reduced member of the family is the dodder, or love vine, a yellowish parasitic vine which grows on weeds in August.

The phlox family (including the sweet William phlox), the borage family, containing the heliotrope and forget-me-not, and the verbenas, follow in order.

The mint family is a large natural group that has opposite leaves, square stems, and aromatic foliage. The two-lipped irregular flowers are pollinated for the most part by insects that alight on the lower lip as a landing stage. Many of the mints yield essential oils, as the peppermint, lavender, and pennyroyal; some—such as marjoram, thyme, and sage—are savory herbs of the kitchen garden. The scarlet sage is commonly cultivated for ornament.

The nightshade family contains many medicinal plants, such as belladonna, capiscum, and henbane, and several cultivated for food. The white potato (so-called Irish potato) is one of the important food plants of the world and a source of starch. It originated in South America but was early introduced into Europe. The tomato also came from South America and was first introduced abroad as an ornamental, but for many years it has been widely used as a vegetable. The red or Cayenne pepper (chilies) and sweet peppers, allied to the tomato, are also of American origin. The eggplant came from Asia. The ground-cherry and strawberry-tomato have berries inclosed in a bladdery husk. Tobacco, another American plant, is now grown all over the world for its leaves. The petunia is a garden flower.

The figwort family, Scrophulariaceae, from its principal genus, *Scrophularia*, so-called because the root of one species was once used as a cure for scrofula, or king's evil, resembles the mint family in that most of its flowers have two-lipped corollas; but the plants are not aromatic. The common mullein belongs to this family, as do some of our garden flowers—foxgloves, snapdragon, monkey-flower, veronicas, pentstemons, and calceolarias.

The family to which the catalpas and trumpet creepers belong and the broom rape family are closely related to the figwort family.

The ribworts or plantains, widespread as weeds in lawns and waste ground, constitute a single family and order, and have no near relatives living.

The madder family is very large but contains only a few familiar plants. The Cape jasmine (*Gardenia*), a fragrant shrub, and the buttonbush belong here, and two important economic plants as well—coffee and cinchona. From the bark of the latter is extracted quinine. Allied to the madder family is the honeysuckle family, which includes the elderberry, the viburnums, the snowball, the weigela, the honeysuckles, and other ornamental shrubs and vines.

The gourd family consists mostly of herbaceous vines, trailing on the ground or climbing by means of tendrils. The family contains many useful plants—watermelon, muskmelon (including the cantaloupe), cucumber, pumpkin (or punkin), and the various kinds of squashes. The pumpkin is of American origin and was cultivated by the Indians at the time of the landing of the Pilgrims. The gourds have long been cultivated for their hard-shelled fruits, which when scraped out served for drinking cups and receptacles. Gourds supplied American pioneers with many conveniences, from dippers to darning eggs. They are still in everyday use in regions remote from trade routes. The wild cucumber or wild balsam-apple is an ornamental vine.

In the related families of the bluebells and lobelias we find a number of our garden favorites—bluebells, bellflowers, and canterbury-bells, and the lobelias, ranging from the brilliant cardinal flower to the little blue edging lobelia, commonly used for borders.

The last family of the series, the aster family, thought to be the most highly developed of the dicotyledons, is also the largest in number of species. The flowers are minute and gathered into heads and many of them, as in the oxeye daisy and sunflower, have inconspicuous flowers in the middle and ray flowers—that is, flowers with strap-shaped corollas—around the edge, the whole simulating a single flower with numerous petals. In the dandelion and its near relatives all the flowers have strap-shaped corollas, and in the ironweed and thistles all the flowers have tiny vase-shaped corollas. A queer group, regarded by some as a distinct family, is that of the ragweeds, most of which have the staminate and pistillate flowers in separate heads. They are accused of being the chief cause of hay fever. The cocklebur, or clotbur, of weedy pastures belongs to this group. Although so large, the aster family, known also as the composites, contains relatively few plants of economic importance. Lettuce, chicory, and endive, dandelion, salsify or oyster plant, globe artichoke (which is the very young head of a plant closely related to the thistle), and Jerusalem artichoke (the tuberous rootstock of an American sunflower) add savory vegetables to our tables. Sunflower seeds are eaten in Russia and elsewhere and in this country are fed to chickens, besides being the favorite food of caged parrots. Pyrethrum, from which insect powder is made, and guayule, a source of rubber, belong in this family, as do many of the herbs such as tansy, boneset, snakeroot, yarrow, camomile, and arnica, prized as home remedies by pioneer mothers far from doctors.

Many beautiful cultivated flowers—asters, chrysanthemums, calendula, cornflowers, coriopsis, cosmos, dahlia, daisies, gaillardia, goldenglow, and zinnia—belong to this family, and our wildwoods, prairies, and swamps, especially in late summer, are gorgeous with purple and gold composites, among which the asters and goldenrods take a prominent place. But a family so aggressive, so adaptable to different environments that it out-numbers all others, can not but intrude where man does not want it, and such intruders are weeds. Dandelions, prickly lettuce, burdock, devils-pitchforks or beggar-ticks, thistles, dog fennel, ragweed, and a host more are cordially hated by the weary gardener.

Only a small number of the 280 families of flowering plants included in the Engler and Prantl system of classification have been mentioned in the preceding outline.

Part II

SYSTEMATIC BOTANY: ITS DEVELOPMENT AND CONTACTS

By

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CHAPTER I

THE ORIGIN AND DEVELOPMENT OF SYSTEMATIC BOTANY

Botany had its beginning in prehistoric time. It arose from the practical need of distinguishing between plants that ministered to man's wants and those which did not—of learning to pick out unerringly those kinds that could serve for food or medicine, for shelter, and for weapons or other implements. For each kind added to the categories of useful plants, scores must have been discarded or passed by; and yet the number regarded favorably, especially among those classed as medicinal, was very large, if we may judge from our knowledge of primitive peoples of the present day.

This special knowledge, slowly acquired by primitive man from trial and observation and handed down orally through untold generations, has afforded many a clue—notably in medicine—leading eventually to the most beneficent usage in our highly complicated modern life. Again and again, on the strength of some such hint, we carry out laborious exploration in distant tropical wildernesses, searching for the sources of useful plant products that primitive man has brought to our attention. To this simplest early type of plant study, crude and unorganized from a scientific standpoint, we owe a debt beyond calculation in agriculture, medicine, horticulture, and a score of related fields, upon which our existence in comfort and our cultural life depend.

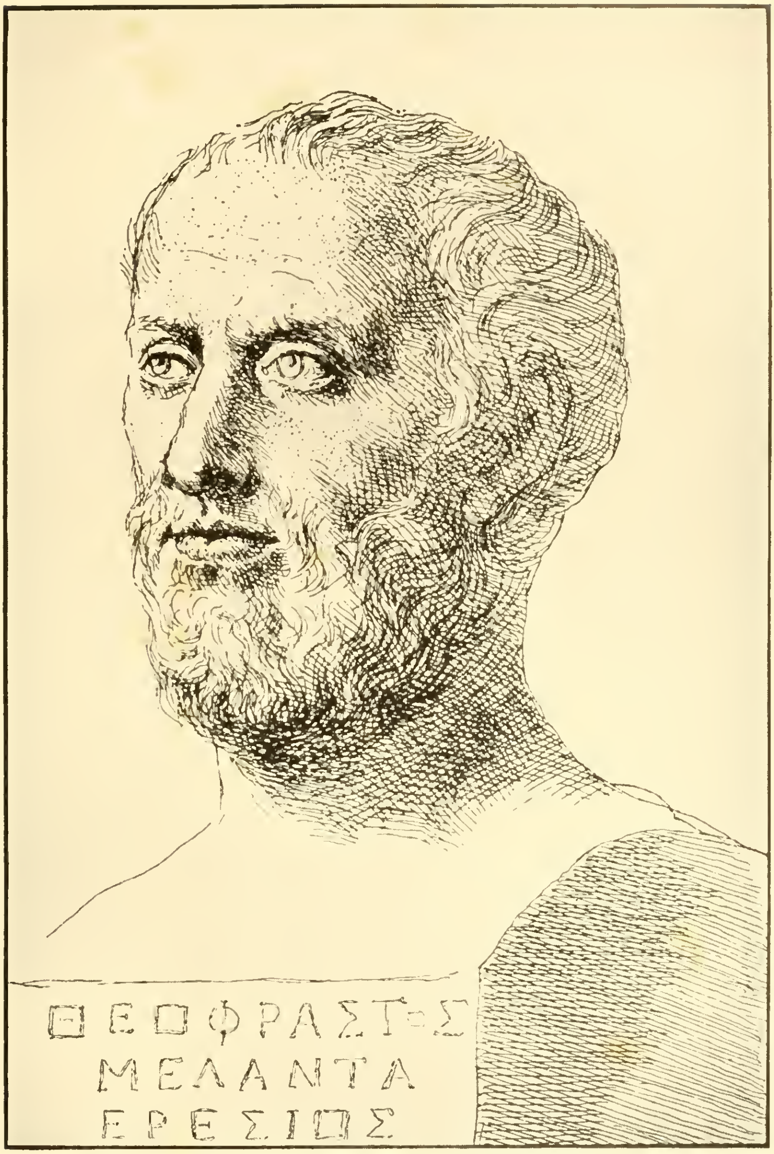
As a science, botany is classic and the oldest branch of natural history. If we are to understand something of its present scope and especially the intimate relation which plant taxonomy bears to the many other fields of modern botanical research, we can scarcely avoid tracing briefly the development of botany from its origin, as disclosed in the earliest writings upon plant husbandry.

Aristotle and Theophrastus

In the wide field of botany, as in so many others, our first recourse is to ancient Greece. As Hippocrates is known as the "Father of Medicine," so also the title "Father of Natural History" is universally conferred on Aristotle. Apart from conclusions based upon personal observation, his sources of information were widely scattered in the writings of early Greek poets and philosophers and were found also in the dubious practices and tenets of the *rhizotomi*, or root-gatherers, a half-illiterate class of men among the Greeks, who for many centuries had followed the occupation of preparing and selling roots and herbs that were of medicinal repute. Many of Aristotle's inferences with regard to the facts of physiology and distinction of sex were inaccurate or quite mistaken; but so, we may recall, were the inferences of many of his successors, all the way down to recent times.

Next after Aristotle comes Theophrastus (Plate 19), supplementing the work of his predecessor and carrying it forward consistently to a point that has earned for him the designation "Father of Botany." He was born at Eresos on the famous Aegean island Mitylene (anciently known as Lesbos), in the year 370 B.C., and while a youth had become, with Aristotle, a disciple of Plato in Athens. Following Plato's death, Theophrastus studied under Aristotle, with whom his relationship appears to have been not only that of favorite pupil but of devoted friend and colleague as well, for on the latter's death at the age of sixty-three he received by bequest the exceedingly rich library of his preceptor, Aristotle's own manuscripts, and the botanic garden which Aristotle had established at

PLATE 19



Theophrastus, "Father of Botany"

Athens. Here during a long lifetime (he is said to have lived to the age of 107) Theophrastus studied, wrote, and lectured. His disciples numbered two thousand. He composed voluminously and upon widely diverse topics, in all more than 225 treatises, of which his two botanical works are foremost. Of these his *Historia Plantarum*, nearly complete in nine books, is the more important.

Concerning Theophrastus as the author of what Edward Lee Greene calls the oldest distinctively botanical treatise extant, one is tempted to quote at length, picturing his unique position with respect to the development of true botanical science and the setting in which he flourished. "He writes," says Greene, "from the midst of an advanced civilization; a state of society in which there is much farming, extensive cultivation of the vine and olive, fruit growing, market gardening, and cultivating of medicinal, aromatic, and ornamentally flowering herbs, shrubs, and trees; a time when many improved varieties of all sorts of things have been devised through cultivation, and when it is already perfectly well known that such improved varieties can not be depended on to come true to seed, but may be preserved, and the stock of each increased by division of roots, by cuttings, and by grafting." With this vast amount of horticultural knowledge, practice, and theory, and with ancient myth and "superstitious fable" Theophrastus was thoroughly acquainted, first of all; and if, according to Greene, "as a mere annalist he had but recorded the untaught industrial and experimental botany of his period, together with that very considerable vocabulary of botanical terms which then formed a part of the Greek language, he would still have done us an inestimable service." Actually he did infinitely more, departing from stereotyped utilitarian method and considering primarily the different kinds of plants in relation to each other and their environment, and plant organs and structures after the method now employed in comparative organography and morphology.

Throughout his writings there is abundant reference to the economic uses of plants and to special plant products, as he was dealing chiefly with plants long in cultivation and with wild species of known utility; but his attitude was purely philosophical. There was no restraining his keen inquisitiveness about all vegetable life, an interest that was mainly concerned with the study of plants for its own sake and that led to the most acute observation of minute structures of fruit, flower, foliage, root, stem, and tendril, and particularly of seeds, their structure and germination, and the behavior of seedlings.

Theophrastus exerted a profound influence on later botanical study and writing. Admittedly no traveler, he naturally drew much of his information from classical and contemporaneous sources; yet the method of treatment was his, and much of the fact new and his own. The very extent, thoroughness, and minuteness of his recorded observations (such as dates of fruiting and flowering, and the effects of drought and moisture) and of his comparative studies point unmistakably to first-hand acquaintance with the living plants, of which a very considerable number were under cultivation in the garden bequeathed him by Aristotle. In all, he discusses some four hundred fifty species, ranging from truffles and seaweeds to pines, domesticated grasses, and thistles. Of the groups that he distinguished, upward of one hundred genera recognized in our present-day botany books still bear the scientific names he gave them; for example, *Crataegus* for the hawthorn, *Aconitum* for the well-known medicinal aconite, *Asparagus* for the table vegetable known by that name, and *Aristolochia* for the grotesque and fetid-flowered plant we know as Dutchman's pipe. Of a unique system of plant names as something apart from the Greek language in every-day use he appears to have had no notion. Different plants were to bear distinct and characteristic names in Greek, his mother tongue; and when in later centuries the Latins studied botany, making the closest use of Theophrastus's Greek texts, not only his descriptions but very many of his Greek plant names as well were carried over into the newer language, and it is thus that they have come down to us in latinized form.

Other Greek and Roman Writers

Of writers upon plants in the period immediately following Theophrastus there were very many among the Greeks, comparatively few among the Latins. These authors, however, were concerned chiefly with horticultural, agricultural, and medical botany, and for the most part copied or paraphrased the works of Theophrastus, adding little to the sum of systematic knowledge, so far as can be made out from the fragments of their writings that are preserved. A few names stand out preeminently. Such are Nicander, a Greek naturalist of the second century B.C., who wrote in verse of agriculture generally and of drugs and poisons in particular, including the earliest known dissertation on poisonous fungi; Cato (234–149 B.C.), whose treatise *De Re Rustica*, dealing with agriculture, gardening, and the culture and propagation of choice fruits, is the earliest work of the sort in Latin literature; Varro (116–27 B.C.), versatile genius and most distinguished of erudite early Romans, who amid the routine of an active military career found time to write of philosophy, literary and political history, antiquities, navigation, education, language, and agriculture, the last treatise (in three books) begun in his eightieth year; Vergil (70–19 B.C.), foremost of Latin poets, whose Georgics, devoted to agriculture and gardening, reflect a profound first-hand knowledge of plants greatly exceeding in amount and extent that of any other early Roman writer; Dioscorides, a Cilician Greek of Nero's time (about 50 A.D.), learned physician and traveler, who in distinction from others of the same period added to Theophrastan botany a knowledge of about one hundred medicinal plants new to Greece and Rome, described them, and systematized the whole for the benefit of medical students, becoming incidentally, as Greene remarks, "the first master of phytography"; and the elder Pliny (23–79 A.D.), indefatigable Roman, jealous of every moment, whose *Historia Naturalis* in thirty-seven books, includes sixteen pertaining to botany, chiefly medical, horticultural, and agricultural.

Pliny's work was very largely a compilation, drawn from the writings of Aristotle and Theophrastus, Nicander, and Dioscorides, and contains little that is distinctly new or of philosophic bearing, its trend being decidedly economic and practical; yet it enjoyed high repute in early medieval times and definitely helped to pave the way for the beginnings of modern botany in the sixteenth century.

Here also must be mentioned Galen (130–200 A.D.), a Greek genius and erudite scholar, who in the annals of early medicine is ranked second only to Hippocrates. An accomplished linguist, from early youth he traveled widely in the countries bordering the Mediterranean, seeking "the most perfect knowledge of every plant anywhere in use remedially." Doubting the care or scrupulousness of herb gatherers and venders, and denying the efficiency of written descriptive comment as a means to the correct identification of plant materials, he urged upon all physicians the necessity of knowing the plants in nature, their distinctive characters, and the appropriate seasons of gathering, in order themselves to be able to differentiate the false and the genuine in pharmacology. Accordingly, although he wrote voluminously, his special province and attainments were those of lecturer and teacher, his contribution to descriptive botany being relatively slight.

The Renaissance

From these centuries onward to the sixteenth the record of growth in botanical science is nearly lost, if indeed there may be said to have been any real advance. However, following the development of printing in Europe the work of Dioscorides was published in Greek (in 1499), and shortly afterward there appeared numerous versions of this in Latin. The plants and plant products known to Dioscorides numbered six hundred. These he had excellently described, and "it was because he had described so many, and often so well, that in after ages he came to be regarded as the supreme botanist," his writing "more attentively studied word by word, and that by a greater number of erudite men, than any other book about plants that has yet been written."

In referring to the botanical renaissance of the sixteenth and seventeenth centuries the term "German Fathers of Botany" has commonly been used to designate as pioneers a group of four famous herbalists—Brunfels, Fuchs, Bock, and Valerius Cordus. The first two were successful physicians, concerned primarily with medical botany, who, realizing the state of confusion into which it had fallen, undertook to make easy and sure the identification of remedies by publishing new and lifelike engravings of medicinal plants, executed from actual specimens.

In strong contrast to the efforts of Brunfels and Fuchs stand the work and method of Bock and Cordus. Both these men were keen students, and it was their conception that, laying aside the misapplied descriptive matter handed down or revived from a distant past, plants of all kinds should now be accurately described with critical attention to every detail, and in such a way as to be recognizable from description alone, without recourse to illustration.

Bock is the first of the so-called German Fathers actually to describe plants. At first he wrote in German and for the enlightenment of German readers, dealing with the plants familiarly at first hand, and it is owing largely to this circumstance that his descriptions, afterwards republished in Latin for the benefit of scholars in other lands, were of such high originality and excellence. His descriptions were in reality word pictures, and they dealt with many species previously unknown, sought out and studied by him in what he terms "the great book of Nature." He was the first investigator of stamens and pistils, and the first also among botanical writers to publish average dates of flowering for native plants, basing his records on observations covering many seasons; yet he could and did believe in the transmutation of one kind of cereal into another, in the raising of a crop of turnips "from very old cabbage seed sown by my own hands," and in the origin of orchid plants from the excreta of birds.

Of far greater and even of epoch-marking import was the work of Valerius Cordus, who has been called the one botanical genius of the German Renaissance. Trained to independent thought and research by his illustrious father, the younger Cordus early became an indefatigable field botanist and in the course of his ramblings discovered among his native German fields and mountain forests several hundred new species. These he elaborately described, and at the same time he redescribed from actual specimens many of the classical plants of remedial repute. At the age of twenty-five he had already prepared in Latin the manuscript of a work in four books, called *Historia Plantarum*, describing in the fullest detail 446 species. He died in Italy four years later (1544), following a period devoted to university studies and to the most laborious exploration, often in unhealthful regions. His great manuscript work, with the addition of a fifth book, was published posthumously in 1561–63 under the editorship of Conrad Gesner. Unfortunately, at the insistence of a practical-minded publisher, it was embellished with 280 figures taken from Bock's *Kreuterbuch*, these in part not applying to the plants so fully described by Cordus. As a result confusion arose; but even this has not prevented the final recognition of Cordus as the first great master of plant description in a modern sense, the first one indeed to draw up complete technical descriptions according to a definitely formulated plan.

The descriptions written by Cordus were all based on mature living plants in fruit or flower, or both. Commonly the most obvious parts of each plant are discussed first, the stem and foliage; then the reproductive parts—types of inflorescence, modified leaf-structures associated with the flowers, and characteristics of fruits and seeds; next the root, with careful attention to its persistence, whether annual, biennial, or perennial; and finally, notes on the distinctive flavors and odors of plant parts, with relatively scant mention of medicinal qualities. The same plan of description was followed by Cordus both with the new German species and with the old medicinal plants dating back to Dioscorides, and its deliberate adoption, together with his important contributions to a knowledge of flower structures, marks a great advance in the method of plant description. Though essentially conservative, Cordus insisted on the regrouping of plants in natural family relationship on the basis of flower structures, as in the legumes, the melons, and the buttercups, and he is reputed to have been the first author since Dioscorides to establish a large number of new genera of plants, these mostly of his own discovery in Germany. His book thus becomes an important botanical landmark and well worthy of the searching study to which it has latterly been subjected.

Other notable figures of this period include the English herbalist, William Turner; Ghini, a celebrated teacher and lecturer upon botany, with whom Cordus had studied in Italy, and the first apparently to study botany from dried plants and to suggest preserving them permanently as reference specimens, attached to sheets of paper; Conrad Gesner, Swiss physician, bibliographer, editor, teacher, accomplished linguist, and classical scholar, founder of perhaps the earliest zoological museum, prodigious writer and skillful draftsman, learned all-around naturalist, whose great work, *Historia Plantarum*, to be illustrated with nearly 1,500 drawings by his own hand, remained unpublished at his death in middle life; John and Caspar Bauhin, the latter's outstanding contribution, *Pinax Theatri Botanici*, a descriptive treatise dealing systematically with some 6,000 species, beginning with the grasses and including many previously undescribed plants, such as the lilac. In later botanical history the influence of Bauhin's *Pinax* proved important, most of the scientific names employed by him being adopted by Ray, Morison, and Tournefort.

Particularly to be mentioned also are the Flemish botanist Clusius (1526–1609), Caesalpinus (1519–1603), Lobelius (1538–1614), and Jung (1587–1657), all of whose contributions were considerable. More and more, plants came to be studied for their own sake and not for their utilitarian values, and the results were continually reflected in new ideas of classification, these pointing a slow but steady advance. In England there were Morison (1620–1683) and Ray (1628–1705); in France, Tournefort (1656–1708), who established a large number of genera. Aside from classification, Ray was keenly interested in the sexuality of plants, a doctrine proved experimentally and almost contemporaneously by Camerarius, who states explicitly that the stamens are male organs and the style and ovary female organs.

The Modern Era

There now appears on the scene Karl von Linné, better known under his Latinized name Linnaeus (1707–1778), a remarkable systematist (Plate 20), whose influence in formal natural history classification has greatly exceeded that of any other person in recent times. At the age of twenty-three he had become curator of the Gardens of the University of Lund. Following this he traveled for several years in northern Europe, settling in 1741 at the University of Upsala, where he occupied the chair of botany during the remainder of his long and uneventful

Linnaeus at the age of 67. After the painting by P. Krafft

life, teaching and publishing. His voluminous writings, devoted strictly to describing and systematizing, had the whole natural history world of that day as their field. In botany his *Genera Plantarum* and *Species Plantarum* are preeminent as providing for the first time a complete structure, erected upon sound philosophical grounds, of the plant kingdom as then known—the species briefly and accurately described (partly by quotation of very numerous phrase names and illustrations published by his predecessors), the genera indicated clearly and precisely as groups of closely related species, and a concise system of names applied consistently to both throughout.[1]

It has been said that Linneaus was no investigator, and that his work contains no evidence of new and important discoveries; which may be admitted without detracting from his fame as a literary craftsman and master-builder, who brought together and dissected the published works of earlier descriptive writers and out of the whole selected and arranged the materials necessary to his own new structure, "a building that was hailed as a masterpiece both by his contemporaries and by generations of admiring pupils." The so-called sexual system of classification adopted by Linneaus was highly artificial and led to the erroneous close association of distantly related groups, and this at a time when a more natural arrangement based upon obvious traits of blood relationship was well under way. From this standpoint the Linnaean arrangement may fairly be called retrograde, yet it is rather idle to speculate as to how greatly its influence may have retarded the general advance. It was, at any rate, a workable system, one by which plants might readily be identi-

[1] The so-called binomial nomenclature, under which each species has a "double" scientific name, generic and specific; that is, the genus name (such as *Polypodium*), applied in common to all the members of a group of closely related species; and the species name itself (e.g. *vulgare*), which is appended to the genus name and is used only for a single species within the genus. Thus: *Polypodium vulgare*, a common fern of temperate regions; *Polypodium aureum*, a tropical American fern with golden-chaffy rootstocks. Both belong to the genus *Polypodium*, but each has its distinctive *specific* name.

fied, and so was of immense utility, even though it tended to obscure natural relationships. Moreover, the service of formulating and putting into universal practice the simple binomial system of nomenclature is one that for all time places students of natural history under deep obligation to this keen-minded and vigorous organizer. For an interpretation of the genera and species recognized by Linnaeus we must in large part go back to the writings of earlier authors, but we still adhere to his choice of scientific names and retain them in common use, in so far as practicable, this in accordance with the so-called rule of priority in binomial nomenclature—a name-system of which Linnaeus was the first consistent exponent.

Notwithstanding the immediate popularity of the Linnaean system in many quarters, it was inevitable that more natural schemes of classification should be proposed. The first of these was offered by a famous French botanist, Antoine Laurent de Jussieu (1748–1836), whose *Genera Plantarum* (1789) proved the forerunner of our modern understanding of plant relationships by families. This in turn served as the basis of the classical *Théorie élémentaire de la botanique* by Augustin Pyrame de Candolle (1778–1841), in which plant anatomy is emphasized as the key to classification; in the last edition of this work, brought out in 1844 under the editorship of his son Alphonse, 213 "orders" or families of plants are described, very much as recognized at present.

In the meantime other and diverse schemes of classification had been advanced, as those of Endlicher, Brongniart, and Lindley, and a wealth of material for study had been flowing in continuously from the four corners of the world. Much had been accomplished in England, largely through the efforts of Sir Joseph Banks and the erudite and versatile Robert Brown. Banks (1743–1820), a famous explorer, is distinguished for his wise, long-continued, and munificent support of botanical undertakings. Accompanying Cook on his first voyage around the world

(1768–1771) he took with him Solander, a favorite pupil of Linnaeus, and subsequently turned over all his materials to Brown, who meanwhile had published illuminatingly on the flora of Australia and New Zealand, following a four-year sojourn there. Aside from detailed studies in varied fields of botanical science and the elaborate monographic treatises for which he is famous, Brown through his studies of the Australian vegetation in comparison with other regions of the Southern Hemisphere, is credited with having laid the foundations of geographic botany. The system of classification followed by him is essentially the natural one of De Candolle. His death occurred in 1858, just one year before the appearance of *The Origin of Species*, by Charles Darwin.

It is almost impossible to over-rate the profound effect of *The Origin of Species* in every department of natural science and upon the progress of civilization itself. Indeed, a recent botanical lecturer has expressed the opinion that this book "has had a deeper and more wide-reaching influence on the trend of human thought and endeavor than any other that has ever come from the printing press." The modern science of natural history is itself essentially an evolution from the infinitely painstaking methods of observation and experimentation followed by Darwin and the principles deduced by him from a study of the phenomena of heredity, variation, and multiplication of organisms, both plant and animal.

It was Darwin's good fortune to have for staunch protagonists Huxley and Sir Joseph Hooker, and our own Asa Gray. There was need of special advocacy, for, to quote Farlow, to hold "that the variations and adaptations of plants and animals were not for the benefit of man, but for the benefit of the plants and animals themselves, was a dreadful heresy!" The rapid adoption of the Darwinian theory, despite vehement opposition in all quarters, was in fact owing very largely to the potent influence of Hooker and Gray, whose views were at all times temperately and moderately expressed.

Hooker himself had been appointed assistant director of the Royal Botanic Gardens, Kew, in 1855; George Bentham had come to the Gardens a year earlier. Both were ardent students. Among their activities, devoted largely to the preparation of a series of "floras" of the British colonies, was the joint publication of the *Genera Plantarum*, in three volumes (1865–1883), a monumental work begun by Bentham, which contains descriptions in Latin of all the genera and larger groups of flowering plants then known. It was in effect a modification of the Candollean system, which it may be said to have superseded for a time; but oddly enough, and in spite of Hooker's well known views upon the origin of species, it reflected few of the evolutionary ideas that were deeply influencing botanical science in general. Bentham, like Louis Agassiz, had not been able to accept Darwin's views, and it was only after the *Genera* was well advanced in publication that he came to modify his opinions regarding the constancy of species.

In the cryptogams, or so-called flowerless plants, meanwhile, knowledge of structures and life histories had advanced steadily through the notable studies of De Bary, Naegeli, Pringsheim, and others in the lower groups, and of Hofmeister particularly among the ferns and fern allies. Without discussing the details of these studies it may be stated that there came now to be perceived a unity of plan throughout the entire plant world—a bridging of the gap hitherto supposed to exist between the cryptogams and the seed plants in structure and in methods of sexual reproduction. The new discoveries of Hofmeister fitted perfectly the Darwinian theory of progressive evolution. At last the vegetable kingdom was seen as one continuous series, its earliest beginning shrouded in the obscurity of a far distant past, very many intermediate forms (and these often of profound importance) lost or known only as fossil remains, and the present flora itself a complex mixture of varied types. Some of these types are old and hardly changed from their primeval ancestral form; others represent the highest peak of a temporarily successful but now decadent line of evolution; and still others, numerous and abundant, mark the most vigorous and luxuriant evolutionary development of plastic stocks that have proved more completely adaptable to recent conditions of environment.

With the acceptance of this concept there has come a truer realization of the extent and difficulty of the problem of classification. The account here given has indicated some of the halting steps by which early botanical knowledge progressed from a mixed basis of myth and utilitarian practice to true botanical inquiry as a science at the end of the Middle Ages, as well as its later increasing complexity. It has dealt mainly with descriptive method, as this phase of botanical study is not only of prime importance and the first to have been developed as a science, but is also the field with which most museums are especially concerned. Of the essential importance of taxonomic botany to agriculture and commerce, and to civilization itself, more will be said in discussing its relationship with the other present-day botanical sciences, to which it stands in the closest affiliation.

CHAPTER II

THE CONTACTS AND STATUS OF SYSTEMATIC BOTANY

The ultimate aim in botanical classification is to unravel the exceedingly tangled and incomplete skein of broken evolutionary threads, and to reconstruct the actual pattern of descent. It is a task of endless extent, calling for every bit of help that may be rendered to the taxonomist by the paleontologist, the plant morphologist and anatomist, and the geneticist. Whether the system adopted be that of Engler and Prantl, which for a generation has generally superseded the plan of Bentham and Hooker, or one of the more recent schemes of classification, the end sought is the same—an orderly arrangement that shall reflect the course of progressive evolution.

The basic service performed by systematic botany consists mainly in furnishing the correct scientific names of plants and authentic information regarding their general and specific characteristics, their relationships, and their geographic distribution. As the name implies, the object of systematic botany is to provide a classification of the different kinds of plants that together make up the earth's vegetation; to describe every category, bringing together all essential data regarding structure and reproduction; to do this in such a way that the resulting classification shall indicate true inter-relationship; and finally, to provide stable scientific names, by means of which all the categories may be readily distinguished and known generally. Undertaking to perform this service is a large

PLATE 21

A live-forever (*Echeveria gibbiflora*, variety *metallica*), originally introduced from Mexico to the Royal Botanic Gardens, Kew. It has since become a popular plant for conservatories. By F. A. Walpole

contract, and this for reasons that are not fundamentally different from those met in zoology.

An ideal descriptive botany would be one written with the living plants in hand, for in this way it should be possible theoretically to draw up complete true descriptions, giving every minute detail as to color, form, structure, size, and relationship of parts. For a limited region close at hand such a course is feasible, and has sometimes been followed. But in general this method of study is impracticable, owing to the large areas usually covered in descriptive treatises and the physical impossibility of bringing together living examples of all plants, or of carrying to them in field, swamp, and forest one's preparation of manuscript; time and expense also enter in.

Thus the greenhouse, or conservatory, becomes an exceedingly useful adjunct in the work of the plant systematist. Indeed, without this aid it is scarcely possible to carry out successful studies of certain difficult groups, such as the orchids, live-forevers, and especially the cactuses, which often have to be assembled from great distances in a flowerless condition, to be described only when they have flowered, after years of careful nurture. These and certain other families, known collectively as succulents, are difficult to make up into herbarium specimens, so that a comparative study of living individuals of the different species in the greenhouse is of more than ordinary importance (Plate 21).

Most of the ferns and flowering plants, and even the mosses, liverworts, and many of the fungi and seaweeds, may be preserved readily as dried specimens, forming the herbarium or *hortus siccus*, literally the "dried garden." Notwithstanding their limitations, herbarium specimens with the aid to be derived from photographs of the living plant, whole specimens or parts preserved in liquid, and the study of living individuals in the greenhouse and botanical garden, will doubtless remain the principal resource of the systematist. Though far from being indestructible, dried specimens, if properly prepared and preserved with due care, are quite capable of lasting for centuries. Many specimens two to three hundred years old are extant, and there is on record the interesting case of funeral bouquets unearthed a few decades ago by Petrie in a Greco-Roman cemetery in the Fayum, in Egypt, in which the specimens though exceedingly brittle had only to be soaked in water to be rendered pliable and quite fit for thorough examination, even as to the minutest structures. In these ancient Egyptian wreaths more than twenty species of both wild and cultivated plants, in a readily identifiable condition, were found.

Of course, no herbarium is complete or even approximately so. European institutions, from their longer period of activity, have a decided advantage. For example, the herbarium of the Royal Botanic Gardens, Kew, with its accumulated 3,000,000 specimens or more, of which a large proportion have been examined critically and annotated by generations of students, and the exceedingly rich early collections in the British Museum (Natural History) have naturally an almost unequalled historic value, requiring that these herbaria must be sought and studied by investigators from all parts of the world (Plate 22).

In America the United States National Herbarium in Washington, under the care of the Smithsonian Institution, is the largest, and stands first perhaps in importance. It contains well over 1,500,000 specimens of flowering plants and ferns alone and is especially rich in material from continental North America. Thus, of the 17,000 species of flowering plants known from the United States and Canada, nearly all are represented; and of the 16,000 additional species of flowering plants occurring in Mexico and Central America, probably nine-tenths are found in its collections. Of the comparatively small European flora (10,000 species of flowering plants, or less) about four-fifths are represented. From the Philippines very ample series have been received, owing to the intensive work carried out by American botanists during the past three decades; but as to continental Asia and Africa, with their huge phanerogamic floras of perhaps 40,000 species each, it is a different story, probably not more than twenty per cent being available. Of the 50,000 flowering plants known from South America not more than thirty per cent are represented by specimens from that exceedingly diverse territory. Considering our expanding commerce with South American countries and the steadily growing dependence of modern industry and civilization upon raw plant products of many sorts from tropical regions, an attempt is being made to remedy this last deficiency through botanical exploration in northern South America. Some account of these expeditions is given in Part VIII of this volume (see page 351).

The original elements of the National Herbarium came in the main from such sources as the United States Exploring Expedition under Captain Wilkes (1838–1842), the North Pacific Exploring Expedition (Ringgold and Rogers), and the several govermental surveys of transcontinental railroad routes; to which have been added vast collections contributed over many years by various Government branches, particularly by the Department of Agriculture, which at one time maintained the National Herbarium in its own custody. As in other large herbaria of a public character, a considerable number of collections have been received also by exchange and by purchase, and large private herbaria have been acquired by gift or bequest. Of the latter, special mention should be made of the Charles Mohr collection, chiefly from Alabama and the southern United States; the Curtis G. Lloyd mycological collection of more than 50,000 specimens of puffballs and woody fungi; the Biltmore herbarium of southern United States plants, presented by Mrs. George W. Vanderbilt; and the John Donnell Smith herbarium of more than 100,000 specimens, assembled by that distinguished botanist during a long life time and representing the most complete series of Central American plants to be found in any institution. The materials thus assembled, though inadequate as to plants of the Eastern Hemisphere, are nevertheless of very special value in studies of the North American flora, and have served as the basis of an extensive literature.

In furtherance of the traditional policy of the Smithsonian Institution, botanical specimens from the National Herbarium are lent freely to duly qualified students both at home and abroad. The gain is mutual. Investigators as a rule are eager to receive for study specimens and still more specimens, large series of them—identified or unidentified—from the widest possible areas, as affording a broad basis for their work. On the other hand, the Institution benefits in having its specimens worked over critically by specialists, whose findings are thus the more easily understood and made available to resident botanists, present and future. Of the papers prepared by members of its own staff, many are published in general botanical periodicals; others, together with treatises based by outside students on material in the National Herbarium, appear in its own publication, issued in parts at irregular intervals, entitled, "Contributions from the U. S. National Herbarium." This series, which has now run nearly to thirty volumes, consists in part of technical papers relating to special groups, such as the ferns, grasses, palms, and cactuses, and partly of whole volumes devoted to regional floras; for example, the *Botany of Western Texas*, *Flora of New Mexico*, *Plant Life of Alabama*, *Flora of the State of Washington*, *Useful Plants of the Island of Guam*, *Flora of the Panama Canal Zone*, and *Trees and Shrubs of Mexico*. Similar series, dealing with results of study of their own and of other herbaria, are issued by nearly all botanical institutions and are widely distributed, mostly free or at slight cost.

Main hall of the herbarium, British Museum (Natural History), London, containing many early plant collections of great historical importance. Courtesy of the British Museum

A characteristic herbarium specimen, mounted on paper of standard size, fully labeled, and stamped with National Herbarium serial number

Uses of the Herbarium

This is how the herbarium functions: Let us suppose, for example, that a student is to undertake a comprehensive treatise upon the clovers of the world. He turns to the herbarium case containing pressed specimens of the genus *Trifolium*, in the family Papilionaceae, located at a point about one-half way down the line from the pines to the asters, if the sequence of family arrangement adopted be that of Engler and Prantl. Under *Trifolium*, in any large herbarium, the student should find at least a thousand tolerably complete specimens. Some of them will be in fruit, others in flower, all of them, presumably, showing foliage and, less certainly, habit of growth. Some—and these not necessarily the most recently collected—will show the nearly natural colors of flower and leaf.

The specimens have been made fast by glue or adhesive strips to tough paper sheets of uniform size (11½ by 16½ inches, in American herbaria), and each will have its own label, affixed at the lower right-hand corner, giving the State or country, special locality, and precise date of collection, together with the collector's name and other pertinent data, such as elevation above sea level, the names of companion plants, or notes on the plants' surroundings, whether found in moist rocky woods, in sunny situations along a sandy lake shore, or elsewhere (Plate 23). In mountainous regions altitude is commonly a point of special importance, not only as an aid to the systematist but to the plant geographer, who is concerned with the range of species and the causes underlying their distribution. So also the ecologist and plant morphologist will welcome full data as to altitude, soil preference, moisture, and exposure, since these facts may prove important in explaining rather obvious differences in form, size, and minor structure, which are suspected of having been induced by environment.

Assuming that the investigator has become familiar with

Trifolium through observation of the living plants "in the field," his future work will be about equally divided between a study of herbarium specimens and mastery of what is called the literature of the subject. Rare publications may have to be borrowed for the sake of copying or photographing important descriptions or suggestive comment, and specimens also may be borrowed from other institutions.

As to method of study, there are no hard and fast rules. Ordinarily the student will first examine in detail certain well-known species, comparing his specimens closely with both the original and later descriptions. Having made out the minute structures and technical points of distinction, or "characters," that are of importance in the group, he will then probably sort out most of the remaining specimens into tentative "species," assigning names to such of these as are readily associable with earlier descriptions. Some of the species will be clean-cut and will stand apart, sharply distinct in structural characters and geographic distribution, from all other members of the group. Others may be represented by very large series of specimens coming from a wide area, and these commonly are the most perplexing, requiring the closest and most painstaking study. For example, a species that is said to range from eastern Canada to the Gulf of Mexico and westward may be expected to show wide variation and to have assumed different forms in separate areas of its extensive range, in response to influences of climate and general environment; indeed, it will often be found to vary greatly even in a single locality. The immediate problem is, then, to sort out all these local and regional forms, to determine which are of major and which of minor importance, and to arrange all members of the series in a logical order that will indicate actual relationship to each other.

But this is hardly more than a good beginning. What our student does for a single clover species he must do for each and every species of the genus, except for those that show no notable variations. Having at last settled to his satisfaction the metes and bounds of the species and their varieties, he must bring together related species into coherent groups and arrange the groups consistently. Finally, having classified and named all the specimens, he must write technical descriptions for the genus, the species, and the minor forms, and provide a "key" as a means of referring later students unerringly to each and every category. The specimens studied should be listed after the descriptions also, so that others may know the basis of the work, in checking its correctness. Naturally the descriptive portion of the monograph will be preceded by a general chapter giving the objective sought, sources of material, important historical notes relating to earlier studies, the place of the group itself with respect to related genera, its geographic distribution, something of its probable evolutionary development, and any necessary notes on special structures and their usefulness and trustworthiness for purposes of classification.

In European countries the flora is relatively well known, and refinements in classification are the rule, owing to a general interest in botany and plant collecting and to the comparatively small number of species involved. In newly settled America, with its enormous stretches of highly diverse territory, detailed studies of the native flora have had to await widespread exploration and collecting.

Type Specimens

In general, herbarium specimens have a double value. In the first place they serve as a sort of illustrated card catalogue of the world's flora, the individual dried and mounted plants, properly classified, being immediately available for description in systematic work, for comparison in the identification of new material, and for use in providing distributional and other information to students in related branches of botany. Like any classified collection of objects, the herbarium is an illustrative series. Equally, or even in greater measure, herbarium specimens are of importance from the strictly historical point of view. Having been studied by competent early botanists, whose opinions are recorded in an extensive literature in which these very specimens are cited, they are invaluable because they supply the irreplaceable data of original investigations.

This last feature is of moment. Often fresh material of a rare plant made known to science a hundred years ago may still reasonably be sought in the distant region where it was originally discovered; yet a recent specimen, even though it comes from the same spot, will not have and can never have a value equal to that of the original. The specimen that actually serves as the basis of description in proposing a new species is known as the "type" specimen, since it typifies the species, not biologically but historically, in descriptive writing. Type specimens thus constitute a court of last resort, to which recourse must be had repeatedly in classification, for without them we should constantly be forming erroneous concepts of species previously described. There is no proper substitute for a type specimen, carefully selected.

One obstacle to rapid advance in the field of descriptive botany in America lies in the location of a large proportion of type specimens in European herbaria. This results in holding up the completion of many special studies until there may come to the student finally an opportunity of consulting these all-important specimens abroad. Photographs, indeed, are proving indispensable. Of great assistance too are topotypes, that is, specimens collected in series at original "type localities," for among certain plants that are not subject to great variation these will sometimes provide much of the same valuable information that may be had from the actual types.

The Practical Importance of Taxonomy

There was a time, less than two generations ago, when to the layman and even to the professional in most American institutions of learning, pretty much everything botanical was comprised in taxonomy, or classification according to relationship. With the rise of new kinds and new methods of plant study in recent years, and a general realization of their worth and deep interest, systematic botany has come unfortunately to occupy a less conspicuous place. Yet from the number and complexity of the new problems brought up there exists as never before an increasing need for just that kind of information which only the systematist can supply. If agriculture is the basis of civilization, it is no less true that botany in its broad sense is the principal basis of scientific agriculture. And of all the present-day botanical sciences there is not one that does not have inevitably to turn to taxonomic botany for assistance.

Thus, in the popular fields of plant morphology, physiology, and ecology, proper identification of the numerous species under investigation is essential. In plant physiology general principles of growth and organic function may, it is true, be established, with the aid of physics and chemistry, without knowing the correct name for the plant studied. Yet in the application of these to other lines of purely scientific work and to economic problems, it is essential to identify with precision the plant studied, whether species, variety, or minor form. For instance, it is very well known that of two forms appearing nearly or quite identical to the unpracticed eye, one may be strongly drought-resistant, the other scarcely at all so.

Similarly for the morphologist, who is concerned with the life history of plants, their anatomy, and the internal structure of their tissues and individual cells, or the ecologist, who seeks to explain the ways by which plants have adapted themselves to special surroundings, such as those of strand, swamp, and desert, it is obvious that deductions based on studies of incorrectly named plants will be of little value. Systematic botany provides the identifications.

Turning to economic or applied botany, the relationship is even closer, whether considered from the standpoint of agriculture, horticulture and plant breeding, forestry, pharmacology, bacteriology, or pathology.

Pharmacology is knowledge of drugs and medicines, of which a very large proportion are of vegetable origin. To know with utmost certainty the plants that yield these medicinal principles, and to maintain a standard of purity in drugs by excluding inferior substitutes therefor, dependence is placed squarely upon taxonomy.

Practically all decay or putrefaction of both plant and animal substances is caused by bacteria, which exist in untold myriads. These single-celled microscopic plants cause also such dread diseases as diphtheria, lockjaw, typhoid, and tuberculosis, although, on the other hand, many of them serve us most beneficently. Not all kinds of bacteria may be distinguished by their form as viewed through the microscope; yet their classification, which is then accomplished by other methods, is none the less necessary to assure a safe food supply, sanitation, comparative freedom from pestilence, and even our continued existence on this earth.

Forestry also, whose prime object is the growing of marketable timber and the perpetuation and increase of timber-bearing areas, is on a strictly scientific basis; and whether the trees to be tended and studied in every phase are the solid stands of pine and spruce of the western United States or the mixed associations of hardwoods prevailing in tropical America, the first need will always be a knowledge of their taxonomy—their names, characteristics, affinities, abundance, and regional distribution. Basic information of this kind is essential, for example, in airplane manufacture, the production of fine furniture, interior fittings, and tools, and of paper and resins, not to mention the flourishing and peculiarly American chewing gum industry! (Plate 24.)

Like herbaceous plants, trees must be guarded from fungus disease—a thoroughly practical consideration. This is the province of the pathologist and the systematic student of fungi. Enormous losses are caused annually by the inroads of wood-destroying fungi, which we know as shelf or bracket fungi, and which appear on tree trunks that have first been injured, usually by fire, insect attack, or mechanical agencies. A remedy must be sought through a knowledge of their habits and life history. Yet not all the pathologists in the world have been able to stem the spread of the chestnut blight, a fungus of quite another order, which since its appearance twenty-five years ago has practically wiped out of existence a beautiful and highly important timber tree in eastern North America. A losing battle is being fought also against the destructive white-pine blister rust, stretching nearly from coast to coast. In the Tropics, cacao and coffee trees are notably subject to fungus attack; indeed, the destruction of the Arabian coffee industry in Java and Ceylon is a classic example of the havoc that may be wrought by the minute parasitic fungi that we call rusts. Aside from various remedial agencies designed to check or destroy the fungus enemy, the solution often is sought by the introduction, in areas of affected plants, of varieties or strains that are resistant or even immune to attack by fungi.

The contacts of systematic botany with agriculture are, of course, almost innumerable, and they are of outstanding importance. So also with horticulture. The subjects under study, with a view to increased yield, improvement in size or quality, disease resistance, or adaptability to new or wider areas of cultivation may fall under the head of vegetables, fruits, or field crops. As examples there are the great citrus industry and its use of orange relatives from all the tropics, either for cross-breeding or as tolerant and sturdy stock upon which to propagate commercially desirable strains; studies of the cotton plant and its relatives, involving not only classification of numerous wild species but of a host of both Old and New World forms that have been cultivated over a long period of time; and similar investigations upon such field-crop plants as sugar cane, oats, barley, wheat, and maize—the last itself unknown as a wild plant and its very origin, though of suspected hybridity, as yet unproven. In all these experiments there is the same need of definite classification, of knowing certainly the name, origin, status, and kinship of the stock in hand.

Exploration for new plants also plays a large part in this work. In these days one may not hope to equal Oviedo, whose writings (1536) contain the first published records of rubber, cassava, the avocado (alligator pear), the guava, and the sweet-potato, all of which were brought to the attention of civilized man by the discovery of America. But there is solid satisfaction in having in our own day brought from Russia to America the "durum" wheat, which is now sown annually to about 6,000,000 acres of semi-arid land, yielding a crop valued at some $90,000,000; in having introduced to the desert valleys of California (Plate 25) the best date varieties from all the principal date-growing regions of the world, presaging the development of a horticultural industry which even now is well beyond the infant stage; in bringing to the warmer portions of the United States from tropical American countries the avocado, which during the past twenty-five years has rapidly won favor as one of the finest salad fruits; in introducing into our country a strain of Egyptian cotton that under careful selection has developed into the now famous Pima variety of Arizona; in bringing in as forage plants alfalfa and Sudan grass, the latter now grown upon some 1,000,000 acres or more, with an estimated annual crop value of over $15,000,000.

PLATE 24

Pure stand of Douglas fir (*Pseudotsuga taxifolia*), Columbia National Forest, Washington. This is the dominant commercial forest tree of the Northwest. Some individual trees reach the age of 1,000 years and grow to a height of 300 feet and a diameter of 10 feet. Courtesy of the U. S. Forest Service

PLATE 25

Grove of the famous Deglet Noor date palms near Indio, California. Under intensive cultivation these palms bear more than 300 pounds a year as against an estimated 30 pounds under Arab cultivation. Courtesy of the U. S. Bureau of Plant Industry

The Future of Systematic Botany

It is safe to say that in the realm of general biology there are today few indeed who in breadth of learning and interest may be called naturalists, in the full sense of the word. So also in botany, during the past three or four decades we have been passing through a period of specialization that, although it has brought about an extraordinary increase in detailed botanical knowledge, has by its very subdivision nearly done away with "old-fashioned botany." The old-time botanist who knew the living plant and the herbarium specimen, pursuing his studies from sheer love of the subject and often as an avocation, has been displaced by the professional specialist in many related fields. In the United States, at least, taxonomy has not kept pace with the newer subjects of cytology, ecology, bacteriology, pathology, plant breeding, and genetics. The botanical "ologies," with their unsuspected wealth of new fact, have nearly submerged systematic botany, notwithstanding their obviously acute need of the help it must give if in the long run they are to succeed. Naturally enough, students trained at college in the newer fields have, in the later role of professors, passed along their preferences to younger students, and one result has been an ever-increasing disparity in number between those who have and those who have not a special interest in systematic botany. It is not clear that the end has been reached. Obviously, specialization in botanical research will continue, even multiply, and improvement in an almost intolerable condition will come only with full recognition of the importance of systematic botany and a realization of the inadequate support it now receives. Moreover, the appreciation must be general, and it must lead to collegiate instruction in the principles and methods of taxonomy.

Three main charges have been made more or less seriously against taxonomists during the last twenty-five years by those engaged in other kinds of botanical work, as indicating dissatisfaction: That taxonomists have failed to agree among themselves upon rules that will insure stable scientific names for general use in the plant sciences; that frequently they have been more interested in technical problems of nomenclature than in the plants classified; and that a good many of them have drawn such exceedingly fine distinctions between alleged "species" that no one other than a specialist in taxonomy could hope to recognize the forms described.

Of these criticisms the first is a fair one. Yet the names actually used at different centers of botanical research are not so diverse as often thought, and at the present time a very sincere and determined effort is being made to harmonize outstanding differences of opinion and practice and to agree completely upon an international code of nomenclature, which all systematic botanists will accept by reason of its honesty and practicability.

Nomenclature, it may be remarked, is a most important part of taxonomy, and its rules and provisions are necessarily technical, often highly so. The more troublesome requirements are those aimed to govern the modern use of scientific names recognized or first proposed by early writers, notably Linnaeus, for genera and species. This class of problems is the major bugbear of plant taxonomy, and calls at once for the nicest technical judgment and the fullest measure of common sense. Occasionally one cuts the Gordian knot by discarding the scant claims of some of the early names; but this method is not much followed, and in consequence systematists are charged with pettifogging over "mere scientific names." To a limited extent this second criticism by the non-systematists is valid; yet the great majority of systematic botanists are interested primarily not in names, but in studies of the plants themselves, and do not deserve to be called name-tinkers.

As to the third specification, that of "splitting" species and genera overfinely, one may reply that in systematic botany as in politics there are conservatives and radicals, not to mention numerous other partisans occupying the whole intermediate range. Plants are highly variable: Why not varying opinions regarding the constancy of their agreement or difference, hence their status as representing few or many species?

One likes to think that the botanical fathers of the period from 1750 or thereabouts to the middle of the last century, could they have foreseen some of the later difficulties of systematic botany, would have pursued a different course; that they would have been at greater pains to preserve their type specimens, for example, or at least to describe them more fully, if they had guessed the multiplicity of species later to be turned up through distant exploration. But original specimens were not invariably kept, or if kept for a time they were not infrequently discarded when better material supposed to represent the same species was received. The four- or five-line Latin descriptions, written perhaps with a single plant in hand, may now apply equally to a whole group of closely related forms since discovered—species indeed so evidently different from each other that all systematists, whether conservatives or radicals, must agree substantially as to their distinctness. Along with this meagerness of description there existed, of course, a general belief in the separate creation of species, fashioned in a rigid mold. We now know that species are legion, and that they are neither fixed nor separately "created." The points of difficulty just mentioned are merely an unfortunate incubus, which must be overcome. Gradually, for all groups of plants, a trustworthy set of opinions backed by herbarium specimens and published data will find general acceptance, as it meets constantly the test of newly discovered fact, satisfying the needs of workers in many fields.

As to what the future holds in store, there can be no doubt: Systematic botany, whether or not receiving the full support it merits, can never be superseded—as well try to do without material standards of any sort. It touches human existence and welfare at too many points.

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Part III

PLANTS OF THE SEA

By

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CHAPTER I

GENERAL CHARACTERISTICS

Few of us have failed to enter into friendship with nature's loveliest creations, the flowers, and most of us know something of the endless variety in form and color they display; not so many perhaps, but still a large number, know that their alluring beauty has been attained by elaborate variations in structure—by the development of hundreds of special tissues and organs. Finally, the botanist goes a step farther and sees in them so many signs of inventive genius, such a wealth of constructive skill, that admiration turns into reverence and he finds that an assiduous lifetime will be too short to finish their study.

In turning, therefore, to the plants of the sea there comes to us at first an impression of monotony in them, of sameness and crudity, in comparison with the more highly developed land vegetation. But a more diligent study soon changes this first impression, revealing that these plainer-dressed relatives of the rose and violet and orchid also have their charm—less vivid, it is true, but not less real—and many other qualities which repay our interest and study. For sea plants hardly less than those of the land reveal marvels of adaptation to the life requirements of their particular world and examples of as nicely attuned ways of meeting the plants' particular needs. Here, too, are found grace and novelty of form, fragile beauty, and rich coloring.

The plants of the sea are almost exclusively algae. They form a group that stands low in the scale of life. Their commoner name—seaweeds—is a poor one unless we remember Emerson's definition—that "a weed is a plant whose use is not known"; for even with our present scanty knowledge of sea life some valuable qualities are already credited to the algae, and the new science of oceanography is discovering many others. In fact, one or two groups of algae undoubtedly deserve high rank among the plants that contribute to the welfare of mankind.

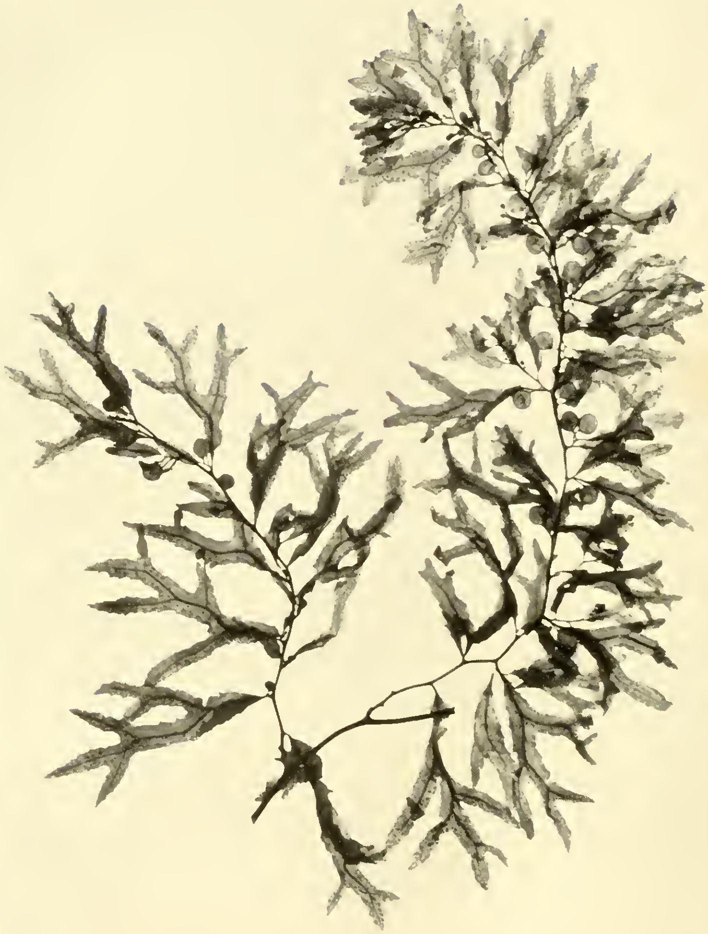
We may pass over the small and unimportant group of plants higher than the algae that are found in the sea. These grow only in the shallow waters of bays and harbors; the most conspicuous of them is eelgrass (*Zostera marina*), and even this is outclassed in frequency, prolific growth, and economic importance by two of the algae—the kelps and the diatoms.

The extreme simplicity of the algae as compared to land plants is due to the fact that they live in a totally different world—a world far less changeable, less rigorous, less menacing; where day by day and century by century the conditions of life are stable and kindly. It will pay to look into this changelessness, for it is the key to the strange forms and habits of the plants with which we have to deal. Take, for example, the factor of temperature. Throughout the year the waters of the ocean and of the bays and estuaries filled by its tides show very little change in temperature. The Gulf of Maine varies in this respect from 35.6° (Fahrenheit) in February to 68° in August, and this mainly near the surface; the Irish Sea from 40.6° to 62.2°, and in the open Atlantic the variation is even less. These variations are extremes, but even so, they are as nothing compared with those met with on the land. For example, St. Johnsbury, Vermont, has a temperature of 30° below zero or lower in winter and 90° above zero or higher in summer. In other words, sea plants may in extreme cases have to endure throughout the year a change of 25° to 35° Fahrenheit (and the low temperature will never be under freezing), whereas land plants must find means to endure a variation of 120°.

PLATE 26

Two brown algae from the coast of Alaska. *Lessoniopsis* hanging in festoons and a palmlike *Postelsia*

PLATE 27



The brown alga *Sargassum cymosum*, from the coast of Florida. This is the characteristic alga of the Sargasso Sea

Evidently the plants of the sea have less need to worry about summer or winter clothing than have their relatives of the land.

Although the watery world shows this greater uniformity in temperature, there are differences between the waters of the Tropics, the temperate zones, and the polar regions, and the algae in these latitudes are correspondingly different. For example, *Laminaria*, *Fucus*, and other brown algae thrive best in cold water, while the red algae and plants like the gulfweed, *Sargassum*, make their home in the subtropics. We should find almost as distinct flora in the different latitudes in the sea as on the land, except for the fact that in the ocean these latitudinal differences are broken down by the great currents that flow like rivers across the seas and carry warm water into cold regions and cold water into warm ones. The Gulf Stream is only one of many powerful currents affecting temperature. The Peru Current moves northward along the west coast of South America and brings the cold water of the far south clear up to the Equator and with the water the cold-loving algae; so that we find the gigantic brown *Lessonia* and *Macrocystis* and similar forms in latitudes where they would otherwise never be. The Labrador Current pushes the icy waters of the Arctic Seas southward as far as Cape Cod, and in consequence the algae that clothe the rocky coast of New England are northern forms. One of the spectacles at the popular resorts along that coast is the huge masses of brown *Fucus* that hang in festoons over the rocks and toss in the waves that beat upon them. The English algae, influenced by the Gulf Stream, are very different from those of Labrador, although the two countries are in the same latitude.

We may briefly mention here another influence disturbing the orderly distribution of the algae, although it is not strictly one of temperature. Depth has a considerable effect on the kinds of algae that grow in the sea. There is a fixed limit below which no plant life can exist, for without sunlight there can be no vegetation; and although some of the algae get along with very little, the deeper parts of the ocean are absolutely without plants. Lamouroux states that algae are found down to a depth of 200 fathoms, or 1,200 feet. This figure is probably too great, and it is certain that vigorous growth is not found below 50 fathoms, or 300 feet. In the dim twilight of the deeper places in the sea the color of the plants is not less but more vivid than nearer the surface, a result due to a greater development of chlorophyll and other light-sensitive pigments made necessary by the reduced supply of solar energy.

There is, too, a change in the abundance of plant life in the sea at different periods of the year; but again, much less on account of any variation in temperature than is the case on land. The change is due chiefly to that annual life cycle common to all vegetation. For plants have their periods of rest and inaction just as animals do. Even among land plants there are many in which growth stops annually, in which life hibernates, later on to resume an active existence, no matter what the thermometer has to say about it. Consequently many of the algae are abundant at one period of the year but rare or wanting at another. Thus the vivid red *Callithamnion americanum*, with feathery fronds as soft as eider down, is in its glory on our Atlantic coast in late February and early March, while *Dictyoneurum californicum*, a brown alga, hardly appears until the autumn. But although these intrusions of cold water into warm regions and warm water into cold regions invariably cause a local difference in sea vegetation it is important to keep in mind that *at any one of these places* the water temperature maintains the same constancy throughout the year which is so characteristic of the sea and which makes the marine climate so much more kindly than that of the land.

The same uniformity seen in temperature is found in the character of the materials from which marine plants draw their life. The salinity of sea water is nearly uniform over the entire earth, a little lower in the partly land-locked Baltic Sea and Hudson Bay and a little higher in the Persian Gulf and Red Sea, but with variations so slight that they do not affect the plants' welfare. Neither the quantity of salt nor that of other constituents of sea water presents any such problems to a marine plant as a land plant has to face in the depleted fertility of its soil and especially in the constant menace of too little or too much water. For there are no droughts in the sea, and therefore no Death Valleys or Deserts of Sahara. And the food supply of the algae is borne to them by the currents that flow incessantly to where they grow.

One of the major modifying influences of plant life on the land is the mechanical menace that they must overcome. There is the lateral strain of winds, demanding great strength and suppleness in plant structure; there is the vertical strain of weight—their own weight added to by snow and ice. To meet these stresses we find superb engineering shown in the structure of such land plants as our trees; the buttressed bases, the sturdiness of their vertical trunks, the fine tapering and elasticity of their limbs and twigs. But such devices and qualities are not needed beneath the sea, where the plants have almost the same specific gravity as the water, or in the case of some algae, even less, by reason of air bladders distributed through their tissues. An example is the well-known gulfweed, *Sargassum* (Plate 27), a never-failing curiosity to tourists, who know by the bright yellow patches of it floating past the ship that they are in the great Gulf Stream flowing northeastward across the Atlantic. Such mechanical contrivances as those mentioned above and nearly all others are left out of the algae. Strength is the thing least needed in marine plant life and the one least often met with, for our idea of the stormy rage of the ocean is literally a superficial one. In the underlying waters not far below the foam-flecked surface of a stormy sea one may find calm and quietness, and many a gale that wrecks a ship fails to dislodge the most delicate seaweed growing on rocks below the surface.

Now it is very evident that plants living under such benign and constant conditions need to be and therefore will be very different from those that grow on the land and are menaced by a hundred dangers which they must prepare structurally to meet or die. For here in the home of the algae no swift tempest or vicious gale can come; no killing frosts and bitter winters; no lack of moisture; no depletion of fertility; no crushing weight of ice and snow. Thus the many structural and chemical safeguards which through long ages have been evolving in land plants to fit them for the battle of life are in sea plants superfluous and therefore omitted. Nature, though lavish in her gifts, always gives wisely and is parsimonious of wasteful effort. As no wise architect digs deep foundations and builds massive pillars to hold up the light roof of a summerhouse, so nature, the master architect, wastes no time or material in unnecessary construction.

Here then we find the reason why the vegetation with which this article deals, though rich in its variety of form and sometimes rivaling land vegetation in its brilliant and diverse colors, is built of soft and delicate tissues unknown on the land—mere gossamer veils, mere satins and laces. By reason of these very features sea plants are fitted for their peculiar life conditions as nicely as are the rugged oak and the supple bamboo for theirs. And here also is the reason why the plants of the sea have changed so little and those of the land so much since those far-off ages when Life first crept from its inorganic birthplace to bask in the sun. The fossil algae that Dr. C. D. Walcott found in the pre-Cambrian rocks of British Columbia are twin brothers to those now living; whereas, the ancestral vegetation that first clothed the steaming plains and bogs of the land is strikingly dissimilar to that which we see today. Day by day necessity has forced

PLATE 28

The brown alga *Pelagophycus porra*, from the Pacific Coast

these evolutionary changes of complexity and sturdiness on land plants, while in the same lapse of time the sea plants have but slowly and slightly drifted from those archaic shapes with which they started.

Our group of plants then, models of simplicity because of these sheltering and stable life conditions, omit, as has been stated, most of the mechanical tissues and protective devices that in variety and ingenuity are the wonder of plant morphologists, and this too on precisely the same ground that we omit today helmets and breastplates and chain shirts, namely, because they are of no use. The most that is done in self-defense is a storing up by a few of the algae of distasteful substances, like iodine and bitter salts, to discourage their being eaten by the hungry hordes of animal life that swarm about them. All the diverse functions of life go on with wonderful efficiency and yet almost without organs, or better, let us say, because the entire sea plant or any part of it is capable of doing the work that its welfare calls for.

Let us take up the matter of food and its assimilation. The land plant, say a rosebush, absorbs food and moisture from the soil through a highly specialized root system and various gases from the air through the complex mechanism of its leaves; the alga performs these functions throughout its entire surface, taking all its nourishment directly from the sea that laves it. The rosebush, hampered by those many struts and fibers that give to it its necessary strength and flexibility, must convey the raw material and the assimilated food products back and forth from root to leaf and from leaf to its growing areas or to places of storage, and special channels must be provided for this transportation. But the alga disperses its raw material and transmutes it into living substance throughout its entire body.

Or let us take life's supreme and permanent puzzle, reproduction. It calls for marvelous chemical and structural mechanisms among the higher plants—mechanisms invented by a genius far surpassing that of Edison and which challenge our thought on every side. To form the ovum and then effect its fertilization; to protect the growing embryo; to disperse the resultant seed into new regions; to guard its vitality from killing cold and long drought until better days come to woo it into sprouting —these demand a thousand developments in tissues and wrappings and appendages which the sea plant is able to do without and still just as efficiently multiply its kind and thrive.

An advantage of great consequence springs from this simplicity; it is enabling biologists to find in these lowly plants of the sea an opened door to a better understanding of the mysteries of life. For the very complexity of vital processes in higher organisms entangles the thought of the student in a labyrinth, just as a visitor in a modern watch factory becomes bewildered among the machines that automatically turn out the screws and pins and springs and wheels of a watch. The Bible metaphor, "A little child shall lead them," is most applicable to science; it is the simple things that must reveal to us the complex. Newton might have discovered the force of gravity from the abstruse interactions of the planets, but he did not; an apple told it to him; and Galileo grasped the principle of the pendulum from the swaying of a chandelier in a church. And in a precisely similar manner science will draw ever nearer to an understanding of vital phenomena through the agency of the simple living organisms in the sea and similar ones in the fauna and flora of the land.

CHAPTER II

KINDS OF ALGAE

THE algae are conveniently divided into four main groups by means of their colors; the blue-green, the green, the brown, and the red. Taken alone, these colors are not perfectly trustworthy guides, for both the brown and the red algae occasionally tone down into a yellow; also a few of the red algae are purple, and here and there a blue-green alga will be far more green than blue. For example, one of the red algae that sometimes grows in rapidly flowing fresh-water streams, *Batrachospermum*, is not red but a dirty yellowish brown. Still, these distinctions generally are so good and so convenient that their use is justified.

We shall take up the most important group first, the brown algae. These plants are world-wide in their distribution and very abundant in all zones, especially so in temperate and polar waters. Probably they occur in greatest abundance in the Australian section of the Southern Seas. The brown algae are almost wholly marine, in contrast to the green, which are especially conspicuous in fresh waters. Some members of the brown group are of microscopic smallness, but most of them are large and robust, and some of them are the longest of all living things. Thus members of the genus *Nereocystis* attain a length of 325 to 350 feet, and Dr. R. F. Griggs states a single plant often weighs over 100 pounds. They are very prolific along our Pacific coast, including Alaska. The genus *D'Urvillaea* does not afford individuals of such enormous length; but their bulk and weight are sometimes very great, the heaviest recorded being about 500 pounds. This genus reaches its highest development in Australian waters. Around the Falkland Islands grow huge fields of *D'Urvillaea utilis*, looking like thick vegetable cables several hundred feet long. Along the coast of Patagonia occur dense groves of an alga called "the tree seaweed," *Lessonia fuscescens*, which has a stem 10 to 12 feet high and 12 inches in circumference and bears at the top a cluster of leafy fronds 3 inches broad and from 2 to 3 feet long. *Macrocystis*, growing in the Southern Hemisphere and frequent on the Pacific coast, is the giant of all the algae (see Frontispiece). Authentic records exist of specimens ranging in length from 650 to 985 feet. Many of these genera will be found illustrated in the accompanying plates.

The brown algae imitate more closely than any other group the forms and tissues of the higher land plants. Their fibrous holdfasts which anchor them to the bottom resemble true roots, but without any root function; their long cylindrical stems correspond closely to the stalks of land plants; and internally we find some of the cells with intercommunicating pores, other cells modified into primitive sieve tubes, and the whole stem when seen in cross section showing a concentric arrangement—agreeing in all these respects with stem structure in the far more complex terrestrial plants. The upper parts of the brown algae also share this parallelism. They are often profusely dissected into startlingly leaflike bodies, which are flat and have a midrib running down the middle and margins that are wavy or indented. One species of *Landsburgia* is named *quercifolia* because its leafy thallus so perfectly imitates the leaf of an oak. Yet all these parts are composed of that simplest of all the plant tissues, parenchym; wood-cells, bast, cork, and a dozen other specialized tissues normally present in higher plants are utterly lacking here. Nor do these strange resemblances prevent all parts of the alga, its rootlike, stemlike, leaflike

The brown alga *Agarum Turneri*, from the coast of Massachusetts

The red alga *Polysiphonia violacea*, from Marthas Vineyard divisions, from sharing equally in the many activities of the living plant.

The multiplication of the brown algae is generally a vegetative one, very slightly modified cells becoming separated from the parent plant, starting independent growth, and developing into adults. There is also a low form of sexual reproduction. This takes place within small cavities located near the surface of the plant and among the simple cells that constitute its general structure. Within these cavities are developed certain generative tissues, called oogonia, that are egg-producing, and others, called spermatogonia, that produce spermatozoa. In some of the brown algae both the egg and the spermatozoon are motile, in others only the latter, and in still others neither. Sometimes both the vegetative and the sexual methods of reproduction take place, alternating one with the other; sometimes one predominates, sometimes only one of the two takes place. This startling lack of uniformity in the way a great life function is performed by members of a single group of lowly plants is most curious. It almost suggests that here we have come upon nature in her undersea laboratory, experimenting with different methods of reproduction in order to subsequently fix upon the best one for adoption in those higher forms to be hereafter developed on the land. But if so, the experimenting was not finished; for some of these crude reproductive methods of the brown algae reappear in ferns and mosses and cycads and even in our conifers, finally dropping out in our highest plants, the angiosperms. As will be noted farther on, the brown algae play a very conspicuous role in certain commercial products and exert a powerful biological influence on certain other forms of sea life.

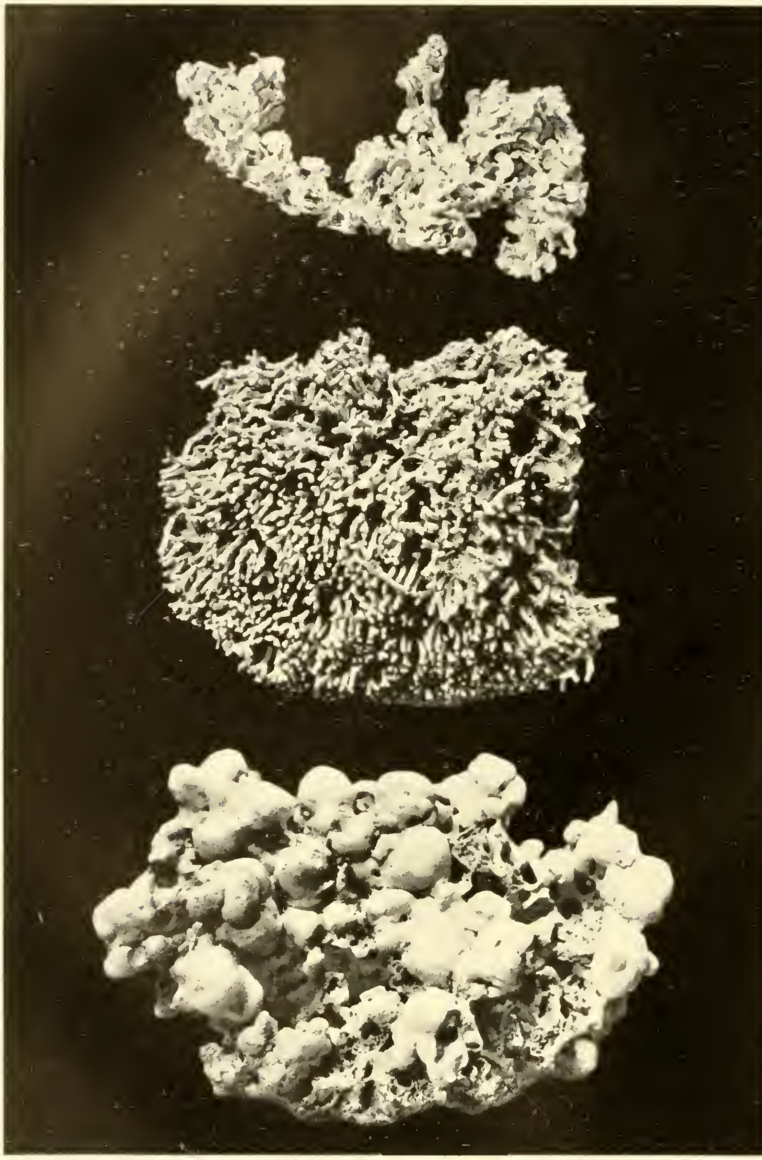
Only a little needs to be said of the green or the blue-green algae, because, although coordinate as groups with the browns and reds, they play a trivial role in the economy of marine life. A few exceptional cases should be mentioned. There is a minute blue-green alga called *Chroococcus*, barely larger than a pin point, which sometimes appears with suddenness and in startling numbers on the surface of the sea. Four to five years ago samples of this alga were received by me from Dr. Hugh M. Smith at Bangkok, Siam, with a statement that the Gulf of Siam seemed to be colored by this plant over hundreds of square miles of surface. Then there is the interesting green alga, "sea lettuce," *Ulva*, looking like a leaf of that garden vegetable or a translucent sheet of bright green tissue paper. It is common along the northern Atlantic seaboard in quiet coves and among piling. It has a close relative, called *Porphyra*, in which the green color is hidden by an overlying pigment of rich purple and which has a surface that glimmers like fine satin. Then, too, there is the dainty umbrellalike *Acetabularia*, its green color softened to that of chrysoprase by an incrustation of lime, a fragile and graceful plant. It is beautifully illustrated in Plate 34.

The red algae are far less robust than the brown and generally are much smaller. They usually develop into profusely branched tufts or feathery filaments (Plate 30), a form which has earned for them the name of "sea-mosses." Because of this complexity of form and a very specialized mode of reproduction they are ranked as the highest group of all the algae. Their tendency to elaborateness is seen also in the large number of genera and species into which they have developed. They grow best where the boisterous pounding of the waves is broken by the more sturdy kelps, living epiphytically among their fronds or on rocks behind a protecting curtain of kelp. They find a congenial home in sheltered tidal pools and harbors. Thus, the splendid crimson *Dasya elegans*, shown in Plate 34, grows abundantly in New York harbor.

In this group are to be found most of the favorite algae of collectors and no other members of the plant world are

PLATE 31

Coralline algae growing on sea shells



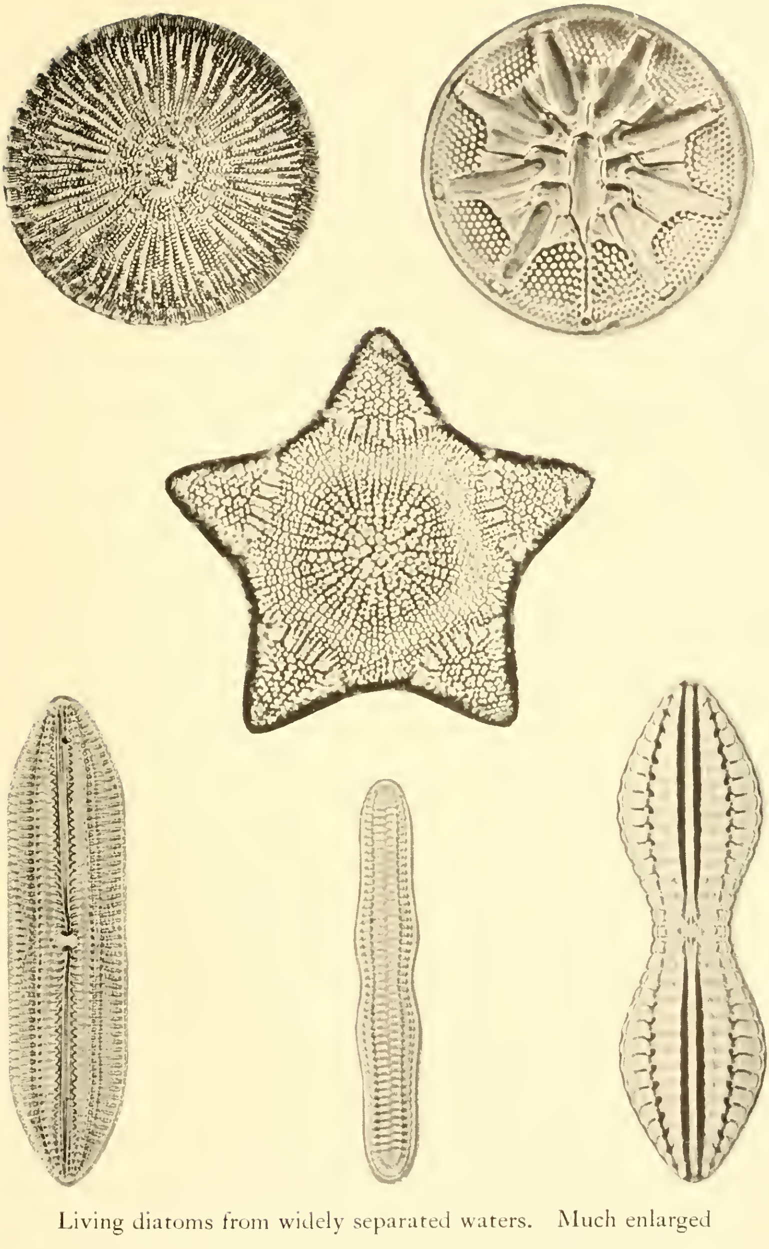
Three coral-like red algae from subtropical waters so perfectly adapted to supply one with beautiful and permanent specimens. Their delicate fronds, when properly arranged on cardboard, look like fine etchings; and their soft or vivid colors rarely fade. In the extensive herbarium of the National Museum are hundreds of these frail children of the sea, gathered fifty years or more ago, yet as fresh and lifelike as if the surf had just dropped them on the shore. Some of these were used as models by the artist, Mr. E. Cheverlange, when painting the two superb marine scenes that are reproduced in this volume as the frontispiece and Plate 34. As will be seen farther on, some of the red algae are a valuable source of food for mankind in some of the wilder parts of the world.

One other subclass of red algae merits special notice—the corallines, so called because they closely resemble coral. They grow in dense masses of stiff, branched, rounded stems, or with flattened fronds, or in heavy nodular clusters like cemented gravel (Plates 31 and 32). They are so thickly incrusted with lime that the red or yellow plant itself is entirely hidden. This lime, of course, is extracted by the plant from the sea water and is then exuded to form a hard, protective armor. In a few with flat stems, like *Mastophora*, this calcareous sheath is much thinner than in the others and is confined to the older parts of the plant. The corallines frequent temperate and subtropical seas, particularly places where the presence of coral reefs insures an abundance of lime in the water, like Bermuda and the Florida Keys. As these incrustations would make the plant dangerously brittle, if not counteracted by other characters, the menace is avoided either by a stocky mode of growth or by flexible joints set at intervals along the stems, a mechanical device reinvented by man millions of years later and used in such parts of machinery as the transmission shaft of an automobile. Thus the typical genus, *Corallina*, has rounded stems made up of these flexible-jointed pieces, which give it the appearance of chains of diminutive sausage. The lime coating of these coralline algae does not, however, exclude the light, because, like all other chlorophyll-bearing plants, without light, they would be unable to assimilate their food. The corallines are not the only incrusted algae, for some are found in other groups and are often mistaken for true corallines.

There remains to be considered one more group of marine plants. They are classed among the algae by some authors and placed adjacent to them by others, but they are so widely different from those already mentioned in form and in mode of life and in the importance of the role they play in the economy of nature, that they stand by themselves and probably deserve the highest consideration of all sea plants. These are the diatoms (Plates 33 and 39), almost the smallest living things on earth, surpassed in that respect only by the bacteria. They are so widely distributed in all the waters of the earth and so enormously fertile that what the other algae do worthy of our notice these minute plants do better and on a larger scale.

They have three qualities that are quite unlike those of anything else in the plant world: First, each diatom builds around itself walls of crystal, made of pure transparent silica and constructed on the general plan of a pill box in that they have an upper and a lower half, the sides of the one slipping over the sides of the other. But, unlike a pill box, they are of all shapes in addition to round—oval, elliptical, crescent-shaped, wedge-shaped, boat-shaped, triangular, square, stellate with from five to twenty rays—in short, of about every conceivable shape in which perfect symmetry and graceful contour can be combined. Then these multiform cases, which are made by the plant and in which it is housed, are ornamented with such astonishing varieties of design and of such incomparable fineness in execution that since their discovery through the invention of the microscope they have excited the unfailing wonder of all observers.

PLATE 33



Living diatoms from widely separated waters. Much enlarged

The second peculiarity of diatoms is that very many of them have the power of free locomotion, moving about like diminutive ships, especially like ferryboats; for they can go forward then reverse and move in the opposite direction. It is true that the diatoms are not the only plants with this power and that some form of motility is the common attribute of plants in general. Thus some of the reproductive bodies of the algae we have been considering are motile for a few hours, but the plants engendering them are fixed; the corkscrew-shaped *Spirillum* is motile, as are also some of the rod-shaped bacteria. There is a genus of blue-green algae, each individual of which, shaped like a thin rod, slowly and incessantly bends back and forth; this habit has given the genus its name, *Oscillaria*. A few of the green algae are locomotile; *Volvox globator*, for example, which suddenly appears in inland lakes and can be seen with the aid of a hand lens rolling along through the water in a stately way. All of us are familiar with the movements by plants of some of their parts; for example, *Desmodium gyrans*, which in strong light keeps twitching up and down some of its leaflets, so that they remind one of the fishing rod of an impatient angler. The sprouting potato in a dark cellar turns its pallid stem toward the light from the cellar window, and the potted plant on the window-sill leans toward the sun, the source of its power. But the movements of the diatoms are different from any of these, much more active and more powerful and they continue throughout the life of the plant.

What causes this locomotion in diatoms has long been one of the puzzles of science and still is shrouded in uncertainty. The swimming of the swarm spores of algae and the planetlike rolling of *Volvox* are effected by delicate whiplashes called flagella, or still smaller ones called cilia, that literally row these bodies through the water. But a diatom does not show any organs of this sort. So far as the best microscope reveals, the diatom seems to be a case of a sailboat without sail, a steamship without paddle wheel or propeller. The best of many weak guesses is that its movement is due to rhythmic undulations set up by the plant in a very thin membrane covering externally its silica walls, which, like a succession of waves, drives the tiny plantlet forward in somewhat the same way that its undulations enable a snake to crawl over the ground. And this fits in with the fact that a diatom really *crawls*, rather than swims. Unless it is in contact with some surface it is as helpless as a grain of sand.

The third distinctive quality of diatoms is their mode of nonsexual reproduction. In general, plants that multiply by the division of an individual into two or more new individuals generally accomplish this by the construction of a dividing wall across from side to side of the parent, after which the two parts thus formed separate into independent individuals. But the diatoms separate lengthwise in what would seem to be a much less convenient mode; and it is this which gives them their name, derived from two Greek words *dia* and *tomeo*, meaning to cut through. This lengthwise splitting is very effective and rapid. It has been computed that, taking the successive groups of descendants in the series thus produced, more generations will result from a single diatom in one year than all the generations of the human race since it started out in the Garden of Eden of Moses (or Mr. Darwin).

There are approximately 8,000 species of diatoms, distributed over the entire aquatic world; no lake or river or stream, no seashore or harbor, no square mile of the ocean's surface from the North Pole to the South Pole, being without some of these remarkable plants. As one sails over the sea or floats his canoe over some lake, he probably does not know that millions of diatoms are in the water about him and form a layer of rich plant life over the entire surface of the bottom and of the submerged objects beneath the water. It is their minute-

A composite scene of living green and red algae from the Atlantic and Pacific oceans. Note the variety of form. The red alga is the exquisite *Dasya elegans* from New York harbor. By E. Cheverlange

ness, not their infrequency that explains this. In a bucket of sea water dipped up anywhere diatoms will be present—sometimes by the millions—and mixed with the sand or the mud beneath the surface will be a teeming population of them in incalculable numbers. I have found in a spoonful of mud dredged near the Delaware Breakwater, 153 species of these plants and many thousands of separate individuals. They are most abundant in the colder latitudes of the sea. They swarm in the icy waters of the Arctic and Antarctic oceans. Though the most gorgeous forms are to be found in the warmer latitudes, they are less numerous there. They came into being comparatively late in the history of our planet, at the beginning of the Miocene epoch or a little before that, but long after some of the higher plants in the sea and on the land had appeared. When they did come, however, they came with such a rush, in such enormous numbers, and simultaneously in so many parts of the world that they assumed at once the dominant position they hold today as the most prolific and most important group of the plants of the sea.

It is not the province of this article to deal with these captivating organisms in detail, and I must ask my readers to note their beauty of form and the marvelous intricacy of their ornamentation as they are revealed in the accompanying illustrations. These have been selected almost at random, for there is such a wealth of artistic beauty offered by diatoms that a "beauty contest" among them sets a hard task for the judge who must render the decision. Some additional facts about these most important sea plants will be found in the next chapter.

CHAPTER III

USES OF THE ALGAE

From earliest times men have gone to the storehouse of the sea for many things. The variety of its stock is vast and the quantity thereof is almost inexhaustible. We may assume that the earliest quest there was for food—for the fish and mollusks that have so largely helped to feed the human race and without which even today millions of people would be hard pressed to eke out a livelihood. The plants of the sea also have contributed to the feeding of mankind. The time was when they were extensively used for this purpose, and in some parts of the world they still are an important source of food supply. But nowadays so many choice vegetables have been produced by man's ingenuity that the algae would find few purchasers in any of the markets of civilized lands. Only fifty years ago, however, one could hear in the streets of Edinburgh the cry of hucksters peddling algae. Two genera were popular in Scotland. One, called Irish moss, including both *Chondrus crispus* and *C. mammillosus*, is rich in a starchlike substance from which a nutritive jelly can be made; the other, called tangle, including *Laminaria digitata* and *L. saccharina*, was equally popular. There is also agar-agar, *Gracilaria spinosa*, still used for food in China, but especially valuable in making gelatinous cultures for the study of bacteria. Its near relative, *Gracilaria lichenoides*, known as Ceylon moss, is sometimes used in soups. *D'Urvillaea utilis* even today serves as a food supply for some of the poorer people of Chile. *Alaria esculenta* and *Iridaea edulis* also are edible.

From *Gigartina spinosa* a palatable jelly is made. *Laurencia pinnatifida* has a pungent taste and is called "pepper dulse." *Plocaria tenax*, although not an attractive food, furnishes a strong glue used by the Chinese. But perhaps the best known of the edible algae is the plant called dulse, *Rhodymenia palmata*. It is this that Longfellow introduces into the complaint of his despondent hero, John Alden, standing on the Plymouth seashore:—

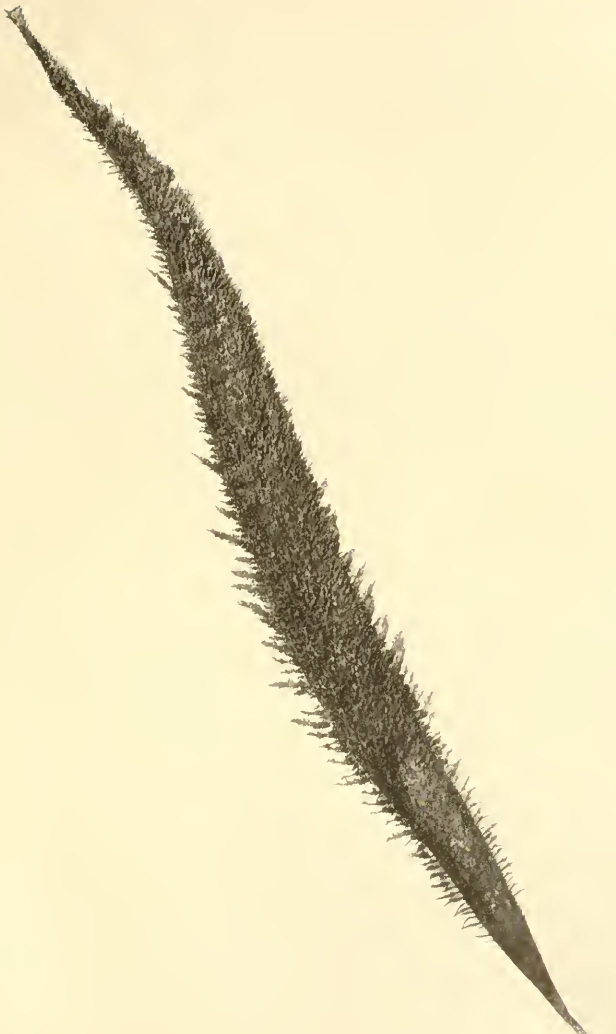
"Welcome, O Wind of the East, from the caves of the misty Atlantic,
Blowing o'er fields of dulse and the measureless meadows of sea grass."

Ranking next to its gift of food as a benefit to mankind is the sea's contribution to the fertility of the land. The fruitfulness of the good earth must have inspired some crude form of agriculture almost at the start of man's eternal struggle for food, as the vivid allegory of Genesis points out, where we read that Adam's first duty was to "tend his garden." After a time, when the virgin richness of the land began to be depleted, the need for fertilizing became evident. The earliest use of seaweed as a manure is hidden in the dim past, but its general use today in all places bordering on the sea proves how ancient must be its employment by tillers of the soil. At the present time a greatly enlarged appreciation of the fertilizer value of algae has developed; and new industries for its exploitation, helped by scientific investigation, are springing up. The primitive custom of taking what the sea casts up on its shore is too inefficient for present needs; and consequently methods of harvesting, drying and extracting the more useful substances from seaweeds are now being employed. They represent one of the larger aspects of the new science of Aquiculture.

The floating fields of giant kelp along our Pacific Coast are the center of this modern industry of seaweed collecting. Flat barges are rigged at one end with modern mowing machines, the cutting blades of which are set about four feet below the surface. Behind these, moving inclined planes carry the cut seaweed up into a hopper. From there it passes into a machine like a lawn mower, which cuts it into six-inch lengths and passes it into the hold of the barge for transportation to the factory. The barge is pushed forward through the fields of kelp at about four miles an hour, and cuts and stores something like twenty-five tons of kelp an hour. But over ninety per cent of this harvest is water, which the factory must get rid of, and then the dried kelp is ground into a meal, or for certain uses the more valuable fertilizing salts and other ingredients are extracted from it.

The most important material supplied by kelp is potash, a prime necessity for the growing of crops and of great use in other ways. Formerly practically all our potash was imported, mainly from Germany, the quantity increasing annually until in 1913 it amounted to 975,000 tons and cost nearly fourteen millions of dollars. But the intervention of the World War cut off this supply, and the need of a home supply became alarmingly urgent. So we did as our remote ancestors had done; we went down to the bountiful sea for help. And in the floating beds of gigantic *Macrocystis*, *Nereocystis*, and *Alaria* (Plate 36) we found our supply waiting for us. Writing on this subject, Dr. R. F. Griggs states that from seven to twenty-six per cent of dried kelp is potash. There is, however, some advantage in using the dried algae as a fertilizer rather than the potash extracted from them; for these plants take from the sea water other ingredients useful in agriculture, like phosphorus and soda, and the plants themselves lighten the soil and through their decay increase its fertility.

Iodine is another valuable derivative from kelp, which is used extensively in medicine, both externally and internally, and in the arts. A rather spectacular recent use is in the treatment of goiter, concerning which a large



The red alga *Gigartina microphylla*, from the coast of California

number of publications are appearing, issued by the Bureau of Chemistry and Soils and several medical journals. How the lowly algae manage to extract the minute quantity of iodine held in solution in sea water, store it up within their tissues, and keep it there behind a thin porous membrane is at present incomprehensible, although no more so than how a wayside weed selectively extracts from the soil the ingredients it most requires. The quantity of iodine in dry kelp varies from a mere trace to a third of one per cent. Other valuable products derived from these plants are certain gelatins used in manufacture and in the cultivation of bacteria; also phosphates, nitrates, a fine grade of cellulose, and a few that are less noteworthy.

It has long since become common knowledge that there is an accurately balanced interchange forever going on between the animal world and the plant world whereby each group gives to the other a different gas without which it could not live; and so fine is the adjustment of this exchange that the quantity of each of these two gases —oxygen (supplied by plants to animals) and carbon dioxide (supplied by animals to plants)—remains practically constant in our atmosphere, although numberless tons of each gas are daily poured into the air or extracted from it. The same process goes on in the sea. Its animal life could not exist an hour if the oxygen ran short, and its plants would die almost as quickly if the carbon dioxide ran short. Bearing in mind, then, that the algae constitute almost the sum total of marine vegetation, it is plain that one of their chief uses is to withdraw from sea water carbon dioxide gas, so poisonous to animal life, and substitute the life-giving oxygen.

Exactly the same organic substance accomplishes this exchange in the algae as in the plants of the land; namely, chlorophyll, that green, granular constituent of living plant cells which gives its color to all vegetation and its tone to every landscape. The chlorophyll in the algae is usually hidden under some thin overlying pigment, brown or red or purple; but its chemical composition is the same as that of the chlorophyll in a maple tree or in a stalk of wheat, and its wonder-working exchange of gases with the aid of sunlight is performed in precisely the same way as in terrestrial plants. The extraction of the one gas and the expulsion of the other generally goes on invisibly; but often when sunlight is strong one can see fine threads of oxygen rising from the algae toward the surface of the water in minute streams of bubbles. Often also, in quiet pools, one finds floating patches of brown scum and by patient watching may see other patches rising to the surface; these are pieces of the pellicle of diatoms that clothes the bottom of the pool, which have been torn away and carried upward by the large amount of oxygen gas generated by these microscopic plants. Let us then put down to the credit of the plants of the sea a part of that unceasing aeration of its waters whereby it is kept in wholesome condition for the animal life that inhabits it.

A minor use of the algae, the exact importance of which it would be hard to determine, is found in the shelter and protection these plants afford to the young of fish, crustaceans, and other marine animals during the period of their helpless infancy. Impelled by some maternal instinct, as wisely ordered as if it were called wisdom, fish, crabs, lobsters, and other sea denizens generally deposit their eggs in quiet inlets and bays along the coast, where the newly hatched young will not only have an abundant supply of the food needed for their growth but where they can find innumerable hiding places from the eyes of their enemies. The soft, tangled fronds of the luxuriant seaweeds become their nursery; their own movements are obliterated by the incessant tossing and interlacing of these plants as the waters flow among them; and a dim, green twilight among their supple boughs, even at noonday, adds to the obscurity and safety of

PLATE 36

A single lamina of the brown alga *Alaria fistulosa*, measuring nearly six feet across, from the coast of Alaska. This alga is an important source of fertilizer

The red alga *Polysiphonia Baileyi*, from the coast of California these young. To all forms of life this initial protection is important, as we can not have the adult stages unless the infant stages are made safe. But with some forms it is singularly imperative. Thus, the lobster is such a ruthless cannibal as soon as it escapes from the egg that, were the young not hatched where they could separate and each newly born lobster hide from its relatives and fend for itself, the stronger members would quickly devour the weaker until only a few or perhaps a single individual was left to represent the family. Seaweeds, therefore, are the great protectors of marine animal life during the period of greatest helplessness, and on that protection depends the ocean's vast abundance, which is so important a factor to mankind.

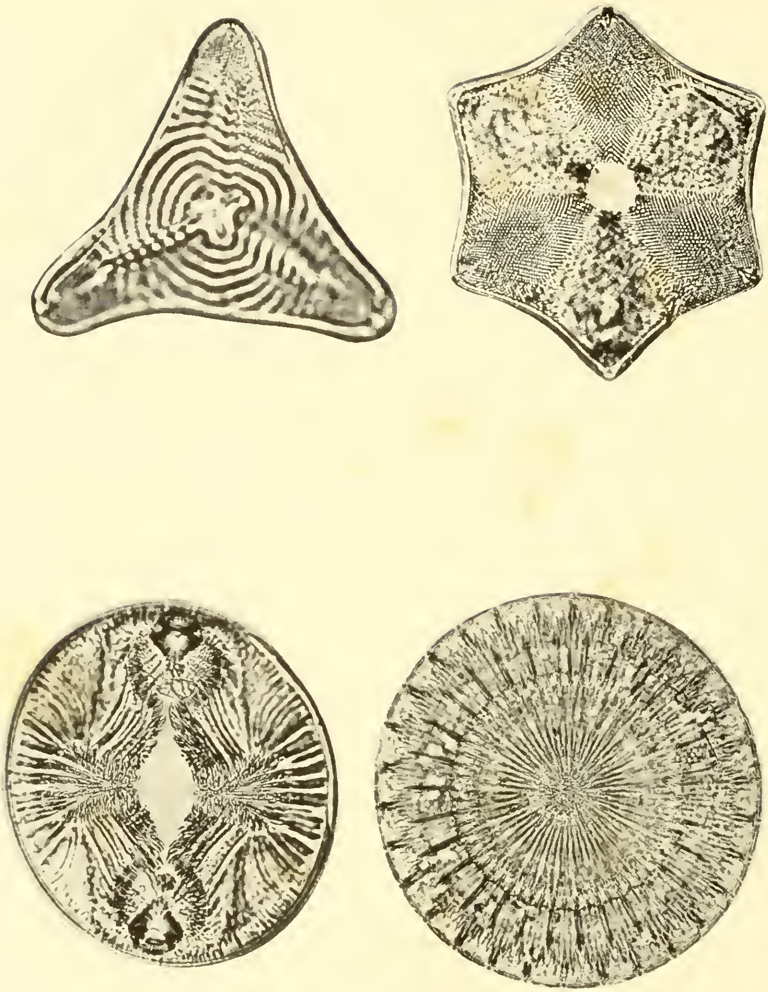
The algae constitute the basic food supply of the entire aquatic animal world. Probably this service outweighs any of the uses hitherto considered. Were it not for this vegetation there could be no marine animals, every sea would be a Dead Sea, and three-quarters of our globe would be as lifeless as the asphalt lakes of Trinidad. For in the marine world as in the terrestrial one, vegetation must furnish the food for animals. Although the latter are composed of a few of the common elements found in the earth's crust and in the air that envelops it—the oxygen and nitrogen and carbon and phosphorus and sulphur and soda and iron and a few more—although they are at hand and abundant, no animal can feed upon them directly or incorporate them into its body. Only a plant can do this wonderful thing, a plant with chlorophyll, which somehow lays hold of the thermal and chemical rays of the sun and by means of this borrowed power gathers up these elements, blends and weaves them into the fabric of its own substance, and turns lifeless matter into living and life-supplying food. This transmutation, this mighty miracle, reenacted every moment of every year wherever a grass blade grows, a leaf flutters in the wind, or a seaweed spreads its fronds from some rock in the sea, is the primordial necessity to every beast and bird and fish and crawling thing on land and in the water.

Only one group among plants must be denied credit for this great service—the fungi—degenerates that have ceased to produce, that merely consume, that feed upon the products of other organisms. There are very few of the fungi in the sea flora, far fewer than on the land. Here and there in salt marshes or far back in some sluggish creek, where the sea water is rank with dead vegetation and the pulse of the tides is weak, the microscope reveals myriads of whitish threads, the degenerate fungus, *Saprolegnia*. One of these ghouls, *Saprolegnia ferax*, is the cause of a very destructive malady in salmon and of a similar disease in many fish kept in tanks or aquariums, such as the goldfish. But out in the clean waters of the sea the plants are honest and industrious citizens and do their share for the general welfare. So, casting aside this exceptional case, we may say that the algae are of high value in the economy of nature and especially in supplying the basic food material for marine animal life.

Most of the large algae are of little use as animal food while they are growing. They are either tough and leathery or acrid and unpalatable; but when they die these repellent qualities quickly disappear, and a vast amount of nutritive organic material becomes available for animal food. But the small algae—the greens, blue-greens and diatoms—have high food value at all times. It is the last named, the diatoms, that are preeminent in this respect. Abundant in all quarters of the globe, multiplying with incredible rapidity apparently always in excess of the needs of the animal life that feeds on them, rich in nourishing qualities, spread as plankton over the surface of the sea, suspended in the water below the surface, clothing the bottom except in very deep areas with a live mantle—the diatoms stand as the great connecting link between inorganic matter and the myriads of

The red alga *Laurencia paniculata*, from the coast of Florida

PLATE 39



Fossil and living diatoms. Upper: left, *Actinoptychus annulatus*, a living diatom from the Philippines; right, *A. wittianus*, a fossil from Haiti. Lower: left, *Auliscus oamaruensis*, from New Zealand; right, *Lepidodiscus elegans*, from Russia living creatures in the sea. They are the true grass of the sea, the richest pasturage of the oceans.

The majority of marine animals, especially the larger forms, do not feed directly upon diatoms or other sea plants but upon those smaller animal forms which in their turn do feed on the plants. Some fish, however, are strictly diatom feeders, as for example, the sardine, the menhaden, and the parrot fishes; and others, such as the herring and the mackerel, feed on diatoms during their period of migration. Furthermore, a very large proportion of all fishes are diatom eaters during their earliest life stages, but change to animal food or a mixed diet in adult life. All the shellfish feed mainly upon diatoms and those minute animal forms that are associated with them. For example, the food of the oyster is from forty to sixty per cent diatoms.

I recently received a letter from the west coast of India stating that the sardines once abundant there had wholly disappeared, causing much destitution among the people of that region. The letter inquired if a deficiency of diatoms was the cause of this exodus and, if so, whether a replenishing of the coastal water with diatoms from other localities would bring back the fish. It is rather remarkable that the facts underlying these inquiries had reached this remote part of the world; for the close interrelation between an abundance of fish and an abundance of food for fish, including the diatoms, has only recently gained the attention that its importance deserves.

A group of very small animals, the copepods, just visible to the naked eye and looking like tiny shrimp, to which they are related, forms the principal connecting link between the diatoms and the fishes. It has been found that year by year the abundance of copepods in the sea rises or falls in accord with the abundance or scarcity of the diatoms, their principal food. One species, *Callanus finmarchicus*, known to sailors as "red seed," often colors the water on the Grand Banks and is common elsewhere in the Atlantic Ocean. I have often examined these animals and never without finding their intestines filled with diatoms.

We see, therefore, that the algae have had no trivial share in feeding mankind, either directly as human food or indirectly—and this is especially true of diatoms—as food for marine animal life. The sea is destined to become an increasingly bountiful provider in proportion as the mysteries of the deep are dispelled by scientific study and as this permits us to acquire the art of rendering efficient our efforts to augment the sea's mighty resources. To show that this is no mere dreamer's prophecy, recent experiments by the United States Bureau of Fisheries and several State commissions have proved that by proper cultivation oyster beds will yield per acre annually a larger return and one having a much higher nutritive worth and a greater market value than any known crop from an equal area of dry land.

The benefits rendered to mankind by the plants of the sea are nowhere more conspicuously illustrated than in the deposits of their fossil remains found in nearly every part of the world and particularly large and abundant in the United States. This fossil material, a long-ago deposited source of wealth, is known as diatomaceous earth, because it is almost entirely composed of the remains of those minute and elegantly ornamented algae last named in the list—the diatoms. It has been mentioned that the outside encasement of these plants is composed of pure silica. This is an indestructible substance and in this respect differs radically from the substances composing the other algae, which readily decay after death and pass back their elements to the inorganic world from which they were taken. As a rule the individual diatoms that compose this fossil material do not show the slightest sign of deterioration. Their crystal walls are as perfectly preserved and their delicate sculpturing as uncorroded as if thousands of years had not come and gone since they came into being. For nothing but the uncommon hydrofluoric acid or hot solutions of alkali has any effect on diatom silica. As a consequence these tiny plants, which lived in former ages in the same enormous numbers as they do today and grew everywhere that water and daylight were to be found, have formed deposits of their imperishable remains, their silica cases; and these, accumulating through long centuries, have become beds of diatomaceous earth. From these deposits the perishable parts of the diatoms and the organic material with which they originally were mixed have decayed and disappeared, leaving a fine, powdery, colorless substance which to the unaided eye looks like pure chalk.

We are justified in suspecting that the diatom growth in certain parts of the world where these beds are unusually large must have surpassed in annual quantity what we find today; and this because it demands so enormous a lapse of time, figured by the present rate of reproduction, to account for the size of the beds. It seems hardly credible that the changes in the earth's crust could have permitted their continued growth in these areas long enough to produce such beds. To take the most striking example known at present: A bed of diatomaceous earth is located at Lompoc, California, which has an area of approximately 12 square miles and a depth of something like 1,400 feet. Indeed the layers that contain some diatoms far exceed this figure in combined depth, as it refers only to those made up of the pure grade of diatom material that has commercial value. Above and below this pure deposit are other diatom layers, but so mixed with sand and other ingredients that the diatomite is relatively worthless. The hills and hollows of the Lompoc deposit are composed purely of diatoms, and each cubic inch of it contains from 3,000,000 to 5,000,000 individuals. When we think of the meaning of this in total individuals we are dealing with a computation that simply stuns the mind. Other beds are less extensive, but still enormous.

The so-called Nottingham earth underlies a great part of the State of Maryland, passes southward through Washington into Virginia, appears along the banks of the Rappahannock River near Fredericksburg, is at least thirty feet thick under most of the city of Richmond, and thence extends southward as far as Petersburg in the same State. Here again the numbers stun one like the distance between us and the remotest star. Fully 150 beds of varied size have already been located in the United States, and great beds are known in other countries. Oamaru, New Zealand, the island of Barbados, Sendi, Japan, Simbirsk, Russia, Luneberg, Germany are just a few of the hundreds of localities that have diatom beds which are scientifically and commercially important.

The uses of this diatomaceous earth are manifold. Its employment as a polishing material for metals, which first made it valuable, is far less important today, because better substances, like carborundum, have replaced it, except as a silver polish, for which, on account of its fineness of texture, it is still extensively used. It was also formerly used in the manufacture of dynamite, which is simply nitroglycerin absorbed into this porous powder and thereby rendered less dangerous to handle. But here also other substances, like wood-meal, have largely replaced it. At present it is the insulating material most extensively used for coating steam pipes and the pipes of ice plants, for lining the walls of blast furnaces and in the construction of other containers where either heat or cold needs to be confined. Thousands of tons annually are used for filtration, especially for thick liquids like oils, varnishes, and syrups. It is a constituent of some kinds of porcelain and enamels. It is being mixed with other ingredients in concrete construction, both in building and in road making. It has many other uses and new ones are constantly being discovered. How far back some of these uses were known and then forgotten it is hard to say, but some of them are certainly very ancient. Thus we find that in 532 A.D. the Emperor Justinian directed that, because of their remarkably light weight, bricks made of this material be used in repairing the Church of Saint Sophia, Constantinople.

Another benefit derived by mankind from sea plants, possibly greater than those just mentioned in the uses of diatomaceous earth, results from this same deposition in enormous masses of these minute organisms. For some of the great diatom deposits undoubtedly are the source of a portion of the world's supply of petroleum, which, in the form of gasoline, is playing such a masterful and sometimes merciless role in our modern civilized life. Much of the world's petroleum supply comes from animal and higher-plant remains; that found in the southern part of California is diatomaceous, while that in the northern part probably is not. These tiny plants store up their reserve food material in the form of oil (a most unusual thing in plant life) and this fact supplies us with the connection between diatoms and petroleum. It is a heavy oil, which by analysis has been found more closely to resemble the oil of certain marine animals, such as the dolphins, than it does any of the other vegetable oils. It is not infrequent to find ten per cent of the bulk of a diatom composed of this oil, and where nourishment is unusually abundant the quantity sometimes amounts to forty per cent. It is easy to see, therefore, that a single bed of diatoms like that at Lompoc, 12 square miles in area and 1,400 feet deep, would contain enough oil to fill a lake 12 square miles in area and 140 feet deep. This very crude computation may help us to see how these minute plants may have contributed greatly to preparing the way for modern civilized life. It should be added that some of the other algae are also sources of petroleum, but in a very much less degree. Recent investigations have made clear that at the present time the same processes are going on; remains of diatoms and other organisms are collecting on the sea bottom, and these also in ages to come will be transformed into diatomaceous earth, coal, petroleum, and other mineral derivatives of organic life.

In this submarine voyage into one of the many regions where the Smithsonian Institution has sought and found new scientific knowledge I have written my account more as a lover of nature than as a technical scientist. If, therefore, any of my readers wish additional information on any particular phase of the subject, especially on the remarkable and complex subject of reproduction in the algae, any technical work on this branch of science will supply the information desired.

Thomas Moore became familiar with the algae and other creatures of the sea through the famous marine gardens of Bermuda during his official residence in the island; and he took from them the inspiration for one of his loveliest verses:—

"As down in the sunless retreats of the ocean
Sweet flowers are springing no mortal can see,
So deep in my soul the still prayer of devotion,
Unheard by the world, rises silent to Thee."

What more perfect simile could there be than this one between our loftiest and purest emotions and the frail sea creatures that are the theme of this article.

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[1] This list of reference books has been chosen chiefly for the illustrations. Most works on this phase of botany are highly technical.

Part IV

GRASS

By

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CHAPTER I

GRASSES THE BASIS OF CIVILIZATION

"He causeth the grass to grow for the cattle," says the Psalmist, and Moses promised the children of Israel, as their reward if they kept the commandments of God, that they should have "grass in their fields for their cattle." With the Prophets grass is the symbol of blessing and redemption—"in the habitation of dragons shall be grass," "the Lord shall give to everyone grass in the field." And the want of grass is the symbol of desolation, "the hay is withered away, the grass faileth." The theme of grazing runs all through Genesis and Exodus. But long before cattle were domesticated, primitive man, living largely on animals he could kill, was vitally concerned with grazing lands. He must have followed the herds of wild cattle and bison, the flocks of wild sheep and goats, as the North American Indian followed the herds of the American bison, or buffalo. An abundant supply of grass meant plenty of tender, juicy meat.

Grazing lands possess other plants than true grasses, but grasses are their most important constituent, because these plants withstand close and repeated grazing better than do other plants. In the grass leaf, consisting of two parts—sheath and blade—growth takes place at the base of the sheath and at the base of the blade (Fig. 36), instead of being diffused about equally throughout the leaf, as it is in clovers and other forage plants. When a clover leaf is bitten off, that is the end of it, but when a grass blade is bitten off, growth keeps on at the base and the blade is soon as long as ever. It is this growth from the base

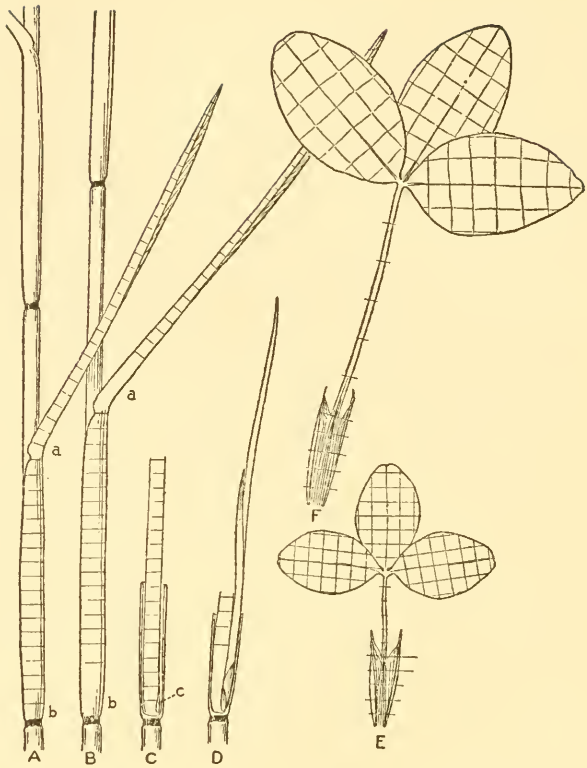


FIG. 36. Leaves of grass and of red clover marked to show areas of growth. A, grass leaf: a, base of blade; b, base of sheath. B, same leaf one week later, showing growth at a and b. C, base of culm in sheath; bud of potential branch shown at c. D, same one week later, showing growth at the base and the potential bud developed into a leafy shoot. E, leaf of red clover. F, same one week later, showing nearly uniform growth throughout, the greatest growth taking place in the petiole, the part of least value

(like human hair) that makes necessary repeated mowing of the lawn. Moreover, in a grass not only is the leaf renewed but the stem also. A grass stem is jointed, each joint bearing a leaf. In the axil of each leaf is a potential bud, which lies dormant so long as the main stem is growing. If, however, the main stem is grazed or cut off, the bud in the axil of the uppermost remaining leaf develops and replaces it. Grass is nature's nearest approach to an indestructible forage plant. So dominant are the grasses among grazing plants that the English word *grass*, which originally meant herbage in general, and from which is derived the verb *to graze*, has come to be applied particularly to the gramina, or "true grasses."

These true grasses seem to have appeared on the earth during Upper Cretaceous time, as their earliest fossil representatives have been found in formations laid down in this period. In the Eocene there was a notable expansion of the grass family, and in the Miocene it was well on its way to becoming one of the dominant types of plant life. Little Eohippus, of the Eocene, the great-great-grandfather of all the horses, and his descendants in the Oligocene, who have left their fossil remains in our Western States, had teeth for eating twigs and bark. During the Miocene our Great Plains were uplifted and became a vast grassland. The little browsing horse, no larger than a sheep, developed teeth for grazing, and, living on a grass diet through many generations, increased in size and swiftness until, when the Ice Age appeared, there were at least ten species of the genus, some as large as the domesticated horse of today and one even larger. The horse and the other graminivorous (or grazing) animals, the ancestors of our domestic live stock, really owe their development to grasses.

Man's first attempts to control his fate, to provide for future need instead of remaining the victim of droughts or other untoward circumstances, which were the beginnings of civilization, must have been on grasslands where the young calves, lambs, and kids he caught and tamed could find forage. It was on grasslands, too, that primitive man, after he had reached the food-producing as distinguished from the food-gathering stage, developed most rapidly. The earliest known records of human culture are found in the Nile Valley and in southwestern Asia, open country of scanty rainfall. It is perhaps significant that the most primitive tribes of living men, the pygmies of Africa, New Guinea, and the Philippines, are found only in forested regions. Sheltered in the depths of the forest they have led their timid lives, so near the verge of starvation that they are relatively few and remain in the Stone Age to this day.

It was while the ice of the fourth Glacial Period covered most of Europe, some hundred thousand to five hundred thousand years ago, according to Breasted, that the earliest Nile dwellers slowly changed from hunters to breeders of flocks and tillers of the soil. Wheat, with ages of selective cultivation behind it, has been found in some of the oldest known graves in the world, in the Nile Valley. The stomachs of bodies from these early cemeteries contain husks of barley and of a kind of millet (*Echinochloa colonum*) no longer cultivated. In the Nile Valley the cultivation of grain seems to have preceded the grazing industry, but breeding of donkeys, sheep, and cattle was well established by 3500 B.C.

In Europe the hunters of the Old Stone Age advanced but slowly until the final retreat of the glaciers some seven to ten thousand years ago. But the domesticated or half domesticated animals of the Nile Valley and the eastern shores of the Mediterranean somehow found their way into Europe, following steppes and valleys until in time they reached the grassy Swiss uplands, where they were again domesticated by the Swiss lake dwellers.

For thousands of years the women of those early ages had gathered the seeds of wild grasses, crushed them between stones, and made cakes of them. At an early period barley and wheat somehow reached these lake-dwellers, for these grains have been found in the remains of Swiss lake villages. Men as well as cattle must have wandered from the East, each generation going further west and carrying seed grain with them. With grain and cattle the Europeans of the Late Stone Age were able to advance rapidly from a life of hunting to one of settled communities of cultivators and cattle breeders. As in Egypt the two types of culture, growing of grain and cattle raising, both based on grasses, proceeded together, the prototype of modern farming.

In western Asia the hunter developed primarily into a cattle breeder, depending on the wild grasslands for forage, ever wandering in search of fresh pasture. When Abram and his family set out from Ur, between the Euphrates and the desert of Arabia, "to go into the land of Canaan," he was a herdsman, doubtless seeking new grazing lands. He followed up the valley of the Euphrates, far to the north, instead of striking across the desert to Canaan, and stopped at Haran (later called Charan) in upper Mesopotamia, a region of good pasture land. Later Abram wandered southward in the country bordering the Mediterranean, stopping where he found water and pasturage, until, when "there was a famine in the land," he drove his "sheep and oxen and he-asses and she-asses and camels" down into Egypt. In that fertile land Abram became "very rich," that is, his stock increased, until, on returning to Canaan with his nephew Lot, they had such vast droves of animals "the land was not able to bear them." And "there was strife between the herdsmen of Abram's cattle and the herdsmen of Lot's cattle," even as there was between the cattlemen of our Western States in the seventies and eighties of the last century. Later there was trouble with Abimelech over a well and more strife between herdsmen, and so the story of the patriarchs unfolds, always against a background of seeking grazing land and trying to hold it. Famine came in Isaac's day and he sowed a field "and received in the same year an hundredfold." This is the first mention in the Bible of sowing, but what Isaac sowed we do not know. The first mention of grain is in the passage where Isaac, blessing Jacob by mistake for Esau, says, "God give thee . . . plenty of corn." This corn must have been wheat or barley, both of which were cultivated in Egypt and adjoining regions centuries earlier.

The Indo-Europeans, our own ancestors, were already herdsmen when, some forty-five hundred years ago, they began to spread from the great grassy steppes which lie east and northeast of the Caspian Sea. Tribe after tribe of these nomads wandered across Europe seeking pasture, until they reached the westernmost land, the British Isles. Besides cattle and sheep, these people had horses. Among the Hebrews and other Semitic tribes donkeys were used as beasts of burden and camels for riding. The early European tribes were horsemen, the great-great-grandfathers of our cowboys. As these tribes found promising land—the valley of the Danube, the plains of Hungary or Lombardy, the valley of the Rhone—they settled down, cultivating wheat and barley as well as raising livestock, just as American pioneers took up homesteads in the West. Middle and western Europe, being a land of mixed forest and relatively small stretches of open grassland, encouraged this settled life of farming and progressive civilization. The great grasslands to the north of the Black Sea and stretching far into Asia remained the home of nomads, who depended on wild pasture. As the tribes and their flocks increased they became ever more warlike, fighting with one another, and periodically—when there was a drought, probably, or when the grasslands were depleted by long overgrazing—moving out in vast hordes, overwhelming towns and agricultural settlements. The Scythians before the Christian era, and the Huns, Tatars, and Mongols, who later overran Europe, were such swarming nomads. Much of history is but the record of invasions of peoples seeking fresh grasslands.

Grasses were the innocent cause of trade wars, also, for caravans of camels or horses had to follow grasslands; and these trade routes were fought for, as sea routes and railways have been fought for in modern times.

Grasses and Old World Civilization

Although grazing was an advance over hunting it did not forward civilization as did the cultivation of grain, which compelled a settled abode. At the dawn of history the beginning of such cultivation was so far in the past that it had become a myth. In Egypt wheat was held to be the gift of Isis, in Greece, of Ceres. Our breakfast "cereals" commemorate the Greek myth to this day. From Egypt and adjoining Asia, the cradle of a civilization based on the cultivation and grazing of grasses, this culture slowly spread in all directions, reaching from China to the British Isles and down through Abyssinia to the tribes of East Africa, a culture built up on the economic foundation of grain fields and herds.

None of the cultivated races of wheat are known in the wild state. A wild form of emmer (*Triticum dicoccum*) was discovered in 1906 on Mount Hermon, in Palestine, and later in Moab, by Aaron Aaronsohn, and called *Triticum dicoccoides* by the German botanist, Koernicke. In 1910 it was found again in western Persia, in the Zagros Mountains. It seems fairly certain that this is the ancestor of cultivated wheat. In emmer and in its wild variety, the axis of the head breaks up, the grain remaining inclosed in the chaff. In cultivated wheat (Fig. 37) the axis does not break up and the grain can readily be freed from the chaff. This character must have been developed and fixed by selection, yet so long ago was it accomplished that the wheat found in the earliest known graves is free from chaff. Breasted states that the stomachs of mummies in these graves contain the chaff of barley, which,

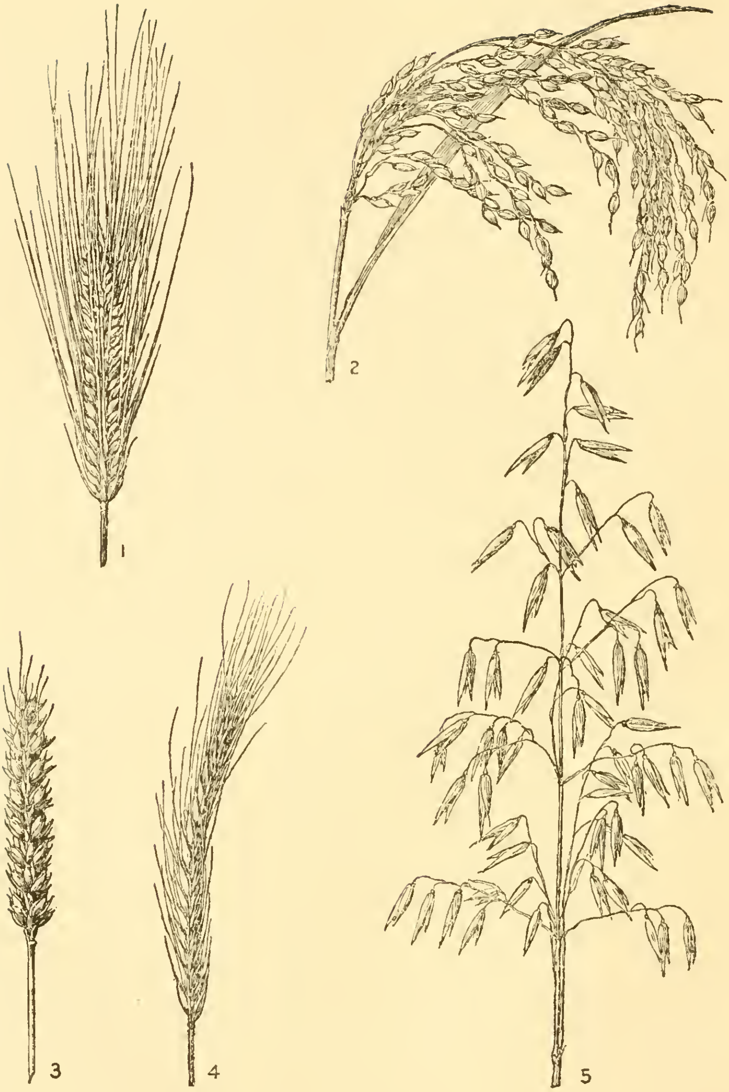


Fig. 37. Heads of grasses. 1, four-rowed barley; 2, rice; 3, cultivated wheat; 4, rye; 5, oats

being difficult to separate from the grain, was present in the bread. The chaff of wheat is not found in the stomachs, because it was readily removed from the grain.

Tales have been told of the germination of wheat found in Egyptian graves, and it has been claimed that the peculiar wheat with branched heads called "mummy wheat" was derived from such seed. These statements are not credited by scientists. It must have been an easy matter for a guide or other person to replenish the wheat in graves shown to travelers, and doubtless many a traveler was willing to pay well for a few grains of wheat from an ancient jar found in a grave with a mummy. But the so-called mummy wheat has not been found in Egyptian graves, and authorities agree that it did not exist in antiquity. Pharaoh's dream of seven ears of corn on one stalk suggests that the branched heads of wheat may have appeared as occasional sports since early times, though it was only in modern times that this form of wheat was fixed by selection and breeding. Certain varieties of Poulard wheats produce branched heads, especially in Alaska, as do some of our native wheat grasses, such as *Agropyron smithii.*

Barley was also cultivated in the New Stone Age, for it is found in Egyptian pottery jars dating from 4000 B.C. and in the remains of Swiss lake villages. The barley of antiquity was the six-rowed kind (*Hordeum hexastichon*) less commonly cultivated today than the four-rowed (*Hordeum vulgare*). The two-rowed (*Hordeum distichon*), also cultivated today, is the only form known to grow wild. The four-rowed barley appears to have been derived less anciently from *Hordeum spontaneum*, now growing wild from the Caucasus to Persia and Arabia.

Wheat reached China long before the Christian era, but rice is the more widely cultivated grain in eastern Asia. Rice was developed in the dim past, being cultivated before 3000 B.C. In an ancient Chinese ceremony five kinds of seed were planted, rice by the emperor himself, the other four by princes of his family. Of the five, esteemed as the greatest gift to the race, four are grasses, rice, wheat, sorghum, and millet. The fifth is a legume, soya or soy bean. Rice was cultivated in India in very early times; thence it spread to Babylon, and finally, about a thousand years later, it reached Syria and Egypt. It also spread south and east throughout the Malay Archipelago. In the Philippines today as for ages past rice is cultivated on the terraced mountain sides, the terraces holding the rains and preventing erosion. In this conservation of soil Philippine culture is far in advance of our own wasteful methods, which have resulted in denuding vast areas of fertile top soil. There are forms of rice growing wild in southeastern Asia which probably represent the species from which the cultivated rice (*Oryza sativa*) was developed.

Rye came into cultivation far later than wheat, barley, and rice, probably about the beginning of the Christian era. It seems to have originated in a region farther north, somewhere in the Russian steppes of Europe or Asia. Unlike the earlier-known grains, rye will run wild and maintain itself under favorable conditions for a time. For this reason it is difficult to determine whether plants that have been found growing wild were really wild forms or descendants of cultivated rye.

The common oat (*Avena sativa*) is generally believed to have been derived from the wild oat (*Avena fatua*); the Algerian oat from *Avena sterilis*, and a few other varieties from *Avena barbata*, all three species native to the Mediterranean region. Oats were known to the ancient Greeks as weeds in grain fields, but appear to have been cultivated in middle Europe during the Bronze Age.

Sorghum (*Sorghum vulgare*) in various forms has been widely cultivated for ages; but, though long grown by Egyptians, it has not been found in the early tombs. A number of closely related species are native to east-central Africa. Sorghum was probably derived from one of them, and introduced in prehistoric time into Egypt, whence it spread to India and China. In warm countries sorghum seeds so heavily that it is the staple food of millions of people, especially in Africa. Sweet sorghum (*Sorghum saccharatum*) also was probably derived from a central African species. It appears to have reached Egypt after the time of the Pharaohs and to have spread to Arabia, India, and China, where it is the *kao-liang*, or "great millet" of the Chinese. In the United States kafir, milo, and durra, forms of sorghum, are grown for seed and for forage. Broom-corn sorghum is grown for its great branching heads from which our brooms are made. Sweet or saccharine sorghum or sorgo is cultivated for the sweet juice extracted from the stem, which, boiled down, was the delicious sorghum molasses so commonly made by farmers of the Middle West a generation ago.

Several other species of grasses have been cultivated by primitive peoples for the seed, but are now largely replaced by wheat and other grains. Common millet (*Panicum miliaceum*), a native of Asia, probably reached Europe nearly as early as wheat and barley, for it is found in remains of Swiss lake dwellings. It has become naturalized in many temperate regions, including the United States. Italian or foxtail millet, with a multitude of derived forms, such as Hungarian millet and German millet, was also commonly cultivated in prehistoric times, apparently spreading westward from China, and reaching Switzerland in the Stone Age. Pearl millet (*Pennisetum glaucum*), another African grass, is grown in Africa and in tropical Asia for food. At maturity the smooth and shining grain bursts through its chaff, the long cylindrical spike being thick set with these "pearls." Coracan (*Eleusine coracana*), a native of India, teff (*Eragrostis abyssinica*), and fundi (*Digitaria exile*), natives of Africa, are also cultivated in tropical Asia and Africa but are unimportant compared to the grains.

Besides the grains, whose seeds furnish the breadstuffs of the world, there is another grass which is the source of an important food, sugar. Sugar cane (*Saccharum officinarum*) is now cultivated in all tropical and subtropical regions of sufficient rainfall (Fig. 38). Compared with the grains its cultivation is relatively recent. Sugar cane seems to have originated in southeastern Asia (New Guinea, according to to Brandes) and was grown in China a century or so before the Christian era, but was not known to Europe until the Middle Ages, when it was introduced by the Arabs into Sicily and the south of Spain. The ancients had to depend on honey for their sweetening; hence the ideal land, flowing with milk (having plenty of grass, that is) and honey. Sugar cane in cultivation rarely flowers and very rarely sets seed. Since the rich store of sugar in the stem would be used by the plant in the production of seed, the species has been artificially selected for sterility. Plant breeders occasionally succeed in securing seedlings, but sugar cane is propagated by planting joints of the cane, which root at the nodes and send up new stalks.

Fig. 38. Sugar cane

Field of sugar cane in the Hawaiian Islands. Photograph by Hitchcock

Grasses and Amerindian Culture

The culture-nucleus, based on cultivation of grain and grazing, spread from Egypt and adjacent Asia throughout the Eastern Hemisphere, except Australia, which developed no civilization of its own. In America a second center of civilization arose, based on the cultivation of maize, which like that of wheat began so far back in antiquity that its origin is veiled in myth. To the American Indian maize was a gift of the gods. One of the legends is familiar to us—the one which relates how Hiawatha prayed that the lives of his people might not depend on hunting and fishing. In answer to his prayer came Mondamin, with whom Hiawatha wrestled mightily, whom he buried, and from whose grave, carefully tended according to Mondamin's instructions, sprang maize, a never failing food for the people. While Eurasia had wheat, barley, rice, and the other grains America had but one. When the white man arrived maize was cultivated from Central America south to Peru and north to Quebec. The Inca, Maya, Aztec, and Pueblo civilizations were based upon it, and it was cultivated by the North American Indians over much of what is now the United States. The hungry Pilgrim Fathers, we are told, found a buried hoard of Indian corn during their first terrible winter in the New World and thankfully stole it. But for this lucky find there would probably be fewer *Mayflower* descendants than there are today. The Indians taught the Pilgrims how to plant maize, or corn as it was called by the English settlers, fertilizing it by burying two fish in each hill.

Maize (Fig. 39) has never been found growing wild, and it is singularly unadapted to maintaining itself without cultivation. No species growing wild is at all similar to maize. There are wild species related to each of the Old World grains, from which the cultivated form has probably arisen; but maize (*Zea mays*) is the only known species in its genus. The genus most nearly related to it is

Euchlaena, to which belongs teosinte, a native of Mexico, occasionally cultivated for forage.

Collins, who has made careful studies of maize and its crosses and also of teosinte, is of the opinion that maize originated as a hybrid between teosinte and an unknown and extinct species resembling pod corn.

Fig. 39. Maize or Indian corn

Maize is the most highly specialized grass in the world; and it was the American Indian who, by artificial selection through thousands of years before the coming of the white man, produced this marvel of plant-breeding.

In the Old World the primitive agriculturist had domestic animals. The American Indian cultivated grain but had no cattle. The American bison, or so-called buffalo, is distantly related to the ancestors of domestic cattle, and in the mountains were wild sheep and goats; but these American animals for some reason were never domesticated. In South America the llama and alpaca were domesticated as beasts of burden, greatly inferior to the horse or donkey, and as sources of wool, but nowhere did the Indians have milk cattle. Though the horse originated in America, it became extinct on this continent before or during the Glacial Epoch and was unknown to the Indians until introduced by the Spaniards.

Herd of pack llamas traveling in the Andes, Peru (elevation 14,000 feet). Photograph by Hitchcock

PLATE 42

Chinese Indian rice (*Zizania latifolia*) bordering a stream just outside the walls of Nanking. The lower part of the stem is used as a vegetable. The placards on the wall are advertisements. Photograph by Hitchcock

The Indians of the Great Lakes had besides maize another grain in the aquatic grass called wild rice, or Indian rice (*Zizania aquatica*). Down to our own day the Indians have gathered the wild rice, the women going about in canoes and tying together the heads of as many of the plants as could be gathered in the arms. These tied heads were left to ripen, when the women returned and, holding the tied heads over their canoes, beat out the grain. From two to three thousand bushels a year have been gathered in this way. Today Indian rice is an expensive dainty, served with game on the table of the epicure. In China the young shoots of a perennial species of *Zizania* are used as a potherb.

All the grains, to which man owes his civilization, are annual grasses, that is, the plant bears one crop of seed and dies. Perennial plants live over the winter or the dry season by means of underground parts that remain alive but dormant. Such plants usually bear fewer seed of less viability than do annuals, which must depend upon their seed for survival. An annual that failed to bear good seed would become extinct. Primitive man, or woman, rather, gathering seeds of grasses to add to the food supply, naturally took those of annuals, which were larger and more abundant. Annuals, being short-lived, produce seed within a few months after planting, while perennials seldom bear seed the first year. Naturally, then, it was annuals that were chosen for cultivation.

CHAPTER II

GRASSES THE BASIS OF WEALTH

So long as man depended on the chase there was danger of famine. By domesticating animals he greatly lessened this danger; but in a prolonged drought the grass would fail and the cattle perish, as has so often happened in our own Southwest. The cultivation of grain afforded a much more certain insurance against famine, for the grain could be stored from one harvest to another or for many years. The shrewd Joseph stored surplus grain for seven fat years; and then in the seven lean years that followed reduced the Egyptians to serfs by selling them back the grain they had raised and he had stored.

Grasses are the greatest single source of wealth in the world; for bread is in truth the staff of life, even if man does not live by bread alone. The prominent place the grass family occupies in the economic life of the world may be shown by a few statistics from the census reports on the value of farm crops in the United States.

The total value of farm crops for 1927 was more than nine billion dollars. Of this more than two billion, or nearly one-fourth of the whole, is credited to maize (corn). The next most valuable single crop is not a grass, but cotton, worth, fiber and seed, one and a half billion dollars. The third most valuable crop is grass, in the form of hay, the wild and tame together being valued at one and a third billions. Wheat, barley, oats, and rye together are valued at one and two-thirds billions. In round numbers the grass family, not even including rice, sugar cane, millets, crops of grass seed, and other lesser items, accounts for five billion dollars of the total of nine billions, that is, more than all other crops, cotton, tobacco, fruits, and the rest, taken together.

Our agricultural statistics do not give the value of pasture, but in the aggregate it must reach an enormous figure. Every farm has its pasture land and vast areas in our Western States furnish forage, largely of grasses, to grazing animals. A large part of the value of dairy products and of beef and mutton must be credited to grasses. The proportional value of the grass family in agriculture is about the same throughout the world, rice and sugar cane being the most important in the tropical regions. The chief food plants of the world are the grains, legumes (beans, peas, lentils), potatoes, bananas and plantains, cassava, yams, breadfruit, taro, and the sago palm. Except among some primitive peoples the grains furnish the principal food, the others being supplementary.

Besides our daily bread, wheat bread or corn pone, knackbrod or bannocks, schwarzbrod or macaroni, rice or cakes of millet or sorghum, the grains furnish other important food products. Maize, the one native American grain, is a host in itself, giving us delicious sweet corn, pop corn, corn flakes, cornstarch, hominy, glucose, corn syrup, and a palatable oil besides. This oil, "Mazola," is obtained from the germ in the kernel of corn, a bushel of corn yielding about a pound of oil. As a by-product the germ yields a rubber substitute, the "red-rubber" now in common use as erasers, rings for fruit jars, sponges, and spongy rubber soap dishes and bath mats. Dextrin obtained from cornstarch has replaced gum arabic as the basis of mucilage. According to Slosson "more than a hundred different commercial products are now made from corn, not counting cob pipes." Cornstalks, formerly a waste product of huge proportions, are now coming into use as a source of cellulose and promise to be of especial value in the production of paper and of wall board. A corncob stone, called maizolith, has recently been developed. It can be worked and polished and used for such purposes as are now supplied by hard rubber and bakelite. Corn is also a source of alcohol. As Slosson further says, "This was, in fact, one of the earliest misuses to which corn was put, and before the war put a stop to it 34,000,000 bushels went to the making of whiskey in the United States every year, not counting the moonshiners' output. . . . The output of alcohol, denatured for industrial purposes, is more than three times what it was before the war."

Rye and barley are used extensively in making fermented and distilled beverages, and in the Orient a wine is made from rice. Much of the commercial vinegar is made from malt liquor, the alcohol being converted into acetic acid (the acid of vinegar) by means of ferments.

The juice extracted from the stems of sugar cane is concentrated until the sugar (sucrose) crystallizes and can be separated from the molasses. In earlier days the sugar was only partly extracted from the juice and the molasses, still rich in sugar, was an important by-product. Much of the molasses was used in the production of rum. With modern methods the separation of sugar is so nearly complete that the residue has little value. The bagasse, or crushed cane from which the juice has been extracted, is now being used in the manufacture of wall boards.

Range and Pasture

Besides supplying us with our daily bread, the grasses, by providing a large part of the forage of grazing animals, indirectly supply us with dairy products, beef and mutton, wool, leather, and horsepower. And, since hogs and poultry are fed largely on maize, ham and eggs are also secondary products of the grasses.

The range is the modern equivalent of the grasslands of our remote nomad ancestors. It is unfenced public land upon which the cattle and sheep of several stockmen graze in common, the cattle being separated at a yearly round-up according to their brands, the calves being branded with the mark borne by the cows they claim as mothers. Our Western States were once immensely rich in good range land, but the best of the land has now been settled and brought under cultivation. But, even so, the acreage upon which livestock is grazed exceeds that under cultivation. The figures for 1920 were 293,794,000 acres cultivated and 350,000,000 acres used for grazing.

Fig. 40. Tuft of grama grass, an important range grass

The range lands lie almost entirely west of the 100th meridian and comprise the vast semiarid region, with an average annual rainfall of less than twenty inches. This land, covered with the hardy and nutritious buffalo grass and grama grasses (Fig. 40), the wheat grasses, bromes, porcupine grasses and numerous other native species, affords excellent grazing. Dry farming is feasible on part of it but stock grazing appears to be the most economical use to which it can be put. Until the end of the last century the Federal Government allowed stockmen uncontrolled use of the public domain. As a result rolling hills knee-deep in grass were reduced to bare knobs, deeply gullied, their fine soil eroded and blown over the land in blinding dust storms; and vast natural pastures of grama grass were despoiled of their palatable and valuable forage and given over to worthless plants or left denuded and subject to erosion. When more stock than the land can support are grazed upon it, the hungry animals not only devour the good forage so completely that no plants are allowed to seed and so replenish the range, but also, in extreme cases, paw the plants and eat them to the very roots. The unpalatable plants and those covered with spines are avoided by the cattle, hence these worthless plants bear seed and replace the good forage. When we read of the wars of the Hebrews and the neighboring tribes in the light of the history of our western range lands we are impressed with the fact that overgrazing changed the Promised Land of plenty to a land of want. "He turneth a fruitful land into barrenness for the wickedness of them that dwell therein," says the Psalmist. Substitute ignorance for wickedness and it is literally true.

One of the great achievements of the United States Department of Agriculture has been the study of grazing problems, and the working out of a system of licensed use of grazing lands. Much of the public range is now under the control of the Forest Service. Permits are issued to stockmen which limit the stock to the number which the range can bear without injury, and are so timed as to permit the plants to set seed, thus restocking the depleted range. The wars and invasions of the ancient nomads were due to the fact that they were ignorant of range management, as, indeed, are many peoples today. Great areas of the once luxuriant campos of parts of Brazil are now denuded and badly eroded from long-continued overgrazing.

Pasture is grassland brought under control. In former times villages had pasture land in common, where the cattle of the villagers grazed under the care of a few children. The "commons" or "greens" of English villages and our own Boston Common were originally such public pastures. Now that townspeople no longer keep cows our "commons" have become parks, and pastures are parts of privately owned farms. Until very recently improvement of pastures has not kept pace with other improvements in farm management. "Only the fact that grass will stand an almost incredible amount of abuse has prevented its utter destruction. Relegated to land too rough to till, neglected by the farmer, abused by the grazier,

FIG. 41. Kentucky blue grass

permanent pastures still furnish one-third the feed consumed by domestic animals." as a writer in the *Rural New Yorker* truly says.

Blue grass or Kentucky blue grass (Fig. 41) is the standard pasture grass for the humid region of the United

States, while Bermuda grass (Fig. 42) is the standard pasture grass for the Southern States. Both these grasses are sod formers, with tough rhizomes or rootstocks forming a close turf that withstands grazing and the trampling of hoofs. Both were early introduced from Europe, the

FIG. 42. Bermuda grass, showing habit of growth

blue grass from north Europe, and Bermuda from the Mediterranean (Kentucky and Bermuda both being misnomers).

In regions of snowbound winters pastures provide forage for but part of the year, and additional feed must be stored for winter. Such feed in the form of hay is cut from meadows, cultivated or wild. In the United States the hay from wild grass, once of major importance, is decreasing rapidly as more and more land is brought under cultivation.

Until the last century or so forage grasses were not cultivated in the sense of sowing seed of a single species. The first forage grass to be cultivated was English rye grass (*Lolium perenne*), which came into use in England about 250 years ago. Other grasses came into use later, until at the present time about fifty species are cultivated for meadow or pasture, several of them to but a limited extent. Although most of these species are cultivated in the United States only a few are of prime importance.

Timothy (Fig. 43, left) is the foremost meadow grass for the Northeastern States and for the humid regions of

FIG. 43. Heads of timothy (left) and orchard grass (right)

the Northwest. It is the standard hay upon the market, that by which other hay is measured. Timothy was one of the earliest grasses to be cultivated for hay in this country and at once became dominant. It is not more nutritious than many other grasses, but its cheap and reliable seed recommend it to growers. The timothy seed is borne in a compact head and does not shatter easily when gathered. The whole crop ripens at approximately the same time and the heads are borne at a fairly uniform height, which make the seed crop easy to harvest. These qualities combine to produce low-priced seed. The hay itself is easily grown and harvested, it cures well and is palatable and nutritious.

A few other grasses are important in certain areas, but none compare with blue grass and Bermuda for pasture and with timothy for hay. Redtop, orchard grass, and meadow fescue are grown for hay and pasture in the humid regions. Johnson grass, a perennial relative of the sorghums, is an important hay grass in the Southern States, but, because of its very aggressive rhizomes, it is an exceedingly troublesome weed in cultivated soil. Brome grass, because it is drought-resistant, has found favor in the semiarid region from Kansas to Minnesota and eastern Washington. On the Pacific Coast, wheat and oats, grown as a winter crop, are cut for hay. In California this grain hay is valued in the thirteenth census report at nearly twice that made from alfalfa.

Of relatively minor importance are rye grass, and tall oat grass, grown in the Northern States, and paspalum, in the Gulf States. The latter is a valuable forage grass in Hawaii and Guam, especially for dairy cattle.

Guinea grass and Pará grass are valuable in the tropical countries south of us, but can be grown in the United States only in southern Florida and southern Texas.

Forage is preserved not only as hay, but also as silage, which is prepared by packing the freshly cut forage, mostly maize stalks, leaves, and ears, in an air-tight receptacle called a silo. The mass ferments a little, becoming a mild forage sauerkraut, readily eaten by cattle.

In tropical countries, where the climate is not suited to haymaking, soiling, that is, the feeding of freshly cut forage to animals in inclosures, is commonly practised. A donkey trudging toward town almost hidden beneath a load of green grass is a frequent sight in the American Tropics. Soiling is also adapted to intensive farming, especially dairying, because large leafy grasses and legumes that would not endure trampling by stock can be grown, which yield a larger amount of feed per acre than does pasture. But the amount of labor involved in soiling makes its cost prohibitive in most parts of this country. Teosinte, the wild grass most nearly related to maize, is grown for soiling in parts of Louisiana, where it yields an enormous amount of forage.

All these cultivated grasses are foreigners, mostly natives of Europe. Paspalum and teosinte come from the American Tropics. Only one of the fifty species cultivated in the United States is a native of this country. This is slender wheat grass (*Agropyron tenerum*), which is cultivated for hay to a very limited extent in the Northwestern States. Our prairies, plains, and upland meadows support numerous native species that are palatable and nutritious, but none of them has been found adapted to cultivation. This is due principally to the high cost of their seed. The grasses which best withstand grazing are sod formers. Perennials as a whole produce fewer and less viable seed than do annuals, and sod-forming grasses particularly, spreading vegetatively, do not produce large seed crops. Timothy, as stated before, is exceptional and is the preeminent meadow grass.

The United States Department of Agriculture and our State experiment stations have been for forty years testing grasses from all parts of the world, but the results are surprisingly small. Brome grass or Hungarian brome (*Bromus inermis*) is a comparatively recent introduction from Europe, where it had already come into cultivation. Rhodes grass (*Chloris gayana*), from Africa, gives promise for the irrigated regions of the Southwest.

The desire for miracles in grasses as in other things leads dealers occasionally to offer "mortgage-raisers" and the like, which turn out to be no better nor as good as grasses already in use. "Billion-dollar grass," widely advertised some years ago, is a variety of our common barnyard grass (*Echinochloa crusgalli*). The rich well-watered soil required for its growth would produce a far more valuable crop of timothy. A so-called "Peruvian winter grass" is being sold at an enormous price, entirely out of proportion to its value. It is a variety of *Phalaris tuberosa* having rhizomes, was described from Australia, where it was introduced from Europe, and has been experimentally grown in California.

The grasses now grown in the humid region and in irrigated areas in this country are well suited to them. It is the ranchmen of the Southwest who are hoping for some grass that will make two blades grow where none grow now on their arid and semiarid acres, especially those depleted by overgrazing; for stockmen have impoverished their own as well as public lands by this practice. In a dry year in western Texas or in New Mexico one may hear a ranchman, holding on to his too numerous and starving cattle in the hope of rain, bitterly complain: "It's funny the Department of Agriculture can't find some grass that will grow on this land." The fact is that the best possible grass for that land did grow there until destroyed by overstocking. No grass, and certainly no other kind of forage—for grasses are the most long-suffering of all forage plants—can grow where it is grazed to its roots.

Land Building

Along our North Atlantic Coast and at the south end of Lake Michigan are great hills of sand, piled up by wind and wave. These sand dunes, unless held by vegetation, travel inland, a thin layer of the upper, driest sand blowing up the windward side and sliding down the lee side, the dune advancing from a few inches to a few feet in a year. The great dune at Cape Henry, Virginia, is thus moving and is burying a cypress swamp. One may walk down the lee side of the dune through the tops of cypress trees sticking out of the sand and come into the still unburied swamp. Where the land back of a dune is valuable, as on the Massachusetts coast and at the head of Lake Michigan, the advancing dunes cause great loss.

Dwarf Indian rice (*Zizania aquatica angustifolia*) on the margin of Lake Champlain, converting marsh into meadow. Photograph by Hitchcock

PLATE 44

Spartina Townsendii building land outside a dike in the Netherlands. Photograph by Prof. F. W. Oliver, of London

Several species of grasses having strong rhizomes flourish on these wind-swept sands and serve to bind them. The principal species is beach grass or marram-grass (*Ammophila breviligulata*) (Fig. 44). When unusually severe winter storms or destruction by man make a break in the protecting zone of this grass a "blow-out" is likely to develop, which rapidly opens great gaps in the barren dunes, permitting the sand to sweep inland, covering towns and farm lands. The attempt of real-estate men to "clear away the sand hills" in order to develop summer resorts on the coast has had disastrous effects in places. It would be as safe to clear away the dikes on the coast of Holland.

Fig. 44. Beach grass, showing habit of growth which makes it an excellent sand binder

In Denmark, Holland, and along the Baltic, barrier dunes are under the care of the government. Areas of bare sand are planted with beach grass (*Ammophila arenaria*, closely allied to our own species) and accidental breaks are replanted.

All marsh grasses are slowly building up meadow land. On mud flats and tidal estuaries such as those in the Gulf of St. Lawrence, Chesapeake Bay, and San Francisco Bay, species of cord grass (*Spartina alterniflora*, *S. cynosuroides*, *S. foliosa*, *S. patens*, and others) are building up dry land. These grasses thrive in the soft mud submerged at high tide, their stout rhizomes forming a dense firm network ever pushing seaward. The coarse grass impedes the oncoming waves, protecting the shore while causing the water to drop its burden of silt, thus building up the floor until it becomes, first, marsh meadow, then dry land, when the *Spartina* dies out, leaving the land ready for the plow. This land building by *Spartina* has been going on along our coasts for ages, and it is going on today on a gigantic scale along the English Channel and the North Sea. The traveler on a ship entering Southampton today will see vast green meadows of *Spartina* stretching into the sea. Fifty years ago these were only bare mud flats. *Spartina Townsendii*, called "rice grass" by the English, a species closely related to *S. alterniflora* of the North American coasts, was first observed on the Southampton salt marshes in 1870. It now occupies the tidal flats for a stretch of one hundred and fifty miles along the south coast of England. "These bottomless muds, though they stood empty of vegetation . . . probably for thousands of years, found no plant capable of solving the problems of invasion and establishment till *Spartina Townsendii* came and made light of the task," says Prof. F. W. Oliver. On the French coast of the English Channel *Spartina Townsendii* now occupies the tidal flats along the Baie de la Seine, and has appeared near the Strait of Dover. A few years ago this grass was planted on the tidal flats on the east coast of England to protect the sea walls of Essex.

Cuttings of this grass have been sent to Ireland, the Netherlands, and Germany for reclamation work, which has proved especially successful in the Netherlands. (Plate 44.) In 1924 the grass was planted on the tidal mud of the Sloe, opening into the West Scheldt, and later along the East Scheldt also. The plants were set outside the dikes in rows at right angles to them. The force of the tide was thus divided and conquered, where crosswise

A clump of bamboo in China. Photograph by Hitchcock

Uses of grasses in China

Upper: A lime kiln on the island of Hainan, China, the wall of which is bamboo. Lower: Joss sticks of split bamboo drying in the sun, Canton. Photographs by Hitchcock plantings might have been uprooted and washed away. The tufts are spreading and filling in the spaces between them, soon to form a solid meadow and later arable land, thus within five years accomplishing the reclamation of miles of land which, left to nature, would take twenty years or more.

Other Uses of Grasses

The bamboos (Plate 45), the largest of the grasses, are of vast importance in the regions in which they grow, especially from Japan to India and Malaysia. The larger kinds reach a height of a hundred feet and are six to ten or twelve inches thick below, tapering to the summit. The culms or stems are very strong and are used in building houses and bridges. When the stems are split, flattened out, and the partitions at the joints removed they make very durable boards, a foot or more wide, for floors and walls. Rafts and floats are made of the hollow stems closed at the joints by air-tight partitions. With the partitions removed bamboo stems furnish water pipes or conduits. Sections of the stem closed at one end by the partition form convenient vessels for holding water. Much of the furniture, and many of the utensils and implements used by the Malays are made wholly or in part of bamboo. Slender bamboo stems are familiar to us in the form of fishing rods and walking canes. Shoots of *Bambusa Beecheyana* and other species of bamboo are a choice vegetable in the Orient and an expensive dainty in this country.

Grasses are an important source of fiber for paper making and cordage. England annually imports more than two hundred thousand tons of esparto grass (*Lygeum spartum* and *Stipa tenacissima*) from Spain and North Africa for paper making. Species of *Spartina* are used for cordage and the roots of *Epicampes macroura*, a Mexican grass, make the stout "fiber" scrubbing brushes now on the market. Brooms are made of the seed heads of "broom corn," a kind of sorghum. Rice straw is used for matting and oat straw for straw hats. Leghorn hats are made of a kind of wheat straw cut young and bleached.

Tons of essential oils used in perfumeries are extracted annually from Asiatic grasses related to our broom sedge. A few of them are cultivated throughout the Tropics. One of them, citronella grass, is the source of the "fly dope" used by fishermen and campers as less unbearable than mosquitoes and black flies.

The resourceful pioneers who first settled the treeless regions of our Western States made grasses take the place of timber, building their houses of blocks of sod piled up into thick walls, which defied the blizzards of winter and the heat of summer. The sod house was to the pioneer of the plains what the log cabin was to the pioneer in wooded country. Today in the Andes the sheep herder builds his hut of sod and roofs it with ichu grass (Plate 47). The poor peasant in China uses grass for fuel to cook his meager dinner.

Injurious Grasses

The grass family, like many other fine families, includes a few vicious members. There are the weedy crab grass, couch grass, and the like, that cost the gardener and cultivator much labor, but they are troublesome only in being too hardy, and in coming where they are not wanted. The villains of the grass family are those that carry spears and daggers and use them without mercy (Figs. 45 and 46). Our native ruffians are bad enough, but a group of assassins from the Mediterranean join in their nefarious work. The native sand burs (species of *Cenchrus*) with their little balls covered with spines as sharp as needles, are troublesome to man and beast. The ripe spikelets of *Heteropogon contortus,* a relative of the broom sedges, have sharp barbed spears at one end and a stout twisted appendage at the other. The spear catches in the wool of passing sheep and the appendage untwists

Sheep herders' huts in the high Andes, Peru (13,000 feet). The walls are of sod. The roof, of ichu grass (*Stipa ichu*), is held down by ropes. Photograph by Hitchcock

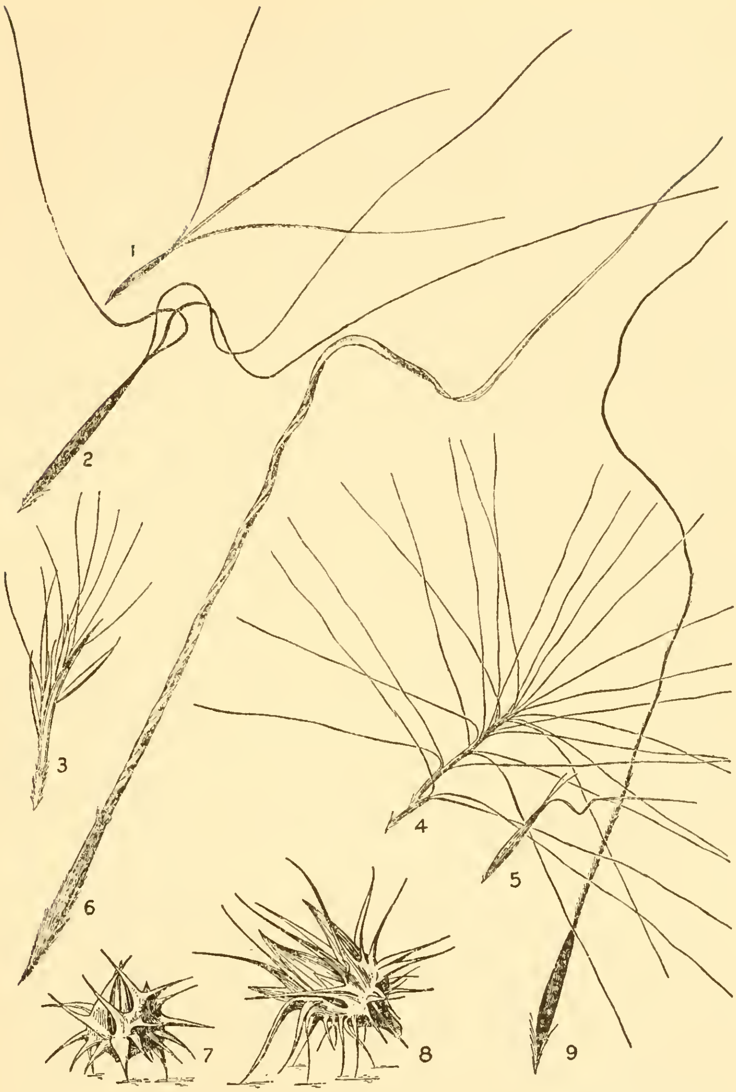


FIG. 45. Villainous native grasses. 1, 2, 5, needle grasses; 3, needle grama; 4, *Scleropogon;* 6, porcupine grass; 7, 8, sandburs; 9, *Heteropogon*

and twists, in dew and sunshine, thus driving the barbed point through the wool into the skin. Some of the invaders from the Mediterranean region are near akin to the grains which have so blessed mankind. The barley grasses (wild species of *Hordeum*) have bristly spikes which break up at maturity, each joint having a sharp barbed point and six or seven rough bristles. The points work into the mouth parts, nostrils, and eyes of grazing animals, causing painful sores and sometimes death. Our native squirrel-tail barley is almost as vicious as its European relatives. *Sitanion*, a related but wholly American genus, has heads which break up as do those of barley grasses and which are equally injurious to stock. An exceedingly unwelcome invader from southern Europe has appeared in recent years in California, Colorado, and Oklahoma. This is goat grass (*Aegilops triuncialis*), a relative of wheat. Its murderous tactics are like those of the barley grasses, but its joints are stouter and its barbs are stronger and constitute a really horrible instrument of torture, the barbs making it impossible for an animal to get rid of it when once taken into the mouth. A few brome grasses, also from the Mediterranean region, have large spikelets, the florets of which disjoint with a sharp barbed point at one end and a long bristle at the other, and inflict injury in the same way as do the barley grasses. The worst of these, *Bromus rigidus*, the California stockmen feelingly call "ripgut grass."

Decorative Value of Grasses

When through the cultivation of grasses man is freed from the fear of famine, his love of beauty seeks satisfaction and again grasses in large part meet his need. Our European ancestors came from humid country where meadows are a natural part of the landscape. The village common was a meadow, mowed and fertilized by cows or sheep. When the cattle were stabled for the night the village green became the playground for the people, the

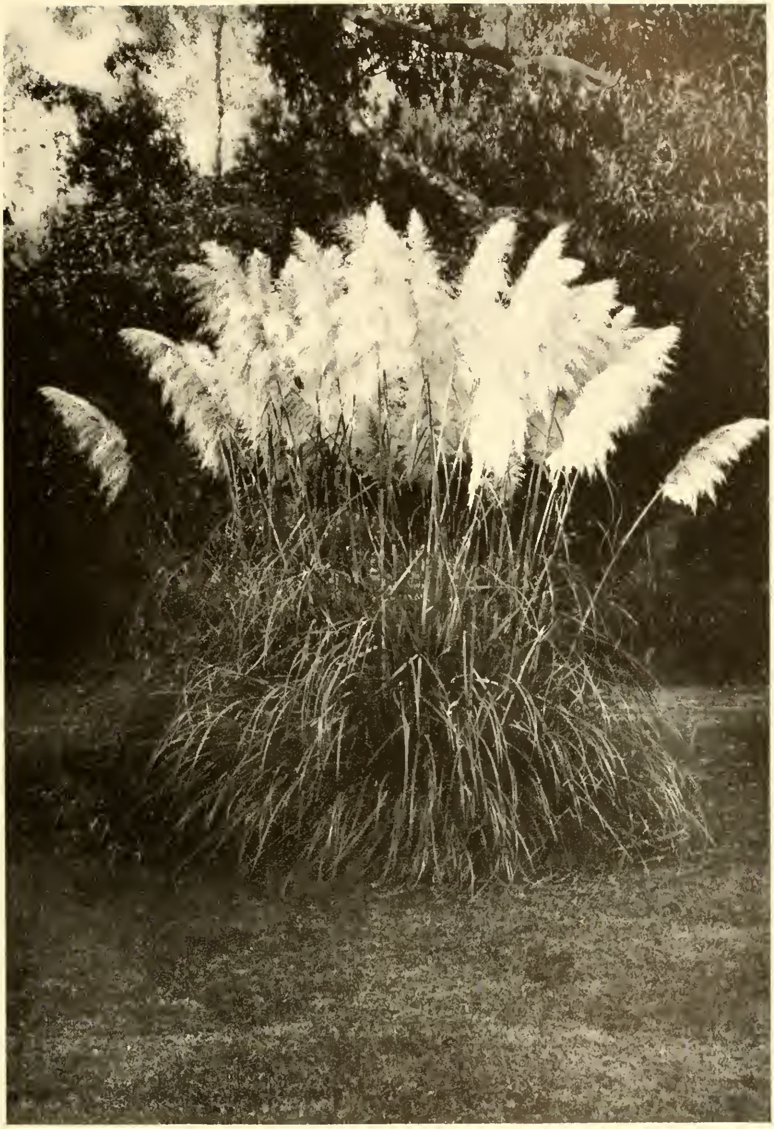
FIG. 46. Villainous introduced grasses. 1, soft chess; 2, ripgut; 3, goat grass; 4, wall barley

place for dances and festivities. The love of greensward is born in us. Most of our parks have more grassland than woods or flower gardens. As soon as an American acquires a home of his own with a bit of ground around it he attempts to make a lawn. Probably nowhere in the world is so much effort expended in lawn making as in the United States. The results are often pathetically indifferent, partly through ignorance, but largely because, except in the cool humid regions of the Northern States, our country has not the moist climate of our ancestral Europe. Our dry summers with scorching heat favor the plains type of grasses, coarse and bunchy, not the fine soft turfy grasses which make velvety lawns. A tale is told of an American landscape gardener visiting England who begged an English gardener to tell him the secret of the wonderful lawns in that country, and giving him good American money for the information. The English gardener replied, "Well, you plow it up and fertilize it and sow grass, then in a few years you plow that under, and sow it again. After you have kept that up two or three hundred years you'll have a good lawn."

It takes knowledge and work and time to make a lawn, especially in a region of hot dry summers. The home gardener often makes conditions already unfavorable still more so by terracing his ground with the sterile earth excavated for his house, lifting the surface a foot or more higher than natural above the water table, so that the grass roots can not reach the moisture below. By copious watering he induces the grass to spread its roots near the surface; the scorching sun dries the top soil and the plants suffer. Shrubbery and perennial borders are much easier to establish and maintain, though some lawn is necessary as a foreground in the picture that a well-planned garden makes.

The chief lawn grasses for the humid temperate regions are Kentucky blue grass (*Poa pratensis*) and certain species of bent grasses (*Agrostis*), such as creeping bent, col-

PLATE 48



Pampas grass (*Cortaderia selloana*) in the Hawaiian Islands. Cultivated for ornament. Photograph by Hitchcock

onial bent, velvet bent, and brown bent. Where these grasses thrive, beautiful lawns may be established by preparing the soil and planting good seed. "The custom of applying a layer of vegetation, part grass and part a miscellaneous collection of weeds, to a soil consisting of the refuse from building operations will never give satisfactory results. Such a lawn is a permanent source of regret and no amount of faithful watering can materially improve it." In the Southern States Bermuda grass (*Cynodon dactylon*) is extensively used for lawns.

The growing popularity of golf, which serves to mitigate the strain of urban life, has created a demand for good turf grasses. Golf, like our ancestors, came from humid Europe, where grazed meadow land offered natural golf grounds. Much time and money are being devoted to golf greens, and many experiments are being carried on in the hope of improving them. When the best grasses for different regions have been found and the best methods of treatment have been worked out, the home gardener can appropriate the knowledge to the bettering of his lawn.

A number of grasses are cultivated as ornamentals. Great clumps of plume grass (*Erianthus Ravennae*), giant reed (*Arundo donax*), pampas grass (*Cortaderia Selloana*, Plate 48) and eulalia (*Miscanthus sinensis*) are often seen in our parks and public squares. Eulalia, however, is an aggressive weed, spreading rapidly, and its cultivation should be discouraged. Fountain grass (*Pennisetum Ruppelii*), with slender pale-pink panicles, is commonly used, though not to the best advantage, as a border for circular beds of cannas.

In warm countries the bamboos are planted in parks and gardens. One of the most beautiful sights on earth is the bamboo grove in the botanical garden at Rio de Janeiro. Even at Kew Gardens, near London, a charming bamboo garden flourishes with hardy shrubby and dwarf species.

In this country we have a large number of beautiful native grasses that deserve to be cultivated as ornamentals. One of the loveliest is the broad-leaved uniola (*Uniola latifolia*), which grows in low woods from Pennsylvania to eastern Kansas and southward (Fig. 47). Though a woodland grass it flourishes in open sunlight and takes

FIG. 47. Broadleaf *Uniola*

readily to domestication. The graceful clumps, with stems three to four feet tall, broad-spreading leaves, and drooping panicles of large very flat spikelets, are charming in a perennial border, or in shaded ground under tall trees. A few stems with their graceful panicles in a slender vase, or a greater number arranged in a standard in a flat bowl are very decorative in the house.

Any of the broad-leaved panic grasses (*Panicum clandestinum*, *P. latifolium*, *P. Boscii* or *P. commutatum*) produce good foliage effects. In spring and early summer their stems are simple, but by midsummer they begin to branch, and by September they look like miniature shrubby bamboos, quite Japanese in effect.

In the Rocky Mountain region and westward are several melic grasses (*Melica spectabilis*, *M. bulbosa*, *M. stricta* and others) with large spikelets of purple or bronze and pale green, as lovely as any flower. Bottle-brush grass (*Hystrix patula*), a woodland species of the eastern half of the United States, is already cultivated to some extent, but deserves wider use. A few of these grasses under a spreading tree, with their slender gray stems, curving leaves and swaying heads of horizontally spreading, long-awned spikelets, suggest a dance of wood nymphs. These and many other beautiful grasses of woods and prairie are as ready to gladden our gardens, if we give them place, as are wrens and bluebirds when we provide nesting boxes and water for them.

CHAPTER III

THE PLACE OF GRASSES IN THE PLANT WORLD

Although grasses have so important a place in the life of mankind—indeed, "All flesh *is* grass"—they are the least noticed of flowering plants. They seem to be taken for granted, like air and sunlight, and the general run of people never give them a thought. Many do not even know that grasses are flowering plants. Their flowers are very small and are mostly hidden by the bracts of the spikelet; but they are as truly flowers as are the gorgeous blooms of the lilies, to which they are not so remotely related. The flowers of grasses are borne on tiny specialized jointed branches, each flower inclosed in two bracts, and with two empty bracts at the base of the branch. This minute branch, with its bracts and flowers, is called the spikelet (little spike). The typical arrangement is really quite simple. In Figure 48, at the left, is a diagram of a flowering branch with leaves and flowers arranged as are the bracts and flowers of a grass spikelet; in the middle is a diagram of a spikelet for comparison (the bracts spread to show the flowers); and at the right is a spikelet of brome grass. It will be seen that the spikelet is a specialized leafy flowering branch, the branch jointed as are the stems of all grasses, and the flowers two-ranked, as are the leaves.

The essential organs of any flower are the stamens and pistil. A stamen consists of an anther, which contains the pollen, and the slender stalk which bears it; the pistil consists of the ovary, which contains the ovules, and the stigma, which receives the pollen and is usually borne on a relatively stout stalk. When the pollen (usually of a different individual of the species) falls on the stigma it germinates and sends its contents, in a minute tube which pushes down through the style, to the ovules, fer-

FIG. 48. Left, diagram of a branch of an ordinary flowering plant, with leaves and flowers arranged as are the bracts and flowers of a grass spikelet; center, diagram of a grass spikelet with the bracts spread to show the flowers; right, a spikelet of brome grass

tilizing them. The matured fertilized ovules are the seeds. The foregoing is true of all flowering plants. In showy flowers, like the lily or the rose, the essential organs are surrounded by a brightly colored perianth or by petals. These showy accessories protect the essential organs in the bud and at blooming time attract insects, which carry pollen from one flower to another, cross-fertilizing them. The essential organs of the grass flower are protected by the bracts which inclose them (the lemma and palea). The abundant pollen is carried by the wind; hence, having no need to attract insects, grass flowers have only a rudimentary perianth, consisting of minute organs called lodicules, which swell up at flowering time and force open the lemma and palea, allowing the stamens and the feathery stigmas to protrude. It is a common observation that a stalk of maize standing by itself does not usually bear a perfect ear of corn; sometimes it bears only a cob with a few scattered kernels. This is because the wind blows the pollen to one side and the silk receives little. In a field of maize the pollen is effective except on the windward border. Even if the flowers are perfect—that is, the stamens and pistils in the same flower—as is usual with grasses, there is some arrangement by which the pollen of one flower is more likely to reach the pistil of another flower than it is to fall directly on its own pistil. For example, the anthers usually dangle on slender threads below the stigmas, hence the pollen is blown away to another flower.

There are many cases, however, in which the flowers are self-pollinated. In some plants at least some of the flowers are so hidden in the sheaths that they can not open and cross-fertilization is impossible.

Grass spikelets are of many forms, but all are built on the same general plan, and they are borne in heads of various shapes and sizes. In wheat, barley, and rye the spikelets are borne directly on the main axis, on opposite sides, forming spikes. In oats, brome grasses and Kentucky blue grass the spikelets, each on a little stem, are borne on the branches of a panicle. In timothy the long cylindric head is really a dense panicle, the spikelets crowded on the numerous very short branches. In Bermuda grass, *Spartina*, grama grasses, and the like, the spikelets are borne on one side of the axis, forming a one-sided spike. In broom sedges, sorghums, sugar cane, and their relatives, the axis or branches of the inflorescence break up, the joints remaining attached to the mature spikelet and aiding in the protection or dissemination of the seed.

In maize, wild rice, buffalo grass, and some other grasses, the flowers are unisexual, the stamens and pistils being borne in separate spikelets. In maize the staminate spikelets are borne in a terminal panicle (the tassel), and the pistillate spikelets in rows on a compound axis (the cob), which is on a short leafy branch (the leaves being the husks) in the axil of a leaf. The "silk" of the ear of corn consists of the numerous long styles with stigmas along their sides. In wild rice the pistillate spikelets are borne on the erect upper branches of a large panicle and the staminate spikelets hang from the spreading lower branches.

Classification of Grasses

There are such multitudes of different kinds of plants (of grasses alone there are about six hundred genera) that it is necessary to classify them in order to put our knowledge of them in usable order. This classification is based on genetic relationship, a sort of family tree. The plants occupying the earth today are the survivors of millions of generations. Countless forms have become extinct, some of them leaving impressions in the rocks or in coal measures (fossils), but most of them leaving no record. The relationship between some plants is obvious, the apple and the pear, peas and beans, the walnuts and hickories, for example. In these cases we assume that their common ancestor is not so very far in the past, a mere hundred thousand years or so. Somewhere in the buried past were the intermediates, the connecting links, between the most diverse of flowering plants. If the history of all plants were known, the living species would be found connected by lines of blood relationship running back millions of years.

The unit of classification of plants is the species, which is a group of individuals closely resembling each other and capable of freely interbreeding. Species that are evidently related are grouped together in a genus. The black oak, white oak, burr oak, and shingle oak, are different species of one genus, *Quercus*. Related genera are grouped in families and families in classes. For convenience in recording our knowledge concerning plants these genera and species are given Latin names. This custom was adopted in the days when Latin was the language of learning, when English, German, Swedish, or French university professors alike gave their lectures in Latin. It is continued today because, so far as the names of plants go, Latin is still an international language. What we call barley, the Germans, Gerste, the French, orge, in Latin is *Hordeum vulgare*, and plantsmen of all countries use that name. The chief advantage of the system of Latin names, however, is that these names indicate the relationship of plants. All species of a genus have the same generic name. Kentucky blue grass and all its kind are Poa, *Poa pratensis*, *P. trivialis*, *P. annua*, *P. Sandbergii*, and the like. The common names of these —Kentucky blue grass, rough meadow-grass, spear-grass, little bunch-grass, respectively—give no clue to their relationship. Knowing *Poa pratensis* anyone familiar with the Latin names of grasses, hearing of any grass named Poa, has an idea of what it is like; it is something like *Poa pratensis*.

Grasses, together with sedges, rushes, lilies, and other families, belong in the class of monocotyledons, characterized by an embryo having a single seed leaf (cotyledon) and by stems having woody fibers not in layers but distributed through them (as seen in the cornstalk). Anyone will have observed that sprouting corn, rye, and other grasses send up a single leaf first, whereas squash, radishes, morning glories (which belong to the class of dicotyledons) have a pair of opposite seed leaves. The grasses form a highly specialized family of about six hundred genera, with a greater number of species than any other family, except the orchids and composites (asters, dandelions, thistles, and the like).

Grasses have been so successful in the struggle for existence that they have a wider range than any other family, occupying all parts of the earth, and exceeding any other in the number of individuals. They reach the limits of vegetation, except for some lichens and algae, in the polar regions and on mountain tops. They are the dominant vegetation in arid regions, sand dunes, salt marshes, and in other places where conditions of plant life are exceedingly severe. Grasses range in height from less than an inch, full grown, to more than a hundred feet. Bamboos, the largest of grasses, form extensive forests and jungles. In the mountains of tropical America and Africa bamboos occupy a zone above timber line and below the short-grass areas of the alpine regions. Some bamboos have developed a climbing habit. Their slender stems push up through the jungle along trails or streams until they reach the sunlight. Whorls of branches then develop which rest on the tops of the trees or shrubs and support the main stem, which continues to grow and to branch repeatedly until the plant forms a lacy curtain hanging from the tree tops. One of the loveliest sights in the West Indies and other parts of the American Tropics are these curtains of bamboos on mountain side or stream bank. Grasses love sunlight, hence only in dense forests are they scarce. A few broad-leaved species carpet the forest floor in the Tropics, and bamboos and others climb out into the sunlight.

The greatest number of species of grasses are found in the savannas of the Tropics, but the greatest number of individuals are found in temperate and cold countries. In the Arctic and Antarctic regions grasses compose about a fourth of all the species. The grasslands of Alaska and northern British America support great herds of caribou and reindeer. On all the great mountain systems of the world grasses are the dominant plants above timber line.

The great grass areas of the world are our own Great Plains, stretching from the Mexican plateau to the Arctic tundra; the semiarid llanos of Venezuela; the campos of central and southern Brazil; the pampas of Uruguay and Argentina; the steppes of Russia and western Asia; the plains of Siberia, Mongolia, and China; the "sud" or elephant-grass regions bordering the upper Nile, the veldt of arid and semiarid South and East Africa, which supports the great game animals made familiar to us by moving pictures, and the steppes and savannas of Australia. In such areas the grasses had their origin and have reached their greatest specialization.

Visitors to Mariposa Grove, California, are told that the big trees (*Sequoia gigantea*) are the oldest living things; and in some of our museums are to be seen cross-sections of *Sequoia* with the annual rings marked at intervals, showing how thick the trunk was at the time of Christ, at the discovery of America, and at other outstanding dates. It seems very probable that individuals of some perennial grasses may be quite as old as the big trees. Some marsh grasses, like *Spartina*, and prairie grasses, such as buffalo grass (Fig. 49), a dominant plant of the Great Plains, propagate by stolons or rhizomes, forming colonies over large areas. Such plants are not only perennial, they are practically immortal. Clumps of *Spartina* in our coastal marshes may be branches of plants that grew from seed thousands of years ago; and much of the buffalo grass which today forms continuous turf for many miles is probably part of the very plants that took possession of the plains as they dried after the retreat of the glaciers.

Bunch grasses, such as the grama grasses, often leave a record of their gradual advance. The bunch grows by accretion at the periphery, where successive stems arise, there being no room for new stems within the bunch. After a few years the center of the bunch dies, but the periphery continues to advance until the colony assumes the form of a ring. Such "fairy rings" are common on

PLATE 49

Sheep feeding on the high plains of the Andes, Peru (13,000 feet). The bunch grass is ichu, common in the high Andes. Photograph by Hitchcock

the plains and in semiarid regions. Eventually the ring, which sometimes becomes as much as a hundred feet in diameter, breaks up into segments, but it can still be traced by the circle of segments, which finally form the beginnings of new rings. The increase in diameter of a

FIG. 49. Buffalo grass, pistillate and staminate plants spreading indefinitely by stolons

bunch may be only a fraction of an inch each year, hence a large fairy ring represents the growth of hundreds or even of thousands of years.

Such vigorous vegetative propagation enables grasses to hold their ground once they have taken possession. Their world-wide dispersal, however, is due to the numerous devices they have developed for the dissemination of their seeds.

Seeds of water grasses may be carried in mud on the feet of water birds. Some are inclosed in air-tight coverings that enable them to float. Darwin made an experiment which shows how widely seed may be carried by water, fishes, and birds combined. He threw seed of barnyard grass into a stream, then caught a fish from the stream and fed it to a stork. He planted the droppings of the stork and barnyard grass came up.

More grass seeds are scattered by the wind than by any other method. People who have lived in the country have seen tumble weeds, roughly spherical in outline, rolling before the wind, scattering seeds as they go. Many grasses scatter their seeds in this way. Tickle grass and witch grass are familiar examples. The diffusely branched panicle breaks away at maturity and is whisked hither and yon, often piling up in fence corners. One of the characteristic grasses of the Great Plains, *Schedonnardus paniculatus*, bears its flowers on slender branches along a narrow central axis. At flowering time the axis may be only ten or fifteen centimeters long, but the whole inflorescence continues to grow until at maturity it is a loose spirally coiled affair as much as fifty centimeters long, which breaks away and rolls before the wind.

The commonest device for dissemination by the wind is an attached tuft of silky or cottony hairs. The seeds of the common reed (*Phragmites communis*), an ancient and world-wide species, of plume grasses (*Erianthus*), broom sedges (*Andropogon virginicus* and its relatives), and many others float in the air like thistledown, and are carried far and wide by the wind.

Some grasses secure dissemination of their seed by barbed spines and spears that catch on the hair of animals. Most needle grasses (*Aristida*), porcupine grasses (*Stipa*), and others that steal rides in this way do no harm to their involuntary carriers, but some, like sand burs, barley grasses, and certain brome grasses are at times injurious. In one of the needle grasses, *Aristida longiseta*, commonly called dogtown grass because it grows in the loose soil thrown up around the burrows of prairie dogs, the seed is borne in a little needle-pointed spear with three slender divergent bristles as much as ten centimeters long instead of a shaft. The weight is so distributed that, as the little contrivance is borne through the air the point is directed forward, ready to strike into any animal in its way and thus secure further transportation. At maturity whole swarms of these seed bodies go scurrying across the plains.

Seeds, especially of annual grasses, are produced in far greater number than can find place to grow. They fall by chance in all sorts of places and all perish save the relatively few that fall in unoccupied spots that meet their requirements of moisture, temperature, and soil. A seed contains a minute plant, the embryo, which was formed while the seed was still attached to the mother plant. Germination is a continuation of the growth which was interrupted during the period of dispersal. While dormant most seeds are dry and the seed coat is resistant to moisture, thus preserving the contents. During germination the seed coat swells and allows moisture to enter the seed. The embryo sends out a little root in one direction and a little stem in the other. The grain or kernel of the maize well illustrates these processes because the seed is large and the changes can be easily followed. The nourishment for the embryo is stored mostly as starch, which is insoluble in water and can not be used directly by the young plant. During germination the starch is converted into soluble sugar, which can be transported by the juices of the little plant. This sugar supplies food for the seedling until it is able to get water from the soil through its developing roots and until its leaves turn green, ready to manufacture its nourishment from the air by means of the sunlight.

The mechanics of germination in the maize seed are interesting. If the seed lies exposed on a moist surface it merely puts forth a root and a stem. If, however, the seed is buried in the soil the stem would have difficulty in passing up through the soil as the tender tip would be injured. The shoot does not bend and elbow its way up as do peas and squashes and other dicotyledons, but goes straight up, the growing parts, one little leaf rolled up inside another, being contained in a tight pointed sheath, closed at the tip. This sheath (technically the coleoptile) elongates, pushing upward through the soil until it reaches the surface, when its tip breaks and the shoot pushes through. There is, of course, a limit to which this sheath will reach. In most kinds of maize it can grow not more than about ten centimeters, though there is a Mexican variety that can grow to the enormous length of twenty-five centimeters.

There are one hundred and forty-seven genera of grasses in the United States and about fifteen hundred species, composing ten to twelve per cent of the entire flora. The grasses of the world have been arranged according to their relationships into fourteen tribes, of which all but one are represented in the United States. The more important are the following.

Bamboo tribe, including woody grasses, the most primitive known. Primitive grasses are those in which there is the least difference between the vegetative and the flowering parts of the plant. Our only native bamboos are the large and small canes (*Arundinaria macrosperma* and *A. tecta*) which form the canebrakes of the Southern States.

Fescue tribe, including fescues, bromes, blue grasses, orchard grass, the common reed, pampas grass and other relatively unspecialized grasses.

Barley tribe, including wheat, barley, rye, and our native wheat grasses. The spikelets are borne on opposite sides of a simple rachis.

Oat tribe, including oats and tall oat grass. The spikelets are borne in panicles. This tribe is especially well developed in South Africa.

Timothy tribe, including timothy, bent grasses, needle grasses (*Aristida*), and others having one-flowered spikelets in panicles.

Grama tribe, including grama grass, Bermuda grass, buffalo grass, *Spartina*, and others with spikelets borne in one-sided spikes.

Canary-grass tribe, including the fragrant vanilla grass or holy grass, sweet vernal grass, reed-canary grass, an important constituent of wild hay, and canary grass, which furnishes canary seed.

Rice tribe, a small group of which rice is the only important member.

Indian rice tribe, aquatic grasses with unisexual spikelets, including our wild or Indian rice.

Millet tribe, containing highly specialized grasses, including two very large genera, *Panicum* (of which the common European millet is a species) and *Paspalum*. It also includes crab grasses, barnyard grass, foxtail millet, pearl millet, and the vexatious sand bur. This tribe is best developed in the Tropics and warm temperate regions.

Sorghum tribe, containing more highly specialized grasses, including the great genus *Andropogon* (to which belong the broom sedges), sorghum, sugar cane, and the cultivated eulalia. The tribe is largely tropical.

Maize tribe, including maize or Indian corn, the most highly specialized of grasses, teosinte, and Job's tears.

Darwin says that a traveler should be a botanist, as the landscape is so largely composed of plants. To know them adds to the traveler's enjoyment. Both the stay-at-home and the traveler could add to their enjoyment of landscape or garden by some acquaintance with grasses, which are not so difficult to study as is generally supposed. An illustrated work on the genera of grasses of the United States can be purchased from the Superintendent of Documents.[1]

[1] Hitchcock, A. S. Genera of Grasses of the United States. U. S. Dept. Agr. Bull. 772. Supt. Doc., Govt. Ptg. Office, price 60 cents.

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PART V

DESERTS AND THEIR PLANTS

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CHAPTER I

CHARACTERISTIC FEATURES OF DESERTS

DESERTS make up as much as one-sixth of the total land area of the world today; and those now shown on the maps are not all the places that have been arid at some time in the long history of the earth. Rocks, salt beds, and wind-blown deposits bear evidence that many regions now moist and fertile have lacked rainfall for long periods of time. Uplifting and lowering of land masses, causing deflection of winds, have brought about a deficiency of rainfall in areas previously well watered and abundant rainfall in others that had been bleak deserts for thousands or maybe millions of years.

Generally such changes take place so slowly that they are difficult to measure in terms of human history, but evidence that certain regions in northern Africa and central Asia have been receiving progressively less rainfall during the last five or ten thousand years seems to be accumulating. However, geographers are by no means in accord on this matter. Those who advocate the theory of desiccation do not hold that every year has been a period of less rainfall than the preceding one, but that decrease has alternated with increase, so that although the yearly rainfall has been less at the end of a thousand-year period, for example, than at its beginning, there may have been during that period increases continuing through a half or even a whole century.

Whatever truth there may be in the theory that great areas of the earth's surface are growing more arid at the present time, we have plenty of full-blown deserts to

Fig. 50. Map of the world, showing location and extent of principal arid areas. Courtesy of the Carnegie Institution of Washington

supply us with our subject matter—the special plant life found in such arid lands (Fig. 50). For the life of desert regions—whether plant or animal—is distinctive. It differs both in appearance and habits from the life of moister environments. The differences are adaptations that are always advantageous and sometimes indispensable to existence in the desert. That the desert molds organisms to a higher degree of fitness for life under the trying conditions it presents can not be proved; but if anything in the vast accumulation of data on plant history is certain, it is that plants which do not show certain specialized structures and habits will die out in dry regions.

Perhaps the development of the peculiar structures and organs of the xerophytes—which is the name for plants able to live with little water—originated as a direct response to the vital needs of plants in arid regions; or perhaps modifications which better fitted them to an existence in such regions appeared merely by chance in certain strains or individuals, enabling them to survive while other forms not so adapted died out. Just exactly what agencies caused the whale and the seal to develop into organisms fitted for life in the salt seas, or the cactus and thorn plants to develop into organisms adapted to continued existence in deserts, is not known. But however this may be, like the whale and the seal, the xerophytes of deserts are where they belong. To see why this is so, we must consider the special conditions of climate and soil peculiar to deserts.

Climate of Deserts

Perhaps the phenomena which most directly bring about desert conditions and so are most characteristic of deserts are scantiness of rainfall and the irregularity of its occurrence throughout the year or from season to season. Thus, in the moister regions of the tropic and temperate zones, where broad-leaved plants form a prominent part of the perennial vegetation, the total rainfall in any year is never more than two or three times as much as it may be in another year. In deserts, on the other hand, no rain at all may fall within a certain year, while several inches may fall in the following year, making the ratio between the maximum and minimum yearly precipitation very high.

The relation of the rainfall to the possible evaporation must also be taken into account. Water from rain saturates the surface layers of the soil; and some of it may, and generally does, percolate deeply, with the result that in moist climates the percentage of moisture increases until a depth is reached at which the water occupies all of the spaces between the soil particles. The upper limit of the portion of the ground wholly saturated with water is known as the water table. The water table as such does not exist in desert regions, or at least it exists only in a greatly modified form. The run-off from the steeper mountain slopes passes to levels deep under the surface, their depth being determined chiefly by layers of hardpan and other semipermeable material, or by clays and their like. Low-lying basins, such as the oases of northern Africa and the below-sea-level basins of the Colorado River desert, Death Valley, and connected basins in California, are underlain by bodies of water which may be reached by boring, but these reservoirs are not fed by precipitation on the surface directly above.

Rainfall in the desert results in wetting the surface of the soil to a depth of only a meter or two. It is from the moisture held in this shallow layer that true desert plants derive their chief supply. As the water in the surface layer has no connection with and is not fed by the deep underground water supply, it naturally follows that evaporation from the surface layer is a very important factor in determining the moisture content of the soil and the practical value to plants of such surface-restricted rainfall.

The rate of evaporation depends largely on the temper-

Caravan ascending sandy slopes leading out of the basin of the oasis of Baharia in the Libyan Desert, North Africa

PLATE 51

Salton Sink, southeastern California, 240 feet below sea level. Rocks in the foreground are coated with travertine formed by the activities of bacteria in saline water ature and upon the total amount of wind flow. To compute this rate, standardized measures have come into use, such as narrow cups of baked clay 15 centimeters long and about 2.5 centimeters across the top, holding 50 cubic centimeters of water. The rate at which water evaporates from the surface of these cups varies with changing winds and temperatures and furnishes the observer with a parallel from which to calculate the rate of evaporation from the soil. Measurement of the amount lost by evaporation from the surface of water in a shallow tub will also give a general indication of what is happening in the soil, although the amount of water which passes off as vapor from a square meter of soil is never as great as that which passes off from a water surface of equal area. The "evaporating power" of the air at a given locality, as it has been termed, may be used in determining the degree of aridity of that locality. When in any region this evaporating power is so great that the amount of moisture which may be lost from a water surface is greater than the amount received by rainfall, some of the phenomena ordinarily associated with deserts will occur. Thus Salton Lake (Plate 51), in the desert of the Colorado River basin, may lose as much as eighty inches in depth within the year, while the rainfall may range from zero to two inches only. At the end of this article (pages 282, 283) there are appended tables prepared by Dr. W. A. Cannon to show the relation of evaporation to rainfall at several localities in the Algerian desert during 1908, from which it may be seen that during April the evaporation in the desert at El Oued was 629 times as great as the precipitation. A careful perusal of these tables shows that in the littoral zone of Algiers, including the city of Algiers, evaporation may be from one to three times as great as rainfall; and in the interior deserts the total evaporation for the year is as much as sixty-three times as great as the precipitation.

But neither the total rainfall nor the ratio of the evaporation to the rainfall can be regarded as a direct index to the amount and character of the vegetation in deserts, because the rainfall of deserts is very irregular both in occurrence and quantity. Thus, the rains may come in torrential storms, in which a large part of the water runs off in floods and does not moisten the soil in proportion to the amount of precipitation; or they may come in frequent slight showers, the water from which, falling on a dry and heated soil, is quickly vaporized; in either case the benefit to vegetation is difficult to estimate. Again, if the rains come in the cooler season (as they do in the Mohave desert), when the temperature is unfavorable to vegetative activity, the plants derive no immediate benefit; and later, with the advent of their growing season, they will respond only to such moisture as still remains in the soil.

So much for rainfall. As for temperature, deserts are proverbially both dry and hot. The extremely high temperatures that are common in deserts occur over areas of land which lack moisture and so can not be cooled by evaporation. And not only may the temperature of the soil and air of arid regions be very high at certain seasons, but also the variation or range of temperature from low to high may be very great. The greatest ranges of temperature are found near the centers of continental land masses, where the air is very dry and hence highly transparent to earth radiation into space. Turkestan is a region which typifies these conditions. At Kazalinsk a range in temperature of 158° Fahrenheit (88° centigrade) has been recorded between summer and winter, and it is reported that at other stations in this region the difference between the minimum and maximum temperature is sometimes as much as 180° F. (100° C.).

As excessive heat seems to offer the greatest trial to man, and must act as a limiting condition to the activities of beast and plant, it may be of interest to mention here some localities where especially high temperatures have been recorded. Such are Wadi-Halfa, Egypt, on the middle Nile, where 130° F. (52.5° C.) has been noted, and Bagdad, California (a small station in the desert of the Colorado River basin just west of Needles), where a maximum of 132° F. (54° C.) has been reached. Similar temperatures have been recorded in Death Valley, California, which lies below sea level and extends eastward from the base of the Sierra Nevada.

As one would expect, the surface layers of the soil of deserts are several degrees warmer than the air after midday. In some places this difference in temperature may be as much as 45° F. The desert traveler soon learns that guns, tools, and all other metal objects, if exposed to the sun, may be handled only with great discomfort during the midday period. The horseman who happens to dismount at noon may save himself some discomfort if he covers his saddle, so as to shade it from the direct rays of the sun, or, better still, removes it and allows evaporation to cool the back of his mount and dry out and cool the bearing surface of the saddle. The top layers only of the soil in deserts hold the absorbing roots of their plants, and yet these layers often reach a temperature of 130°–150° F., if we may judge by common reports. Buxton reports a temperature of 122°–140° F. (50°–60° C.) for soils in Palestine, of 172° F. (78° C.) for a sand dune in the Sahara, and, most remarkable of all, a temperature of 183° F. (84° C.) for soil on the Atlantic coast near Loango, French Equatorial Africa.

We may well ask, "What is the effect of such temperatures on living cells?" The protoplasm of some specialized organisms which live in hot springs is attuned to withstand great heat, but most organisms will suffer harm if subjected to a temperature above 140° F. (60° C.). Seeds, however, are not damaged by heat of that degree, nor are plants at those periods when their organs are dormant. An organism's resistance to high temperatures depends primarily on the proportion of water to other materials in its make-up, and secondarily upon the composition of those other materials—that is, on how highly specialized they are in their heat-resisting properties. Protein (an essential constituent of all living cells, familiar to us in the form of white of egg, in which it exhibits its typical properties) coagulates at the highest of the temperatures just mentioned; so it may be assumed that death from heat involves similar changes in plant and animal tissue, although other alterations equally deleterious may take place simultaneously. The actively growing layers in a plant may normally contain as much as 99.5 per cent of water; excessively high temperatures would cause evaporation at a rate so high that the necessary proportion of water could not be maintained and desiccation and death would result. In some experiments on plants at the Desert Laboratory at Tucson, Arizona, the heat of the sun was supplemented by that radiated from electric heaters. The flattened joints of *Opuntia* were found to continue growth in temperatures as high as 137° F. (58° C.). When the growing layers were heated still further—to 146° F. (63° C.) —no damage resulted to the plant, but growth ceased and was not resumed until the joint was cooled to 122° F. (50° C.). *Opuntia* is well adapted to endure daily exposures to direct sun over long periods. The protoplast of its cells has a high content of mucilage, such as is found in gum arabic or agar, which undergoes little change when subjected to a temperature as high even as its boiling point in water. It is to be noted, also, that seeds which lie on the surface of the soil not only survive a hot season several months long but may endure several such seasons and still germinate. Although subjected to extreme heat, the protoplasm underneath their tough coverings is but little affected, because it is inactive and low in water content.

Such immunity from excessive heat is not possessed, however, by lizards, beetles, and other small animals which stay on the surface of the soil or in the layers of loose soil just beneath the surface or traverse the flat faces of rocks exposed to the direct rays of the sun and whose bodies must therefore be of almost the same temperature as the soil. It may be safely assumed that the protoplasm of these animals remains more or less active through a range of bodily temperature of more than 100° F., as they lack the controls which maintain the body temperatures of higher animals within a narrow range. Even in such warm-blooded animals as man, however, variations in bodily temperature as great as 14° or 15° F. are reported.

So far no mention has been made of low temperatures in arid regions, but these also are to be encountered in the deserts of the trans-Caspian region, in certain dry tracts throughout north-central Asia, and in the dry regions of northwestern North America.

Deserts experience great heat and much of it, for since they have so little rainfall it follows that the actual total number of hours of sunshine in deserts in a given period may be but little less than the possible total number. And not only do the sun's rays pour down on the desert soil from an unclouded sky, but the relative humidity (amount of water vapor) in the air, is very low, so that the rays of the solar spectrum which reach the earth are made up of waves of the higher frequencies, or shorter wave-lengths. Some screening effect is exerted by dust particles, the quantity of dust depending upon the wind flow. At times volcanic dust is blown into the upper air, blanketing great areas of the earth's surface for long periods and screening out or obstructing completely the passage to such areas of some of the rays at the blue-violet end of the spectrum. It is these blue-violet rays, together with the ultra-violet ones (which are not visible), which produce the most direct effect on living tissue. Only recently have scientists realized the importance of the ultra-violet rays to plant and animal organisms, and especially to the latter. Green plants, particularly large ones with leaves, seem less sensitive to these invisible rays; but small plants with thin skins respond quickly to them, as do the higher animals.

Deserts provide the most intensive exposure to ultra-violet rays; hence they are largely visited by health seekers.

Soil of Deserts

The soil of deserts is as distinctive as is their climate. Since the surface is devoid of that mat or carpet of vegetation which in other regions holds the particles of soil together, forming a "sod," and since, also, the particles of desert soil are too dry to cohere of themselves, even a very slight wind will suffice to stir up and shift the material of the surface layers. The most familiar topographic feature resulting from wind action is the sand dune (Plate 52). In a sandy area whose surface layers are made of hard particles of almost uniform shape, size, and weight, the wind shifts the sand and piles it up in mounds or dunes of more or less regular form. Furthermore, the wind is continually picking up the particles on the exposed side of the dune and carrying them to the summit, whence they may roll down the lee side. thus making it steeper than the windward side.

Rock surfaces, when subjected to gusts of wind laden with sand, are smoothed, carved, and fluted by the corrasive action of the pelting sand grains. Another characteristic feature resulting from wind action is the desert pavement, which begins as a surface made up of small rocks, gravel, sand, and dust. The wind removes the smaller and lighter constituents from between the larger and heavier ones, so that the heavier ones are allowed to sink. After this process has continued for many years, the pavement becomes an irregular mosaic of rocks, which may vary in size from a small pebble to stones as large as the closed fist and whose surfaces have been polished by the action of the moving grains of sand.

In addition to altering the surface, wind action in deserts is responsible also for the rounded outlines of small hills, mounds, and even artificial structures, as is

PLATE 52

Wind ripples in the sandy soil of the Mohave Desert, California. Portion of dry lake bed is visible in distance on the left

PLATE 53

Rounded wind-worn hillocks in the Libyan Desert, North Africa. This landscape is devoid of vegetation evidenced by certain ancient stone structures in the Libyan desert, whose right-angled corners have been worn away by the abrasive action of wind-borne sand. While on an extensive journey with a camel caravan in this desert, I encountered many rounded hillocks like those illustrated in Plate 53. Ages of attrition by flying sand have streamlined these hills so that the wind flows by them with very little obstruction, forming an eddy on the lee side such as forms in the sea in the wake of a ship. Such hills offer very little shelter from the direct force of sand storms.

A consideration of the special conditions peculiar to deserts must include some notice of alkaline and salty soils and of dry lakes. In regions with adequate rainfall the run-off collects in streams and fills natural basins to their rims, thus forming lakes, whose waters may ultimately find outlets to the sea. A continuance of this process of stream and lake formation results in complete systems of drainage such as are found on each of the continents today. In arid regions, on the other hand, there is not enough rainfall for the run-off to fill the natural basins to their rims, so that the lakes (if any form) are shallow and have no outlets; such streams as reach the sea run their full courses only intermittently, and the others lead into great shallow basins.

All drainage waters, including those which slowly percolate to the lower levels of the earth's strata, carry salts which have been dissolved from the soil. The salt of the sea has such an origin. In incomplete drainage systems the salts carried by the run-off waters are deposited as layers in flats or basins, or else accumulate in inland lakes or seas and make saline the waters of such large bodies as Great Salt Lake in Utah.

CHAPTER II

ORIGIN AND DEVELOPMENT OF DESERT PLANTS

It is in an environment resulting from the meteoric (atmospheric) and edaphic (soil) conditions described in the preceding chapter that plants and animals exist in deserts. In the scantiness and irregularity of its rainfall, the wide range of temperature of its soil and air, its low humidity, its high intensity of sunlight (with especial reference to the rays with the shortest wave lengths in the ultra-violet), the greater ionization of its atmosphere, the greater salinity of its soil, and its pronounced wind action—in all these aspects of environment deserts offer to plants and animals conditions of living widely different from those encountered in the moist, well-watered regions of the tropic and temperate zones.

So rigorous are the requirements of life in deserts that most of the plants native to the more humid regions can not survive there. The most notable examples of the successful growth in arid lands of plants native to moist regions are orange and lemon trees, common crop plants, and certain tender vegetables; but all of these must be cultivated in soil which is irrigated by water from wells and diverted streams. These plants would in no wise survive without the most intensive and meticulous farming.

But plants and animals which are native to deserts find the conditions of life there acceptable. They display modes of activity suited to the climate and soil and, presumably, have developed or were evolved under the same conditions as those which now prevail in these regions. The characteristics of these native desert organisms constitute one of the most interesting phases of biology.

Weird and grotesque as some of the plants which inhabit the deserts may seem to us, they are none the less in harmony with their surroundings, or at least as nearly so as are most other living things. It is customary, in speaking of a plant which flourishes in a given locality, to say that it "grows like a native." This is assuming that all species of plants are now to be found in the places best suited to them. No assumption could be more fallacious. The fact that plants which man has transported from distant places often run riot and become weeds and serious pests in their adopted pastures and fields is a signal refutation of this too general statement. And many wild species left in their native habitats may be dwindling and moving toward extinction because of some deleterious agency in their environment which we do not apprehend or have not taken into account.

Plants, like human beings, are found in those localities which they have happened to reach, in which they can endure season after season, and in which they can reproduce themselves. And the vegetation of deserts is no exception to this rule. The fact that the desert environment is unusual and trying, perhaps, to most plants does not mean that all of the species found in arid regions are under greater stress than all of those found in woodlands of the Mississippi Valley. In fact, most species characteristic of deserts suffer notably when taken into what might seem more favorable environments. It is by no means to be taken for granted, for example, that the plants of deserts would be benefited if furnished more water. The regulation and restriction of the water supply of succulents transplanted from Mexican, South American, or African deserts to moist regions is, in fact, one of the most difficult problems in gardening.

The peculiar forms of plants which endure or even thrive in deserts may be best understood in the light of their origin and development. The primitive ancestors of all plants probably began as simple masses of protoplasm in water, or in water-saturated sand or small fragments of rock; for, in the beginning, there was no soil. Accumulations of small water-worn bits of rock made sandy beaches, or particles even smaller might be blown about by the wind and piled up in dunes; but of humus, or the softer material of the ground, as we know it today, there was none. Soil could come only after plants with hard, woody tissues and animals such as beetles, with durable constituents, had left their remains on the surface to slowly disintegrate; for the surface layer which we know as soil is a mixture of minute bits of rocks and of fragments of dead plants and animals in various stages of decay and disintegration.

The progenitors of plants, whatever form their bodies might take, were composed largely of water—perhaps as much as 99½ parts in 100. If for any reason they became exposed to the air they dried out and perished. Not only in this did they differ from the modern plants, but also in their ability to multiply by the division of one simple mass into two, as a large drop of water separates into two or more smaller drops. While we do not have the evidence to show all of the intermediate steps, yet it is known that after a long time these simple early plants developed special methods of reproduction. The entire body was no longer concerned with the process, but certain masses or cells were differentiated and specialized to perform this function. These specialized reproductive cells, or spores, became detached from the body of the plant and could move about only in water and germinate only when immersed. The next step was the further differentiation of the reproductive cells into two kinds, male and female, constituting sex and making it necessary for the two different kinds of reproductive cells to come together and fuse in order to produce new individuals. Forms as high in the

PLATE 54

Typical vegetation of the Arizona desert, as shown at the mouth of Pima Cañon, Santa Cruz Mountains. The red flowers grow on the candlewood, ocotillo (*Fouquieria*); in the right foreground is the tree cactus (*Carnegiea*)

scale of plant life as ferns, liverworts, or mosses might have evolved from the first plants near pools or stretches of shallow water or in moist sands, especially in regions characterized by continuous fogs or heavy clouds. Vegetation in those early days, however, no matter how abundant it might be, still could not venture away from the shores and banks of streams and lakes, and might even occupy extended areas of shallow water, which, with their accumulations of dead stems and other débris, must have resembled a modern swamp.

Thus the greater part of the land surface of the globe was still inaccessible to plants, which could not exist far away from bodies of water. A further very marked step in evolution was necessary before plants could spread across the country and occupy in some fashion or other almost the entire face of the earth between the polar regions. While still living in swamps, the fernlike plants had developed a life cycle which included two generations. An example of one of these generations is the ordinary plant known as a fern, which is asexual and produces the familiar brownish spores. The spore germinates and produces an inconspicuous organism recognizable as a fern by the specialist only—a prothallium, as it is termed, which must have abundant moisture to thrive. The prothallium is thin, flattish, and green, and may be so small that it can be covered by the letter *o* of this type. The two kinds of reproductive cells known as the sperm and the egg are produced in special sex organs on the under surface of the prothallium, and the sperm cell must swim from its place and fuse with the egg cell in order to fertilize it. The germination of the egg results in the larger fern as we commonly know it. Now it is obvious that a plant which needs two such forms, one of which must live in a very moist locality, must be confined to the waterside if it is to complete its life cycle and reproduce itself.

Not until the larger plants acquired the more delicate bisexual generation and protected it from desiccation was it possible for them to get away from the swamps and streams and develop into the more highly specialized forms. This they finally accomplished. All the large modern seed plants, such as trees, shrubs, and herbs, are homologous to the fern. Unlike the fern, however, the spores from which the gametophyte (generation which bears sex organs) of seed plants is produced are deeply buried in the flower tissues, and the whole process of reproduction is carried on inside of structures in which the elements fusing to form the fertilized egg are shielded not only from desiccation but from other deleterious agencies. Once the sporophyte (generation which bears asexual spores), as illustrated in the fern, had developed the gametophyte and acquired the ability to carry it safely protected within its flower structures, the plant was ready for its pilgrimage across the high open stretches of the earth. The first time that a plant accomplished this feat marked the beginning of one of the great epochs in biological history. For animals are dependent upon plants for food; and until the plants began to move from the well-watered areas out upon drier land, animals too were confined to the waterside.

Up to this point in our discussion we have thought of the necessities of reproduction alone as governing the evolution of plants, but it is plain that the occupation of drier lands brought up other problems in plant life also. Root systems which were adequate for anchoring the stems in moist places and for taking up water from ground in which it was abundant would hardly suffice in arid regions, where the moisture might be in the surface layers only on days immediately following rains or might run deep underneath a thick layer of soil in which the oxygen supply necessary for plant growth was very scanty.

A leafy plant which is to survive in a desert must not only have roots which can pick up the precarious water supply, but it must restrict its use of such moisture as it has picked up. The extent to which a plant may use the energy of sunlight depends in the main upon the area of green surface that it can expose to the sun's rays. But the greater the surface exposed to the air, the greater the loss of water by evaporation. However, evaporation compensates in a large measure for this loss by a good service it performs at the same time. For the photosynthetic action of the green cells requires a continuous flow through the stem of the water, or sap, picked up by the roots, which holds in solution the nourishing salts of the soil; and evaporation in the walls of cells exposed to the air is the force that pulls the sap upward from the soil. A thousand pounds of water must be lifted for every pound of dry matter laid down in the aerial tissues of a plant, and evaporation is the agency that does this mighty work.

A leaf is therefore a sun-driven factory in which water must be evaporated in sufficient quantity to lift solutions from the soil, and in which some of the water of the soil solutions enters into chemical combinations used in the nourishment of the plant. In moist regions the capacity of the leaf factories is probably limited only by the number of hours of sunshine received and its intensity; for an adequate water supply is always at hand. But in arid regions, where the sunshine is always adequate, the capacity of leaf factories depends directly upon the amount of water which the plants may secure from the soil, a workable proportion of which is present only during certain seasons.

It seems abundantly clear that the first plants lived in the moister regions, and that not until species appeared with specialized root systems and with water-conserving green organs was a notable amount of vegetation to be found in deserts. This is emphasized by the fact that no fossils have ever been found of plant types which we recognize as suitable for existence in very arid regions. The nearest approach to such types is seen in the hard leaves of the cycads and in pine needles, whose fossil prototypes probably have been preserved; for genera with similar leaves are well represented in the paleontologic record. It is therefore reasonable to suppose that these were the first of the higher orders of plants to occupy the parts of the earth's surface not so well watered as the regions with abundant rainfall. It is true that the climate and soil of deserts are not in the main favorable to the preservation of fossils, although the alluvials along the streamways might be counted upon to entomb and preserve some of the more durable structures; and the heavy spines of such desert plants as the cactus and other thorny shrubs contain a high proportion of calcium and silica and should be as capable of preservation as the bones of animals. Rich finds of animal skeletons and of shells have been uncovered in arid deposits, but so far nothing suggestive of the metal-hard spines of the tree cactus has come to light.

CHAPTER III

ADAPTATION OF PLANTS AND ANIMALS TO DESERT CONDITIONS

It would seem, therefore, that the characteristic plants of the deserts of today are of very recent development, and, in one sense, represent the highest specialization of which the leafy shoot of seed plants is capable. For it must be understood that before the desert species appeared plants with erect stems and many branches bearing broad-bladed leaves had developed; and these could thrive on solid ground, instead of only in swamps, as was true of the first plants. From these early land-dwelling forms desert plants evolved. An intimate study of the structure and habits of xerophytes, or desert plants, brings to light two marked characters not displayed by their ancestors, or, at least not displayed by plants of the same species living in well-watered regions today. Whatever the agencies which started a species or strain of plants toward modification of its structure and habits so as better to equip itself for living in dry regions, these two characters in thousands of species of the higher or seed-forming plants bear evidence that such modification has taken place. They are, first, the possession of thorns and spines rather than branches and leaves, and, second, succulence (Plate 55). Let us now consider briefly how these two characters may have been acquired.

Modification of Leaves

The first and most noticeable reaction of a leafy plant to an arid environment is its failure to attain that expansion of leaf surface which it might attain in a moist or humid region. Take, for example, a pair of rapidly growing sunflowers. Allow one to develop in a moist greenhouse in a well-watered pot and cultivate the other in a dry house such as would be suitable for growing succulents. The total area of leaf surface will be much less in the plant left in the dry house than in that which was copiously watered. However, it must not be taken for granted that the plant species now found in deserts have resulted from an experiment by nature as direct and simple in its effects as that described above. So far as any experiments yet made by man have divulged, the direct effect of a new environment on the organism of a plant (in this instance, restricted leaf surface) is not transmitted by the seeds to the succeeding generation. The seeds of the sunflower grown in the arid environment, if germinated in a moist house, would produce plants as broad-leaved as those of any other sunflower. In other words, change of environment does not establish heritable characters in a plant.

Now, the primary function of stems and branches is to support the weight of the leaves, which contain the vital chlorophyll. And so it follows that lessening the total spread of its leaf surfaces, as the xerophyte has done, renders unnecessary as many branches as are required by a plant with wide leaves. To illustrate: Take a profusely branched shrub bearing many large leaves, such as is common in the moist temperate zones. Remove some of the leaves, and trim away the margins of those that remain until they are much reduced in size. Then cut away the smaller branches or twigs (which, since the leaf surface is lessened, are no longer necessary), and reduce the size of the remaining branches. The resulting specimen is something like a thorny, desert shrub. And even the spiky appearance of the xerophyte may be produced by paring away the outside layers of the branches until their tips are sharp pointed. The spinosity of a desert shrub is further accentuated by the fact that not only does its

Typical desert vegetation near the Gulf of California in Sonora, Mexico. A low-growing spiky agave, a thorny ocotillo, and a succulent organ cactus are in the foreground

PLATE 56

Vegetation in the Mohave Desert, California. In the foreground clumps of a low composite (*Isocoma*) and a single succulent opuntia. Joshua or tree yuccas are characteristic of this region stem contain rigid woody tissue, but the outer layers of its spines also (which are entirely of cellular tissue), are indurated by a growth of woody material in their cell walls and by a deposit of calcium and silica in their cell cavities.

In many spinose xerophytes a layer of waxy material, also, is formed on the surface of all the external organs, including the leaves, thus lessening further the rate at which water may evaporate from the plant. Spinose plants exemplify the earliest and the most fundamental changes by which plants of moist regions have altered so as to become capable of living in regions with a scant supply of water in the soil and with little rainfall. They are the most abundant and widely distributed of all desert species. Plants in any family may show modifications of this kind.

Succulence

The second marked character developed in desert plants by modification is succulence, or the quality of having juicy or watery tissues (Plate 57). To acquire this character it was necessary for the early plants to form large masses of specialized tissue in their roots, branches, or leaves for the storage of surplus water, available in times of failure of outside sources.

These two changes—reduction of surfaces exposed to evaporation by a modification of branches and leaves into thorns and spines, and the acquisition of the quality of succulence—may have taken place simultaneously in some plant species. While the shoot and leaves were gradually diminishing their surface extent, certain of their tissues, such as the medulla (or pith) and the cortex (or epidermis), may have been enlarging so as to increase their capacity for water storage. The *Mesembryanthemum* and *Sedum* are typical plants which have such enlarged tissues in their leaves. The most extraordinary types result when the surface-reducing tendency and the swelling of the water-storing tissues are carried to the extreme in the same individual, as in some of the Cactaceae and Euphorbiaceae. Continued reduction of a shoot will eventually bring it down to a thin cone; and the exaggerated enlargement of its pith or cortex, if carried far enough, will cause the stem to swell out into a fleshy cylinder or globe of irregular outline. This seems to be about what has happened in the long evolutionary history of such a plant as the barrel cactus of the deserts of Mexico and the southwestern United States. In this bizarre plant the woody cylinder of the stem is no larger than the forearm of a man, although the swollen cortex surrounding it is several inches in thickness. The epidermal, or outer, layer of the stem's covering is heavily waxed to prevent the escape of water. The hard, curved spines, which are the vestiges of foliar organs of an earlier period, suggest that the ancestors of this plant had a branched shoot. Perhaps as many as two thousand species of cactus and other plant families show a development toward this type, which may be said to have reached its extreme specialization in the barrel cactus (Plate 58).

A comparison of the conditions under which spiky plants grow most abundantly with those under which succulents reach their highest development reveals some interesting correlations. Thus it is noteworthy, in regions in which the rainfall is very slight and uncertain, such as the great desert areas of northern Africa and of Asia, that the dominant members of the scanty flora are spiky shrubs or tough herbs which spread only a limited expanse of leaf surface to the evaporating force of the sun and wind (Plate 59). The rainfall in such regions never comes in sufficient quantity to allow the plant to take up a supply of moisture in excess of its immediate needs; or else it arrives at a time when the plant is not capable of taking up an excess. The root systems of these spiky shrubs ramify through the loose soil and penetrate into the crevices of rocks, gathering in minute supplies of

PLATE 57

Succulent *Coralluma*, which has a milky juice, near Port Sudan on the Red Sea

Principal types of desert vegetation. Green-barked tree at the left is a paloverde; beneath it is a flat-jointed opuntia; in the center are spinose shrubs of acacia; a paloverde leans across a columnar tree cactus; at the right are two barrel cactuses moisture from a comparatively extensive area of soil. When the proportion of moisture in the soil falls so low that only oven heat could extract the tightly held remnant, the acquisition of water by the plant goes on very slowly. In fact no absorption at all would be possible were it not for the osmotic action of the highly concentrated sap of these plants. Laboratory tests show that the sap of some xerophytes has an osmotic pressure of a hundred and fifty to two hundred atmospheres, or three thousand pounds to the square inch. The absorptive or sucking power of the cells in plants of such highly concentrated sap would be sufficient to raise a column of water six or seven hundred feet. Such energy, tremendous as it seems, is necessary for plants which exist in the extremely dry soils of deserts.

The possession of the power of suction to a high degree, however, does not entirely solve the problem of taking water from a soil which holds but little of this indispensable element on its minute particles by the strong grip of surface tension. The soil particles are at all times slowly disintegrating. The complex union of chemical elements which form rocks is constantly being broken up into soluble salts of sodium, magnesium, calcium, potassium,and other elements, which dissolve in the minute layers of water from which the plant must draw its supply. These salts are being continually carried off in a moist region by the sloping drainage, but in the low basins and level plains of deserts, which lack drainage, they must remain; consequently the soil becomes highly charged with soluble salts. If at the same time the chemical combinations in the soil are such as to make it "alkaline" only a comparatively small number of plant species may survive. For the highly concentrated saps of the plant cells are "acid," that is, they hold free hydrogen ions in solution. In the alkaline soil solutions, on the other hand, an opposite condition prevails; for all of the hydrogen content is firmly bound to oxygen, so that free hydroxyl ions are present instead of free hydrogen ions.

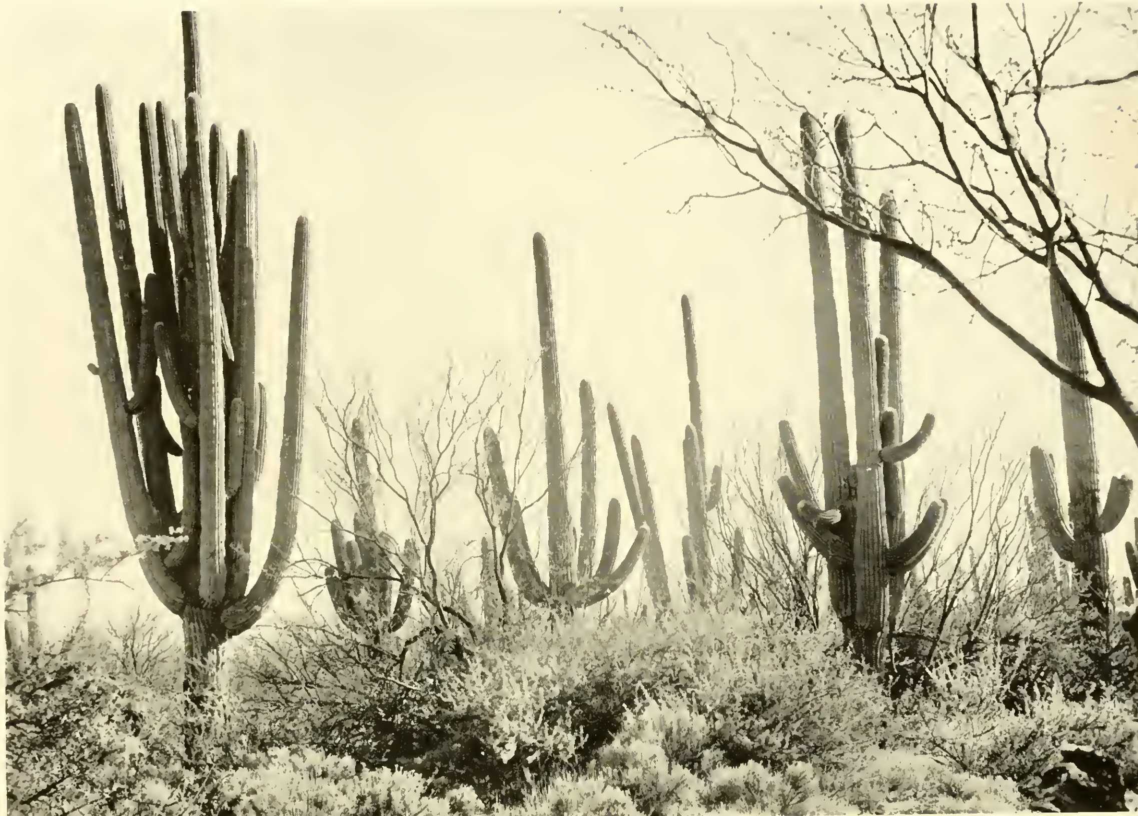
The absorbing cells of the plant must therefore suck up their "sap" from a soil solution which is not only alkaline but which contains a higher proportion of salts than can be utilized, and at the same time the acidity and osmotic pressure of the sap must be maintained—a seemingly impossible task. The plant's problem is to isolate water from a solution heavily charged with deleterious ingredients. It is as if a thirsty man were given a fascicle of lemonade straws through which to suck and told to extract a pleasant-tasting drink from a briny pool. Now, to accomplish this, he would need a chemical screen that would obstruct the passage of the undesirable constituents while admitting the desirable ones; but no such screen has ever been devised by man. If one is ever invented it will be of incalculable value in obtaining fresh water along many thousands of miles of arid and torrid seacoasts.

But though man has not solved this problem, desert plants have. They have a process for extracting fresh water from briny and alkaline solutions and are thus capable of living in black alkaline soils and in the white and salt-encrusted areas around dry lakes and inclosed basins. According to results of experiments which I have made with capsules of cellulose, mucilage, and gelatin, whose properties simulate some of the activities of the living plant cell, this screening action of xerophytes is made possible by the presence of certain lipoids, or combinations of fatty substances with phosphorus in their cells.

Succulent plants are obviously best suited to places in which there is at times an abundance of water which may be taken up and stored. This condition prevails in the arid regions of North America; and the cactus, which is common to these regions, is a striking example of a water-storing species. In regions well away from the seacoast, or in places where a "continental" climate prevails, periods of plentiful rainfall may occur in midwinter and in midsummer, although the total amount received an-

Watering domestic animals from supply obtained by digging pits in sandy stream bed in Upper Egypt. The spiny shrubs are typical of North African deserts

PLATE 60



Vegetation at the foot of the Santa Catalina Mountains, Arizona. The tree cactus, spiky shrubs of mesquite, and acacia are the prominent forms nually may be small. However, the soil is thoroughly wetted during the rainy seasons, and at such times considerable water may run off through the intermittent streams, which have dry beds during most of the year.

Heavy rainfall during restricted periods does not alone insure the proper development of succulent plants. This fact is strikingly illustrated by a comparison of the deserts of Sonora (Mexico) and southern Arizona with the Mohave Desert, which is the southernmost of the series of arid basins in southwestern North America and which includes the famous Death Valley. Arizona and the arid regions in Mexico receive both midsummer and midwinter rains, and the climate in these districts is such that a large number of plant species are active in growth in both seasons. Rain falls during February and March and again during July and August, wetting the soil thoroughly and thus providing water which may be taken up by the plants. As would be expected under these conditions and as noted above, numerous species of succulents, principally of the cactus family, occur in these regions and form the greater part of their flora (Plate 60). But now consider the Mohave Desert, which also receives ample rainfall. It lies at the same elevation above the sea as do the cactus deserts of Arizona and Sonora, but on account of its nearness to the sea and the configuration of the surrounding mountain ranges the greater part of its rainfall occurs in the winter season, in the period of low temperatures. Only at rare intervals do cloudbursts cause its slopes and basins to be flooded in the warmer season. Thus the soil is wetted only during the cold season, when the roots of plants are inactive. With the approach of warmer weather in March and April new absorbing rootlets are formed, but the water content of the loose soil is then depleted at a rapid rate by the rising temperature and by the high wind flow of the region. Therefore only the remnant of the winter precipitation and the uncertain and rare summer cloudburst are available to the plants of the region, so that but few succulents have been developed, among which are a small number of species of the cactus family (Plate 61). None of them, however, attain great size and none are abundant.

The sap of succulents is by no means so concentrated as that of the spiky shrubs, showing an osmotic pressure of only three to fifteen atmospheres; but the suction power of the plant cells is adequate to the speedy absorption of great quantities of water within a brief period. Thus the trunks of the massive tree cactus of Arizona, which are one or two feet in diameter, may swell as much as an inch in diameter during the day and night following a warm rain at the end of the early-summer dry season. The massive trunks of this and other types of cactus, as well as the flattened stems of the *Opuntia*, can hold enough water to meet the needs of the plant for a year or two if no further supplies are available. Specimens of the barrel cactus (Plate 59) have been kept on a table for five years with the entire surface of the plant, including the roots, exposed to the air, after which the plant has resumed normal growth when placed with its base in the soil and given water in the quantity and with the same frequency to which it was accustomed before it was uprooted. The highest observed endurance record for desert plants living exclusively on their own accumulated water and food material was made by the thickened tuberous base of an *Ibervillea guarequi*, native to northern Sonora, which I kept for thirteen years on a museum shelf. This plant is a member of the gourd family; and the basal part of its stem, which is perennial, forms a rounded mass as large as the crown of a man's hat. This mass is well waterproofed, so that moisture can not escape from it, and accumulates not only water but starch and other food material to a bulk and weight far greater than that of the thin stems which are sent up every year. A specimen of a tuberous base of this kind, apparently as lifeless as a knotty piece of wood, was placed on a shelf in a display case in the museum of the New York Botanical Garden during the first half of the year 1903. During the summer of that year a few thin green stems formed, which reached a length of a few inches and then died without producing flowers. This procedure was repeated the following summer and every summer thereafter until 1916. Thus the woody tuber held enough water and food material in storage to start its growth during thirteen seasons. If the plant had been in the open and lying on the ground, numbers of small thin roots would have been sent down into the soil and its water balance maintained by replenishing the supply every summer. Such small roots customarily perish at the end of the warm season; and so the traveler may find the storage tubers only slightly embedded in the soil, generally under trees, where they appear as lifeless chunks of woody material except for a period of sixty to eighty days during the season of the summer rains. The leafy shoots developed at this time die as far back as the basal swollen part and soon fall away.

Such are the adjustments that plants have made to the peculiar conditions of climate and soil found in deserts. When next we look upon a cactus we shall see back of its pulpy stem to the solid branch whence it evolved and know why that evolution was necessary, and back of the bristling, close-fisted spines, with little evaporating surface to the broad-surfaced leaves of plants of moister regions. Desert plants are but another evidence of the inexorable logic of nature.

Adaptation of Desert Animals to Desert Plants

We may ask as a closing question how desert animals have adapted themselves to desert plants. Much reliable evidence is being accumulated to show that some species of large animals in Asia, Africa, and North America may live normally for long periods on the water contained in the vegetation which serves as their food. Some desert rodents are capable of existing for months on a diet of hard seeds in which the proportion of water to dry weight is much less than ten per cent. Many of the animals of American deserts are known to eat the soft tissues of cactus in which water constitutes as much as ninety-five per cent of the total weight.

Neither man nor the horse is well adapted for life in the desert, as both require large quantities of water daily. Thus a man walking in the open in the deserts of Arizona, California, or Mexico during the summer season will require from a tenth to an eighth of his total weight in water every twenty-four hours—from sixteen to twenty pints. A horse would use eighty to a hundred pints during the same period. The juices of the succulent plants which might suffice to yield an emergency supply of water to a cow, antelope, rat, deer, or peccary generally carry bitter substances which make them unfit for man even in the extremity of thirst. The whitish tissues of several species of barrel cactus, however, contain so little objectionable material that small quantities may be taken to relieve man's thirst without injury. It has been found that the Indians of southwestern North America frequently resort to the barrel cactus to quench their thirst when on long journeys during the hotter season of the year. The method employed is to break open the apex of the ovoid massive stem with a rock or remove it with a knife, then to crush the uppermost parts of the pith and cortex by pounding them with a rock or with the end of a heavy stake of wood, after which the juice may be squeezed from the mass into a vessel or into the cavity thus formed in the stem.

The profound effect of deserts on both plant and animal life may be readily understood when it is recalled that all living tissue contains over ninety-nine per cent of water and that the earliest forms of life floated in pools, were embedded in ooze, or lay in swamps and marshes in which there was as much water outside their protoplasm as inside it. While plants and animals, as they have evolved

Typical vegetation in the Mohave Desert, California, along the dry streamway of the Mohave River

PLATE 62

Altar-candle trees (*Iddria columnaris*) growing near the Gulf of California in Sonora, Mexico from their primitive forms, have appeared to move toward all points on the horizon, one main tendency in their migrations was obviously inevitable: Since primeval life occupied the regions of the earth's surface with the most water, it could move only as it evolved, so as to occupy the regions with less water. Certain animals, including man, might penetrate the drier regions, moving in and out of them as their needs required; but plants, being immobile, in order to use the deserts at all, must equip themselves for continued existence under the arid conditions. The spiky shrubs, succulent cactuses, vines with enlarged storage roots, and all those species which suck their nutriment from alkaline or salty soils have accomplished this; and so they represent the widest possible departure from their primeval progenitors. The desert plants have traveled farthest of all living organisms along the road of biological adaptation. Though we may not recognize it as such, its peculiar plant life is an element in the fascination of the desert for us. The desert panorama comprises far horizons, wind-swept dry expanses, deeply tinted rocks and mountain ranges, blazing sunlight and shimmering mirages, all bathed in an incessant swirl of heat and color suggestive of an elemental and as yet unconquered world. Into this hostile environment armored forms of vegetation have forced their way, showing by toughened leaves, indurated stems, and stored-up water, the means by which they have gained a foothold in a land so widely different from that of their ancestral origin.

TABLE SHOWING RATIO OF EVAPORATION TO RAINFALL IN THE ALGERIAN DESERT, BY SEASONS AND STATIONS, DURING THE YEAR 1908, AND AVERAGE RATIO FOR THE YEAR BY STATIONS.[1]

Station	Winter	Spring	Summer	Autumn	Annual
Littoral:					
Nemours	2.69	44.09	24.1	7.4	3.0
Cape Falcon	1.83	8.75	58.6	16.3	3.7
Oran	2.54	3.7	71.0	7.95	4.2
Algiers	1.0	7.96	86.4	2.44	1.8
Bouzarea	0.58	3.0	28.5	1.45	0.93
Maison-Carrée	.62	5.0	117.4	1.48	1.5
Tell (Atlas):					
Fort National	0.39	1.4	83.2	1.67	1.1
Sidi-bel-Abbès	.73	8.2	38.3	6.0	2.2
Saida	.69	1.0	3.5	3.9	1.9
Batna	1.8	2.1	0.35	3.6	4.4
Tebessa	4.7	4.05	88.2	2.8	6.0
High Plateau:					
Bou Saada	5.9	7.0	76.0	9.2	11.0
Barika	4.1	6.6	93.5	35.2	12.2
Ain Sefra	1.4	12.5	67.9	18.5	11.1
Géryville	7.0	9.8	20.8	3.2	3.5
Desert					
Laghouat	6.0	73.2	271.6	64.6	17.0
Ghardaia	154.9	416.3	293.7	195.9	59.7
El Oued	68.3	354.0	485.2	109.5	63.0

[1] Reprinted from Cannon, W. A. "Botanical Features of the Algerian Sahara." Publication 178, Carnegie Institution of Washington, p. 10, 1913.

TABLE SHOWING RATIO OF EVAPORATION TO RAINFALL IN THE ALGERIAN DESERT, BY MONTHS AND STATIONS, DURING THE YEAR 1908[1]

Station	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Nemours	1.07	1.3	1.39	1.9	131	5.4	23.6	43.3	8.6	3.1	10.6	5.7
Cape Falcon	1.5	1.8	1.46	16.0	8.8	10.3	29.7	136.0	38.1	1.9	8.9	2.2
Oran	1.3	1.9	1.6	1.3	17.4	8.5	59.0	146.0	18.0	2.45	3.4	4.4
Algiers	0.63	1.3	0.5	1.1	22.3	11.7	219.0	28.8	5.07	1.06	1.2	1.1
Bouzarea	.57	0.67	.22	0.56	8.3	4.8	53.7	27.1	3.4	0.2	0.76	0.5
Maison-Carrée	.72	.64	.55	1.1	13.5	11.8	149.0	12.0	5.2	.9	.35	.51
Fort National	.72	.29	.34	.58	3.7	192	42.5	15.5	2.7	1.6	.71	.16
Sidi-bel-Abbès	.63	.76	.6	1.1	18.8	18.5	77.8	37.8	14.8	1.4	1.9	.8
Saida	.67	.64	.36	.83	2.2	6.9	86.7	12.1	4.7	5.8	1.2	.78
Batna	1.6	2.3	1.5	2.5	46.5	33.4	24.4	7.6	3.5	4.9	2.6	1.6
Tebessa	4.6	6.05	21.2	3.9	252.0	2.8	9.8	14.8	1.1	3.9	3.5	3.7
Bou Saada	4.05	5.4	12.1	2.9	6.1	165	43.5	19.5	8.3	13.9	5.6	8.3
Barika	2.4	8.7	9.9	5.0	5.03	270	6.1	4.1	11.4	3.7	90.6	1.3
Ain Sefra	9.2	21.5	1.5	23.8	12.4	63.1	16.4	124.0	328.0	14.7	13.2	1.2
Géryville	6.3	1.9	2.1	23.9	2.5	16.7	22.5	23.4	3.4	2.1	4.1	3.9
Laghouat	3.09	4.7	9.8	203.0	7.0	373	421.0	21.0	25.9	14.2	154.0	104.0
Ghardaia	8.9	233.0	81.4	529.0	38.9	699	166.0	25.6	66.9	23.2	49.7	225.0
El Oued	53.9	27.7	67.0	629.0	369.0	465	509.0	482.0	68.6	46.1	215.0	123.0

[1] Reprinted from Cannon, W. A. "Botanical Features of the Algerian Sahara." Publication 178, Carnegie Institution of Washington, p. 10, 1913.

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Part VI

THE DEPENDENCE OF PLANTS ON RADIANT ENERGY

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CHAPTER I

LIGHT AND PLANT NUTRITION

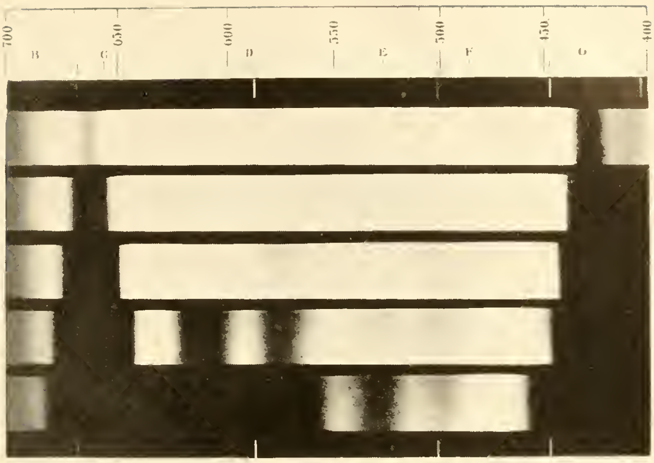
In the Biblical account of creation light is said to have appeared on the "first day" and the sun and moon on the "fourth day." Yet the "third day" saw the earth yielding grass, herbs, and trees. Evidently the sun was not always considered the main source of light and energy for the earth, nor its rays a necessity to vegetation. Yet without the sun's radiant energy plants could not perform their daily miracle of the conversion of minerals and other inorganic substances into food and there would be no life on earth. The influence of radiant energy on plants is complex, and science has been rather tardy in inquiring deeply into the subject, but much of interest and economic importance has already been learned.

As a background to our discussion of some of these things we shall need to remember that light as ordinarily understood is limited to a very narrow band of wave-lengths of radiant energy. The waves originate from energy disturbances within the atom, are of different lengths, and are transmitted through the ether. Somewhat as the number per second of air waves determines the pitch of a sound as detected by the ear, so the length of light waves determines color as detected by the eye. The longer ones give us the sensation of red and the shorter ones, of blue and violet. Certain high pitches on the musical scale can not be detected by the human ear. Similarly the eye fails to detect radiant energy waves longer or shorter than those we call visible light.

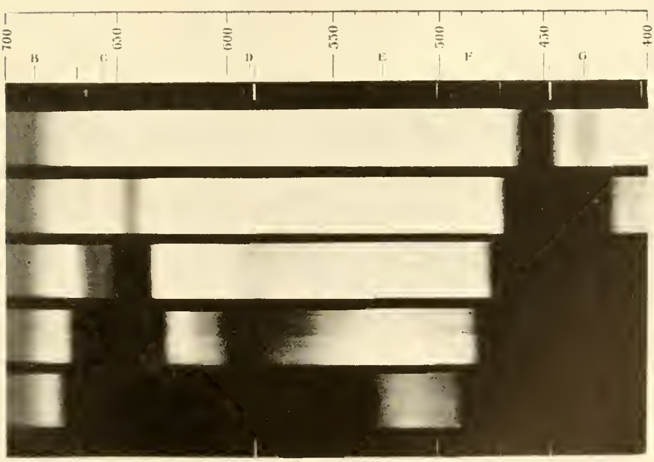
The visible spectrum covers but a very small portion of the great electromagnetic spectrum. This immense series of ether waves extends from far beyond the short gamma waves, which are produced from radioactive substances such as radium, to the long wireless waves. In wireless telegraphy, waves from 3 meters to 20,000 meters in length are used; the shortest gamma rays, on the other hand, are approximately one-trillionth of a meter in length. If this range of wave-lengths found in the great electromagnetic spectrum were represented on a key board 2,300 miles long—the air-line distance from Washington to Los Angeles—then the part covered by the visible spectrum would be an extremely small fraction of an inch in length. Beyond the small visible spectrum, on one side, are the ultra-violet rays, the Röntgen or X-rays, the gamma rays, and the cosmic rays; on the other side are the infra-red rays, the so-called heat rays, Hertzian waves, and the long wireless waves.

In addition to the wave-length of light (perhaps rather than *light* the term *radiant energy* should be used), there are two other factors to be taken into account when considering the relation of plants to radiant energy. One of these is the intensity of the energy; the other is the length of time the plant is exposed to a given radiation. All three of these factors, duration, intensity, and wave-length—sometimes spoken of as quality—have been given considerable study by chemists, physicists, and plant physiologists.

Not all plants are directly dependent on radiation, for not all plants manufacture their own food. Those that do not are the saprophytes, which feed on dead or decaying organic matter, and the parasites, which grow and feed on the body tissues of other plants or animals. Neither type needs light, and so we find saprophytic mushrooms and toadstools thriving in dark caves, and parasitic bacteria in darkness within the body of man and other animals. All these plants lack the green coloring matter, chlorophyll, which with the aid of sunlight enables plants



Chlorophyll a



Chlorophyll b

Absorption spectra of the two chlorophylls The successive horizontal bands represent a series of spectra of light after passing through solutions of increasing depth. The red, or longer, wave-lengths are on the left; the violet, or shorter, wave-lengths on the right. After Willstätter and Stoll

to manufacture food out of inorganic matter, water, and carbon dioxide. It is the green, or chlorophyll-bearing plants in which we are interested here.

Light and Photosynthesis

Man, like all other animals, secures from his food enough energy and the necessary building material for growth, reproduction, and other life processes. The foods essential to the supplying of these requisites are carbohydrates, proteins, and fats. Green plants obtain the same things from similar foods. But they do one thing more, which they alone of all living organisms can do—they manufacture their own food. The manufacture of carbohydrates (sugars and starch) by green plants is called *photosynthesis*—putting together by light. Let us see what is known of this unique and fundamental manufacturing process.

There may be and probably are numerous other photochemical reactions going on in plants, but photosynthesis refers exclusively to the building up of carbohydrates. The process has also been termed carbon assimilation because of the large amount of carbon dioxide (CO_2) absorbed in its accomplishment. The exact chemical reactions that take place during photosynthesis are not fully understood in every detail. We do know that the raw materials needed are carbon dioxide and water; that light and chlorophyll and proper temperature conditions (usually from 32° to 115° F.) are essential to the process. Beyond these temperature limits photosynthesis ceases or goes on very slowly. We know, also, that one of the early products formed is grape sugar, or glucose ($C_6H_{12}O_6$). The chemist's shorthand system for representing this reaction is:

$$6\,CO_2 + 6\,H_2O + \text{light} = C_6H_{12}O_6 + 6\,O_2$$

Evidently chlorophyll does not enter the reaction as a raw material or as a by-product. It apparently acts as a catalyzer; that is, it effects the rate of a chemical reaction yet itself remains unchanged.[1]

The nature of chlorophyll was but vaguely understood until a few years ago when two German scientists, Willstätter and Stoll, greatly increased our knowledge by their brilliant research work. Chlorophyll is composed of two separate pigments made up of carbon, hydrogen, oxygen, nitrogen, and magnesium in the following proportions:

Chlorophyll *a* $C_{55}H_{72}O_5N_4Mg$
Chlorophyll *b* $C_{55}H_{70}O_6N_4Mg$

Chlorophyll *a* constitutes about seventy-two per cent of the total green pigment and chlorophyll *b* the remaining twenty-eight per cent. Although the presence of iron (Fe) is necessary for the formation of chlorophyll it does not occur in the molecule of either pigment. Lack of iron results in a pale or yellow plant, a condition which has been corrected in young conifer trees and in pineapple plants by spraying them with solutions of iron salts.

Now, to consider the relationship of radiation to photosynthesis, we find that the strength, or intensity, of light required for the process varies somewhat with the plant: some work under the high light intensities found on the deserts of southwestern United States; others thrive best in the subdued light of a dense forest floor. One curious little moss (*Schistostega osmundacea*) grows in caves, where light is very much reduced. It is equipped with a plate

[1] Dr. William F. G. Swann, of Philadelphia, is responsible for an amusing illustration of the property of a catalyzer. His story runs as follows:

A certain Arab of property, dying, left his estate in this curious manner: one-half to his eldest son, one-third to his second son, and one-ninth to his youngest son. The executors, however, were somewhat embarrassed to find that the estate comprised seventeen camels, a number divisible neither by two, three or nine. In this quandary they appealed to the Sheik. The latter said:

"While compared to our deceased brother I am but a poor man, yet in my great concern to promote his dying intent I will even add one of my camels to his estate. Then the eldest son shall have one-half of eighteen or nine camels, which is more than our brother intended; the second shall have six camels, and the youngest, two, still in each case more than our brother intended. And now behold the blessing of Allah on generosity! For lo! nine camels and six camels and two camels make altogether but seventeen camels, and my camel returns to me."

of cells forming a battery of lenses capable of focusing the scattered light on its chlorophyll-bearing bodies (chloroplasts) and is thereby provided with a means of carrying on photosynthesis in very dimly lighted corners of the earth.

Plants display numerous adaptations for adjusting themselves to various light intensities. The English ivy (*Hedera helix*), for instance, arranges its leaves in a mosaic pattern that exposes the greatest area to the light. On the other hand, the compass plant (*Silphium laciniatum*) and the wild lettuce (*Lactuca scariola*) turn the edges of their leaves in a general north-south direction. Thus in the morning and the evening when the light intensity is weakest, the flat surfaces of their leaves are in a position to receive the maximum amount of light, whereas at noon, when the light is strongest, the edges are turned toward the sun. Even the shape and arrangement of the cells containing the chloroplasts are such that the amount of chlorophyll exposed to the light can be varied, as illustrated in Figure 51.

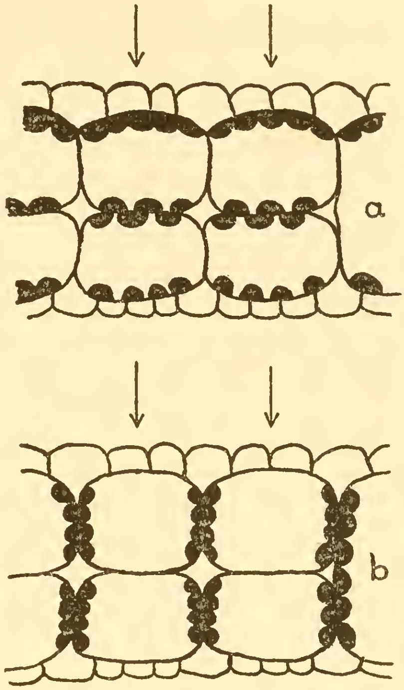


Fig. 51. Cross section of a leaf, showing position of chlorophyll bodies (a) in diffused light and (b) in intense light. Arrows indicate direction whence light is coming. After Stahl

The intensity of sunlight varies under natural conditions from 0 at night to 10,000 foot-candles at brightest noonday. A foot-candle is the intensity of light from a "standard candle" at the distance of one foot. Most plants need far less light than maximum sunlight intensity for photosynthesis. In recent years some very interesting results have been obtained by growing plants in the artificial light of Mazda electric lamps. For instance, plants quite normal to all appearances have been grown under intensities as low as 2,000 to 3,000 foot-candles. Photosynthesis frequently goes on even at much lower intensities.

The wave-length, or color, of light also plays a determinant part in photosynthesis. If a beam of white light is passed through a prism, it is broken up into a series of colored lights called the spectrum. These colors correspond to energy waves of different lengths. The wave-lengths of representative colors are approximately as follows:

Red	0.650	micron[1]
Orange	0.600	"
Yellow	0.580	"
Green	0.520	"
Blue	0.470	"
Violet	0.410	"

Anyone who has seen a rainbow or the spectrum knows that one color merges gradually into another. If a green leaf or an alcoholic solution of chlorophyll be placed in the beam of a white light before it enters the prism the spectrum will look quite different. One heavy dark area will blot out a considerable portion of the red light and another will remove a wide area of light in the blue and violet (Plate 63). This means that the chlorophyll has the power to absorb a portion of the red light and most of the blue and violet.

[1] Micron is a measure of length and is equal to 0.001 millimeter or 0.000001 meter.

Not all wave-lengths, or colors, are of equal importance in photosynthesis. This can be shown by spreading light through a prism on a leaf previously kept in the dark and carefully noting the portions of the leaf covered by the various colors. If the leaf is then bleached with alcohol and stained with iodine the portions illuminated by the red, blue, and violet lights will be stained blue or black, indicating the presence of the carbohydrate, starch. The inevitable deduction is that wave-lengths corresponding to portions of the red, blue, and violet are more effective in photosynthesis than the others. Specifically, radiant energy corresponding approximately to wave-lengths running from 0.640 to 0.680 micron in the red, and from 0.475 micron in the blue to the end of the visible spectrum are very important energy sources in the production of carbohydrates by the chlorophyll.

How efficient is this plant food factory in its utilization of solar energy? Two English scientists, Brown and Escombe, made a very interesting study in which they measured the amounts of energy received by the leaf and then attempted to account for its distribution and use. Considering all the energy received as 100 per cent, its utilization in one example may be expressed as follows:

	Per cent	Per cent
Energy used in photosynthesis	0.66	
Energy used in evaporating water from the leaves (transpiration)	48.39	
Total energy expended in work		49.05
Energy transmitted (radiant energy passing through leaf)	31.40	
Energy lost by heat conduction to the surroundings	19.55	
Total energy not used by leaf for work		50.95
Total energy to be accounted for		100.00

Recently Professor Shull, of the University of Chicago, has pointed out that another important loss of energy from a leaf is that by reflection. In his own experiments he found that the darkest-green leaves lost by reflection as much as six to eight per cent of the light falling upon them, and the lightest-green leaves lost twenty to twenty-five per cent.

Energy is usually measured in terms of heat, because all forms of energy can be reduced to heat. Energy of motion, such as that of a moving automobile, can be reduced to heat by applying the brakes and measured by noting the heat given off from the brake drums; electrical energy may be passed through a small wire and the rise in temperature of the wire observed; energy of sunlight that fell on the earth ages ago and was stored in the form of coal may easily be converted to heat by burning the coal; even the energy of our daily bread has been calculated in terms of heat, and it is now quite easy to determine from prepared tables how much of each food must be eaten per day to give our bodies the proper amount of energy for the type of work we do. The unit of heat energy used by scientists is the calorie. It represents the amount of heat required to raise the temperature of a gram of distilled water from 15° to 16° centigrade.

Professor Transeau of Ohio has made some interesting calculations on the energy budget of a hypothetical acre of corn (10,000 plants) based on growth from June 1 to September 8 (100 days). The following is the summary of the budget.

	Calories	Calories
Total energy available		2,043,000,000
Energy used in photosynthesis	33,000,000	
Energy used in transpiration	910,000,000	
Total energy consumed		943,000,000
Energy not directly used by the plants		1,100,000,000

(Energy released by respiration, 8,000,000 calories.)

A study of these figures indicates that the plant uses about forty-six per cent of the available energy, and the environment takes up fifty-four per cent. Some of the

Healthy tomatoes on plants grown in water cultures. The roots absorbed the necessary mineral elements from a watery solution and were never in contact with soil

The spotted appearance of the tomato leaf on the left is the result of deficiency of potash in the plant's diet. A normal leaf is shown on the right interesting generalizations which he makes from his calculations are that:

> An acre of 100-bushel corn uses during the growing season about 408,000 gallons of water or 15 acre-inches.
>
> The evaporation of this water consumes about 45 per cent of the available light energy.
>
> In photosynthesis the corn plant utilizes about 1.6 per cent of the energy available.
>
> An acre of 100-bushel corn manufactures on the average 200 pounds of sugar a day.
>
> Of the sugar manufactured nearly one-fourth is oxidized in respiration.
>
> At maturity the grain contains about one-fourth of the total energy utilized in photosynthesis, or about 0.5 per cent of the energy available.

One fact stands out above all others in studies made on the energy budget of plants, and that is that plants are very low in efficiency. It is certain that a man-made machine as low in efficiency as is the green plant would not be tolerated in the present age of mass production and its concomitants. However, since man is still unable to do the work of a plant he is hardly in a position to give adverse criticism.

The Influence of Light on the Absorption of Elements Other than Carbon

Photosynthesis, as we have said, refers only to the building up of carbohydrates by the green plant. From the simple sugar, glucose, which is an early product of photosynthesis, other carbohydrates are built up. Such substances as starch, cane sugar, and cellulose, or wood, have the same elements as glucose but in slightly different amounts and proportions. How does the plant get its other foods, such as proteins and fats? Apparently they are built up from carbohydrates and certain inorganic elements absorbed from the soil, including principally nitrogen, phosphorus, potassium, calcium, sulphur, and magnesium; these are the elements found in the common fertilizers used by the farmer. By properly uniting the atoms of these elements with the carbohydrate compounds the green plant is able to form the organic foods essential to all life.

This discovery of the use by plants of inorganic substances as food material is relatively recent. In ancient times men believed that plant food consisted entirely of decayed animal and plant remains—a belief based probably on the theory that organic matter could originate only from other organic matter. But in the year 1699 experimenters began to grow plants with their roots in pure water and in water containing small amounts of dissolved matter, and in 1840, Liebig, the famous German chemist, made the bold announcement that the food material of plants is not decayed organic matter, but inorganic substances such as nitrogen, phosphate, and potash. Since Liebig's time many experiments have been conducted in the growing of plants in water containing a great variety of dissolved minerals, and much exact knowledge has been gained regarding plant-food materials. Plate 64 shows how successfully tomato plants can be grown in water cultures. Work of this nature has a direct practical bearing on fertilizer practices, for unless one knows what a plant requires for its growth, both time and money may be lost in feeding it useless material.

We have so far mentioned the elements carbon, hydrogen, oxygen, phosphorus, potassium, nitrogen, sulphur, calcium, iron, and magnesium as essential to plant growth. The omission of any one of them from the plant's diet will bring about a serious distortion of growth followed by death. For example, plants suffering from a deficiency of phosphorus will turn a dark green or purple and eventually die; without calcium the growing points of the stems die in a very few days; a lack of nitrogen or of iron will cause the plant to turn a pale green or yellow; a deficiency of potassium is frequently indicated by the appearance of tiny spots or dead areas on the leaves (Plate 65).

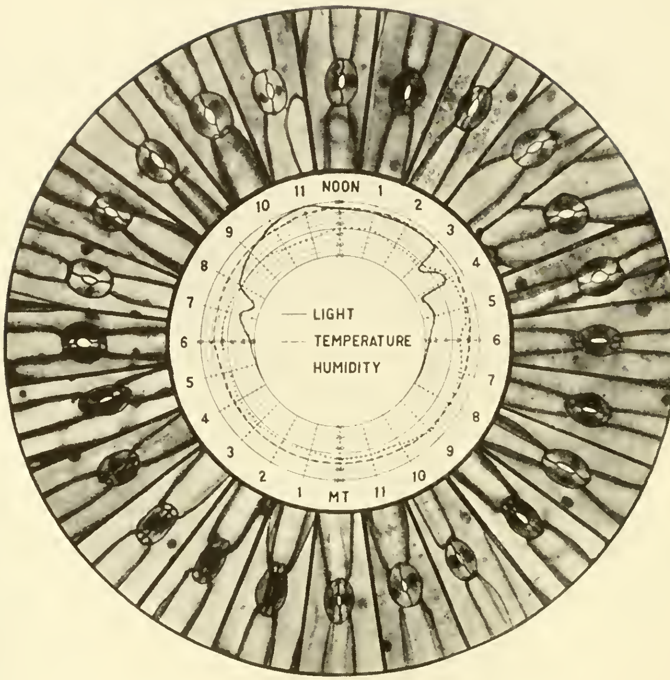
To this list of essential elements several others have been added in recent years. With improved technique and the use of highly refined chemicals it has been found that plants will not grow normally unless they are given exceedingly small amounts of certain substances like zinc, manganese, and boron, which, in larger quantities, would be very poisonous. A tomato plant, to take a specific example, will fail to grow in a solution lacking boron, which is the element found in ordinary boric acid. If, however, one part of boron is added to two million parts of the solution bathing the plant roots, the resulting growth is amazing. Two tomato plants are illustrated in Plate 66. The solutions in which these plants were grown were exactly alike with the exception that to the one on the right this small trace of boron was added in the form of boric acid.

How plant roots absorb these inorganic substances has provoked much controversy among investigators. It is certain that very small particles of these elements (ions and perhaps even molecules) often enter by a process called diffusion. A little ink dropped into a glass of water will spread to all parts of the water and finally become equally dilute at every point; this is diffusion and results from the fact that the general movement of particles is from a concentrated to a dilute condition. In a somewhat similar manner particles of calcium, potassium, and other inorganic elements diffuse from the watery solution in the soil into the watery interior of plant cells. The process differs, however, from that of the ink in a glass of water. Plant cells are surrounded by membranes which, under certain conditions, make the passage of many small particles exceedingly difficult, even though there is a continuous waterway connecting the outside with the inside. These plant membranes are very sensitive in their behavior and react to changes in temperature, light, chemical surroundings, and electrical conditions. The entrance of the various elements is not controlled by the rate at which water is drawn into the cells, but depends largely on the properties of the membranes and cell sap. Water may enter at one rate while the inorganic elements move in or out at other rates, somewhat like ships entering or leaving a harbor independently of the direction of the tide.

It frequently happens that a given element accumulates in a cell so that there are more of its particles per unit volume in the cell than outside. Here the movement can not be explained by diffusion alone for if that were the entire story the particles would be moving out. It seems evident that light in some manner not yet fully understood influences this movement. Perhaps it brings about changes in the cell sap or in the cell membranes themselves. Sir E. J. Russell, the director of the famous Rothamsted Experimental Station in England, points out that "tomatoes respond better to nitrogenous fertilizers in a sunny than in a dull, cold season, but better to potassic fertilizers in a dull, cold season than in a sunny one."

To study the fundamental processes of absorption of mineral elements by plants was the primary object of a number of interesting experiments carried out by Prof. D. R. Hoagland and his associates at the University of California. *Nitella*, a water plant, was selected for this work because of the large size of its cells (they vary from a half inch to three inches in length). When these cells are punctured it is comparatively easy to squeeze out the cell sap without contaminating it with crushed cell walls and other cell structures. The chemical element chosen for the experiment was bromine, because in low concentrations it is practically nontoxic to plant cells and because it is not normally found in the sap of these plants. The plants were grown in a nutrient solution to which a very small amount of the element bromine was added. Some plants were kept in the dark while others were exposed to light. When the sap was squeezed out and

Tomato plants grown in similar solutions except that in the solution of the plant on the right one part of boron was added to two million parts of water



The influence of light on the opening and closing of stomata as illustrated by the reactions of stomata of an onion leaf during a twenty-four-hour day (x 240). After Loftfield; courtesy of the Carnegie Institution of Washington analyzed, it was found that sap taken from the illuminated cells contained as much as four times the amount of bromine contained in the sap from the cells kept in darkness. The concentration of bromine in the sap of this second group of cells did not become greater than that in the solution surrounding the cells. On the other hand the bromine in the sap of the illuminated cells reached a much higher concentration than that of the medium in which they were growing. It was also found that doubling the light intensity increased the absorption of bromine thirty per cent.

Professor Hoagland's own words summarize this discussion very well. "All the evidence now available shows that it is possible for certain inorganic elements to be taken out of a dilute solution and stored in a solution of much higher concentration inside the cell. . . . Light obviously contributes energy to a system, and it would seem necessary to assume that this energy, which, under appropriate conditions can be stored, may be utilized to bring about a movement of solutes [dissolved mineral elements] from a region of low concentration to one of higher concentration." There is evidence on record that the absorption of the essential elements is likewise influenced by light, but the exact relationship is an important problem yet to be solved.

Although plants secure mineral elements from the soil, very important building blocks for the complex foods manufactured by them come from the air. As mentioned earlier, carbon dioxide enters the plant from the air. On the under side of many leaves are tiny openings through which this gas enters into the spacious interior where it is absorbed by the moist cell walls abutting on those wonderful corridors. From the surfaces of these cells the carbon dioxide gas, in the form of a solution, is taken into the cells and manufactured into the carbohydrates—sugar and starch.

The architecture of this portion of a leaf is a beautiful example of the economy of nature. Carbon dioxide is very soluble in water so that it is to the plant's advantage to expose a large moist surface for its absorption. But a large moist surface exposed directly to the air would result in an enormous loss of water from the plant, cutting down growth and resulting in other injuries. For structure of leaf see Part I, page 24. For this reason the surfaces of leaves are covered with layers of epidermal cells usually so constructed that very little water can evaporate from them. A microscope will show us how the plant has got around the problem of obtaining carbon dioxide without undue loss of moisture. Large areas of moist cells are exposed to the atmosphere of numerous passageways called intercellular spaces. These passageways open to the exterior world through tiny ventilators called stomata. Each stoma is protected by two crescent-shaped cells, the guard cells, which open and close it as conditions require. When the guard cells are supplied with a sufficient amount of water, it has been discovered that they open the tiny ventilators in the presence of light and close them in the dark. In Plate 67 the position of the guard cells and the size of the tiny openings are shown for different hours of the day and night. This seems to be logical, for the chlorophyll is actively engaged in the process of making carbohydrates during the period of light and large quantities of carbon dioxide are then needed. At night the factory shuts down and closes its flues. It is thus seen that light is an extremely important factor in assisting the plant to obtain its raw material for the manufacture of sugar and starch as well as a requisite for the process itself.

CHAPTER II

LIGHT AND GROWTH

Plants growing under the natural conditions of the out-of-doors are constantly submitted to enormous changes of light intensity. In the temperate zones this intensity changes from zero at night to as much as 10,000 candle-power at noon in clear weather and back again every twenty-four hours. Passing clouds, the presence of dust particles in the atmosphere, and even changes in the sun itself may alter the intensity of light during the day or for several days. In addition to these daily changes there are seasonal changes such as that occasioned by the fact that sunlight in the northern hemisphere is more intense in summer than in spring or autumn. Plants must be capable of adjusting themselves to all such daily and seasonal changes of light intensity.

The importance of the intensity of sunlight in photosynthesis has already been mentioned. To a large extent this factor determines also the type of plant growth. In darkness plant stems grow much longer than they do in light, while prolonged darkness will produce long internodes in many plants and check leaf growth almost completely. Under proper light conditions these same plants would have short stems and well developed leaves. Leaves grown in bright sunlight show marked differences in structure from those grown in dim light. Shaded leaves are thinner and contain poorly developed palisade tissue. Even the shape of leaves on the same plant may be altered by shading. The bluebell (*Campanula rotundifolia*) develops two kinds of leaves. The basal ones are round or heart-shaped and for the most part toothed around the edge and have long petioles. The stem leaves, which develop later under better light conditions, are narrowly lanceolate, smooth edged, and have shorter petioles. Properly shaded, this plant will develop long-petiolated leaves on its upper part similar to the basal ones.

In view of the immense changes that occur in the intensity of sunlight, one may wonder what intensity best suits the needs of plants. Of course, plants differ greatly in this respect and some will grow under light conditions which would be fatal to others. The Boyce Thompson Institute for Plant Research has made a number of interesting measurements of tomato, tobacco, and buckwheat plants grown out-of-doors under cloth shades of different thicknesses. The plants were uniformly ventilated and other conditions were made as nearly equal as possible. One shade cut out eighty per cent of full daylight, another, fifty-three per cent, a third, only twenty-six per cent. A fourth group of plants was grown without any shade. When these plants were dried and weighed, it was found that a reduction of one-half full daylight in midsummer made little difference in the weights; but from August 10 to September 30, when the light was weaker, all degrees of shading retarded growth. The Boyce Thompson Institute also found in other experiments that a number of plants were just able to survive at the very low light intensity of forty foot-candles. This, of course, is too low for good growth. Doctor Shirley states: "Low light intensities tend to produce vegetative growth at the expense of flowers and fruit, top growth at the expense of root growth, large leaf areas at the expense of leaf thickness, and succulence at the expense of sturdiness."

A second factor that greatly influences plant growth is the duration of light. North of the equator there are in summer more hours of sunlight than of darkness; in winter the reverse is true. During the northern growing season the duration of daylight near the pole is twice that near the equator, and there are corresponding differences for localities between these extremes. On the other hand, the light intensity increases tenfold progressively from the pole to the equator. Duration of light is a factor in plant growth that man has but recently begun to appreciate; by artificially lengthening or shortening the daily light period the type of growth can be controlled to an extraordinary degree.

The term photoperiodism has been used by Garner and Allard, of the United States Department of Agriculture, to designate the response of plants to the length of daylight. Numerous experiments which they have carried out demonstrate conclusively that many plants "attain the flowering and fruiting stages only when the length of day falls within certain limits, so that in such cases flowering and fruiting occur only at certain seasons of the year. . . . It was discovered, also, that exposure to a daily light period intermediate between that favorable only to vegetative development, on the one hand, and that favoring only flowering and fruiting, on the other hand, tends to cause both forms of activity to progress simultaneously. This combined form of activity constitutes what is commonly known as the 'everflowering' or 'everbearing' behavior." The length of the light periods was controlled by placing the plants in and out of darkened sheds. In some experiments the period of light was lengthened by exposing the plants to Mazda electric lamps.

One set of the Garner and Allard experiments illustrates the curious localization of the response in plants to the relative length of light and dark periods. Yellow cosmos plants were used. The arrangement of the apparatus was such that the tops of some plants were grown in light-proof compartments which were opened for ten hours each day, while the lower portions were exposed to the full length of daylight. Flowers promptly appeared on the upper parts of these plants, whereas the lower portions continued to grow without flowering. The upper and lower portions of other plants were treated similarly but in a reverse manner. Under these conditions the upper portions grew vegetatively, while the lower halves flowered. In still other experiments the middle section of the plant was exposed to long daylight periods, while the upper and lower portions were given short exposures. The result was that flowers appeared on the upper and lower sections but the middle section continued in the vegetative stage. Thus the length of the lighting period appears to bring about in the same plant a localized response in much the same manner as it would in separate plants of the same species.

Several years ago a new kind of tobacco was found growing in southern Maryland. It produces many leaves per plant and has become important economically. This Mammoth tobacco (Plate 68), as it has been named, usually does not flower and set seed under field conditions in Maryland. The periods of daylight are too long during the summer, and when the days become short enough for flower production the temperature is too low. If, however, the plant is grown in the winter in greenhouses or is grown further south, it will produce flowers and seeds. On the other hand, if the short daylight periods of winter are supplemented by artificial light in the greenhouse, flowers will not form (Plate 69).

The third light variable affecting plant growth is wavelength, about which something has already been said. One naturally thinks of sunlight as white light. In reality white light is a mixture of colors. That is, it is composed of a large number of radiant energy waves of different lengths. Years ago Sir Isaac Newton demonstrated the composition of white light by passing a beam of it through a prism. The separate colors of the spectrum were then reflected from small mirrors to one point, thus combining them again into white light. Sunlight is composed of the colors of the rainbow in such a manner that it usually

Mammoth tobacco, which in southern Maryland produces large yields. Under long-day light conditions it does not flower. After Garner and Allard

Effect of duration of light on Mammoth tobacco plants grown in the greenhouse in winter. The plant at the left flowered under the normal short-day light; supplementing the daylight period with electric light prevented the plant at the right from flowering. After Garner and Allard looks white at noontime. By means of a spectrobolometer, an instrument for measuring the intensity of different light waves, it is found that the color composition of sunlight changes greatly from noon to sunset. At noon, the sunlight coming through the earth's atmosphere is more intense in blue, but as the sun sinks the red becomes predominant. On clear evenings this color change can be detected by the eye. Light comes through so great a thickness of atmosphere in the evening that the less transmissible colors—violet, blue, and green—are reduced, leaving the red preponderant. Change of season also produces a change in the color composition of daylight. Evidently, therefore, plants depending directly on the sun for their supply of energy are compelled by nature to grow under constantly changing conditions of color as well as of intensity and duration of light.

It is a common observation that stems of many plants grow more rapidly at night than in daylight. White light actually appears to retard stem growth; so do the different colors of which it is composed, though each does so to a different degree. The short wave-lengths at the violet end of the spectrum have the greatest retarding effect, the longer green and red waves have less effect. In general, plants will grow tall under red glass and remain short under blue and violet glass. Furthermore, chlorophyll development—that is, the amount of green pigment formed in the plant—will be more rapid in red light than in blue or violet light. It is thus seen that although a definite range of wave-lengths is beneficial for one plant function such as growth in length, it may be superfluous or even detrimental for another function such as the manufacture of chlorophyll.

Flowers exposed to sunlight from which the short wave-lengths have been removed will become paler. The brilliant colors of Alpine flowers are attributed to the presence of light of short wave-lengths found at the high altitudes in Switzerland and in the Rocky Mountain regions of America. Plants transplanted from these high altitudes to the plains below lose some of their brilliant coloring, a phenomenon explained by the fact that light of short wave-lengths is cut out by the denser atmosphere.

The Boyce Thompson Institute for Plant Research has built a series of greenhouses, using special glass which transmits light of rather restricted wave-length ranges. Experiments in them have shown that the blue and violet end of the spectrum can not be eliminated from sunlight without impairing the growth and vigor of the plants. Plants grown in greenhouses from which the blue and violet light waves were cut out grew taller and had thinner stems and fewer branches; also the cells of their stem and leaf tissues were thin walled and held together less compactly than in normal plants. These same plants showed good chlorophyll production, but a decrease in the amount of carbohydrates, and considerable delay in time of flowering.

Light is clearly one of the important factors controlling plant growth. Its effects are direct, as shown in the preceding pages, and indirect, through its influence on climate.

CHAPTER III

PHOTOTROPISM

If we examine the ivy covering the wall of an old house we will find myriads of tiny stalks growing out away from the wall. These stalks, or petioles, supporting the expanded leaves, suggest small arms outstretched and extending the palms of as many hands to the world for assistance. In reality that is just what is taking place. The ivy plant needs light to run its carbohydrate factory. The petioles of the leaves grow out toward the light while the broad expanded portions of the leaves set themselves at right angles to the light rays, so as to use to best advantage the light coming within their reach. A potted plant like the geranium will grow symmetrically in a greenhouse where light is of uniform brightness on all sides. If, however, it be placed by the window of a living room where light is much brighter on one side than on the other, it will turn its leaves toward the window and resemble the ivy in its growth habit of turning toward the light. Physiologists apply the term phototropism to this type of growth. Plants very easily grow lopsided when exposed to light that is more intense on one side than on the other. If the plant by the window were slowly and continuously turned it would grow symmetrically like the one in the greenhouse, for each part of the plant would receive an equal amount of light and so grow uniformly.

Some parts of plants, such as leaf petioles and young shoots, grow toward the light, and are positively phototropic. Other parts grow away from the light and are negatively phototropic, whereas those like the expanded portions of leaves, that grow across the beam of light, are transversely phototropic. The roots of most plants are relatively unresponsive to light. There are, however, a few plants—such as the mustard and radish—whose roots show negative phototropism. Plate 70 shows a white mustard seedling growing through a tiny hole in the center of a glass dish, with the root extending into a beaker of nutrient solution. The source of light for this plant was a 200-watt electric lamp placed about two feet away and so fixed that the light came to the plant from the direction indicated by the arrow. Note that the small leaves have already started to expand at right angles to the path of light, thus showing their transverse phototropic tendencies, while the stem and root show respectively positive and negative responses.

Although it is perfectly clear that a plant profits greatly by facing its leaves toward the light, it is difficult to believe that it is conscious of what it wants and acts accordingly. To be correct in this materialistic age, all such actions should be explained on a physical or chemical basis. Accordingly we may ask, what are the mechanics of phototropic bending?

To go back to some of the earlier explanations, about one hundred years ago De Candolle, the Swiss physician and botanist, thought that positive phototropic bending was due to the retarding effect of light on growth. The side of the stem most brightly illuminated would grow more slowly and so bring about a bending toward the light source. The remarkable elongation of potato sprouts in a darkened cellar would seem to substantiate the view that plant stems grow longer in the dark than in the light. Thus it seems logical to deduce that the shaded side of the stem of the geranium plant growing at a window would elongate more than the side receiving more light, and thus cause the stem and the petioles to bend toward the window. De Candolle's theory is further supported by the fact that mature plant tissues that have almost

The reaction of parts of a mustard seedling to light. Stem bends toward, roots away from the light, and leaf places itself at right angles to the light

completed their growth cycle do not show this bending nearly so much as young tissues. Only the tissues that contain cells still capable of dividing or of enlarging are capable of exhibiting this phenomenon.

But objections came to be made to this early view of phototropism. Such distinguished men as Darwin and Pfeffer, the German plant physiologist, were led to be-

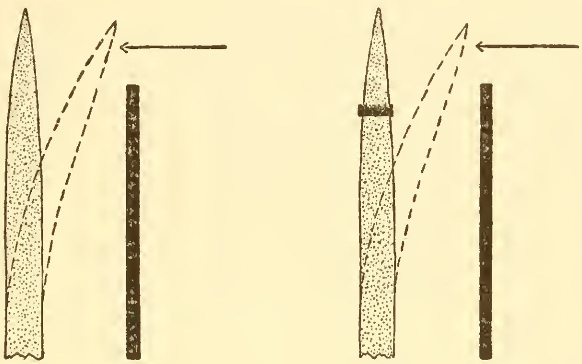


Fig. 52. Diagrammatic representation of phototropic bending of coleoptiles at their bases when the tips are illuminated from one side as indicated by arrows. The tip on the right has been cut off and attached with gelatin

lieve there existed a region in the plant capable of receiving a stimulus and that such a region was more or less localized. In one experiment the apex of a young sprout was exposed to light, but the bending occurred at the base, which was not illuminated (Fig. 52, left). It thus appeared that in addition to a region of perception, there is a region of response. If this is true, then the tissues between these two regions must be capable of conducting the excitation from the former place to the latter. This suggests on the face of it that a plant is very much like an animal, which, for example, sees food with its eyes. The excitation travels over the nerves to the legs which react in such a manner as to carry it toward the food. In a growing shoot, the tip perceives light on one side. The sensation is transmitted to the part lower down where differential growth goes on in such a manner as to point the stem or shoot toward the light. But this is accrediting the plant with a reflex nervous system which it does not have.

A good deal of work on phototropism has been done with the coleoptiles of plants belonging to the grass family, particularly the oat. The coleoptile is a leaf sheath surrounding the bud of the ascending foliage leaf. As recently as 1910 one ingenious experimenter hit upon the idea of cutting off the top of a coleoptile and sticking it back on the stub with melted gelatin. When the tip was illuminated on one side the shoot still showed marked phototropic bending at the base (Fig. 52, right). Did the stimulus received by the tip travel to the base after passing through a layer of gelatin? Further interesting experiments are reported in which the "heads" of coleoptiles illuminated from one side were cut off and stuck on the stumps of decapitated coleoptiles grown in the dark. These "doctored up" coleoptiles when allowed to continue their growth in the dark showed positive phototropic curvatures in the proper direction.

Still other theories have been suggested to account for the phototropic bending of coleoptiles. Certain experiments would indicate the presence of growth-accelerating substances in the tips of growing stems. The phototropic curvatures depend upon the way these substances travel through the stems and this in turn is governed by light. It is further claimed that some of these substances have been extracted from the coleoptile tips and used to induce in other seedlings certain phototropic-growth responses independent of light. Some extremely interesting work has also been done in Holland by Professor Went and his students. Accounts of their investigations should be consulted by those interested in going deeper into the subject of phototropism.

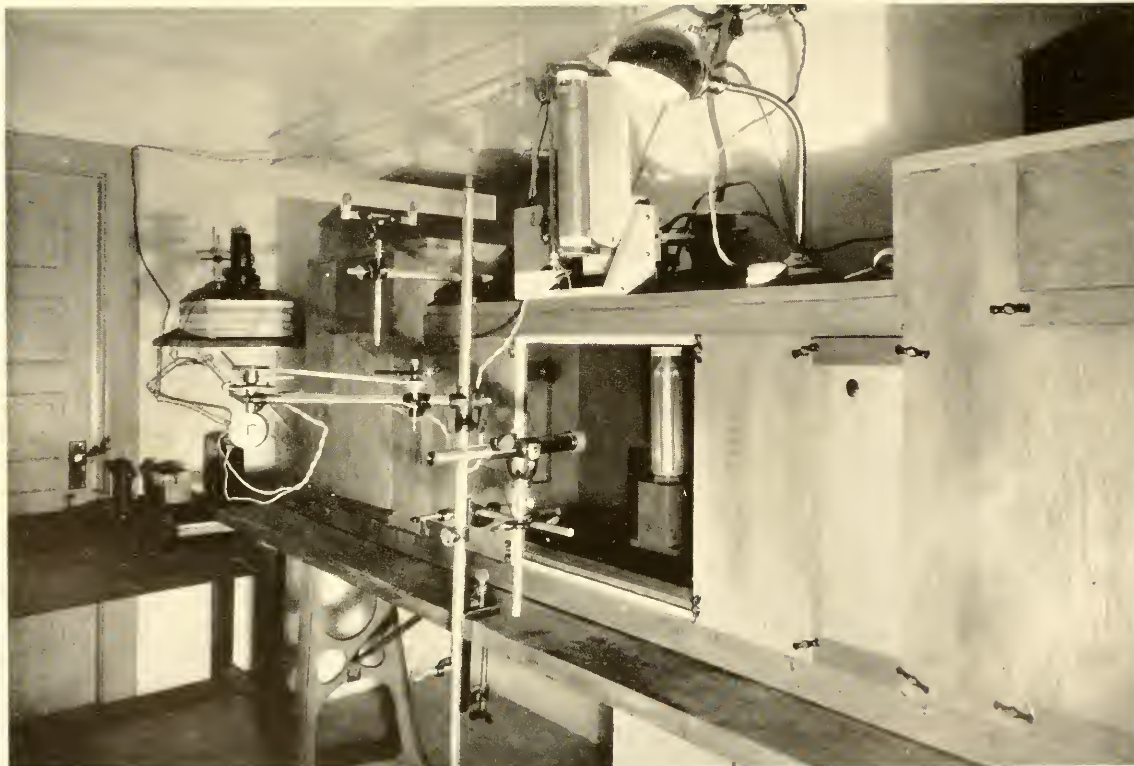
Professor Priestley of England has recently been studying these very fascinating plant traits and has done much toward giving this peculiar phenomenon a rational explanation. He shows that phototropic curvature in coleoptiles is consistent with De Candolle's hypothesis of the retarding effect of light on growth in spite of many seemingly discrepant experiments.

To understand what takes place, we must consider a few essential conditions of growth in plants. Plant tissue that is capable of growth by active cell division is called the meristem tissue. To permit of meristem growth water and food are necessary. Plant stems have tiny tubes extending up and down through which water and solutions of food material may pass. In order for these materials to reach the cells located at a distance from the main-trunk service tubes, they must pass through the walls of the intervening cells. The more permeable these walls are to water and the foods dissolved therein, the better are the chances for rapid growth of the meristematic tissues. Cells stop growing when they lose water faster than they can absorb it or when they can not get a sufficient amount because of a blockade in the line of cell walls connecting them to the water mains (vascular tissue). The entire system is very delicately balanced.

How then is this sap, or water, system related to phototropic bending? As Professor Priestley states, "In this delicately balanced equilibrium, *strong* lateral illumination may mean that the sap supply first fails on the side more directly lit, where evaporation will more rapidly bring about a state of 'incipient drying' in the walls of the tissues. . . . If the walls between the vascular supply and superficial meristem are in this condition, food supplies to the meristem will fail, and there will be a cessation of meristematic growth." That is, less growth will occur on the drier or more illuminated side because the drying of the cell walls has cut off the food supply of cells on that side. This will result in a positive phototropic bending.

The amount of light required to induce phototropic curvature in shoots grown in normal light is greater and must be continued longer than that required to bring about similar curvatures in etiolated shoots (as those grown in the absence of light are called). Etiolated shoots are white or pale and usually differ from normal plants in the structure of their tissues. Also the mechanism of bending is quite different in the two. The walls of the cells making up the tissue in etiolated shoots contain fat and protein, a substance similar to the white of egg. These substances prevent the ready passage of sap and water from the vascular supply to the meristematic tissue, which, under favorable conditions, is capable of rapid growth. But relatively small quantities of light produce a photochemical action in these shoots. Protein and fatty materials disappear from the cell walls, the fatty substances migrating mainly to the cuticle. The passageway between the meristematic cells and their water and food supply is thus opened up, so that in the words of Professor Priestley, "Increased superficial growth now ensues. Growth as a whole may be as active as ever on the more brightly lit side of the etiolated shoot, but it is differently distributed. More cells are added to the surface of stem and leaf and less proportionately contributed to the inner layers of the shoot axis. The result is, therefore, in the aggregate, a retardation of growth in length on the illuminated side and a positive phototropic curvature."

Although many roots are not sensitive to light, there are, as previously mentioned, a few which show negative phototropism. The section of the root capable of bending is situated just back of the apex or tip. In this region the cells are rapidly enlarging by taking in water, which fills up a space in the cell's interior called the vacuole. Negative phototropic bending of these roots is attributed to the increased rapidity with which these vacuolating cells



Plant photometer box for the study of phototropic bending. Center chamber, containing the plant in a glass cylinder, is open; the light chambers are closed

Oat seedling curved toward blue light and away from red light enlarge under the influence of light. Those on the shaded side of the root enlarge less rapidly.

With the above explanations in mind, we may proceed to examine the results obtained with decapitated coleoptiles. These organs, at the stage at which they are used in such experiments, grow entirely by cell enlargement and not by cell division. Light increases the rate of cell enlargement but the final size is less than it would have been without light. Each vein or water pipe running to the tip of a coleoptile terminates in a pore. When the shoot becomes gorged with water this pore serves as a safety valve and frequently a drop of water is seen on the tip of this shoot. If the water pressure is decreased in the pipe line on one side, growth on that side is retarded. Light makes the passage of water through the coleoptile tissue comparatively easy, hence when one side is illuminated the flow of water through the vein in that region is facilitated, thereby reducing the turgor or water pressure. This in turn retards growth on the brighter illuminated side. On the less-lighted side growth is faster. This causes the shoot to bend toward the light. By cutting off the tip, water is freely lost and growth retarded. Now if half the stub is covered so that the veins in that region are blocked, bending due to increased rate of growth will occur even in darkness in such a manner that the blocked veins are on the convex side of the curved shoot.

All in all, there seems to be little doubt that the mechanics of phototropism is a light-growth reaction based to a large extent on the relation of growth to available water and food supply.

One phase of phototropism that has been investigated in the laboratories of the Smithsonian Institution is the effect of wave-length, or color, of light on the growth curvatures of plants. As a first step it was necessary to divorce the intensity effect of light from the wave-length effect. To achieve this a long wooden light-proof box was built containing three separate chambers or compartments. In the two end compartments lights were placed, and the central section was used as the plant chamber. Between the plant chamber and the light chambers were placed ray filters through which light of given colors could be passed (Plate 71).

In one experiment with this apparatus (plant photometer), red and blue lights were used. In the middle of the central or plant compartment a very delicate instrument was placed for determining the intensities of the lights coming from the end compartments. When these lights were so adjusted as to be of equal intensity a plant shoot growing in a small glass container was placed at this central point and permitted to grow for a few hours. When examined it was found to have bent sharply toward the blue light in the manner shown in Plate 72, and the deduction was inevitable that the blue light retarded growth more than the red. With this type of apparatus it is possible to evaluate the different wave-lengths in their effect on plant growth.

The relation of radiant energy to plants is a limitless subject, and modern science has scarcely put its foot on the threshold of all there is to be known. Much of the research in this field has been confined to that portion of the great electromagnetic spectrum known as visible light. Only those with the boldest imaginations dare dream of what lies hidden in the regions beyond—the infra-red and the ultra-violet.

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Part VII

MAIZE, THE PLANT-BREEDING ACHIEVEMENT OF THE AMERICAN INDIAN

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Color patterns in corn ears achieved by the Indians of the Southwest. Left, an ear grown by the Tewa Indians; center and right, ears grown by the Navajo. The all-rose color is rare and found only in Indian-grown corn. About half natural size

CHAPTER I

THE DOMESTICATION OF PLANTS AS A MEASURE OF CIVILIZATION

HUMAN progress is generally measured in terms of man's mechanical skill. The accepted signposts of advancing civilization are perfected stone tools and weapons, woven baskets and textiles, smelted metals and fired pottery, and the wheel and arch. These undeniable attainments are readily evaluated in our mechanistic age but they tend to obscure man's truly fundamental achievement—the domination of his biological environment. Every step of the way from utter barbarism to the present is marked by an increase in man's mastery of living things; and progress in mechanics, physics, and chemistry was forced upon man by this need to control the animate world.

In the beginning man contended with predatory animals; later he learned to mold plants and animals to meet his food requirements; the present day finds him struggling with the insects and pathogenic bacteria which threaten his existence. One after another of these biological obstacles has been removed, and in the achievement man has left an indelible record of his upward climb. Perhaps the most fascinating of these records is the one that pictures the development of agriculture. Agriculture is the very foundation of civilization, and the primitive societies of today owe their precarious condition to their failure, for one reason or another, to develop an assured food supply. Without an adequate and assured supply of food there can be no manual arts or sciences; no leisure for abstract thought and all that it connotes.

Thousands of years ago the ancestors of civilized man faced and solved the problem of food for all time by profoundly altering wild plants and animals—patiently forcing them into modified varieties. Every species of cultivated plant and domesticated animal is a living monument to prehistoric breeders.

Those who have not experienced the disappointments which follow attempts to change permanently the characteristics of plants and animals can have little conception of the difficulties encountered and surmounted by early man in shaping the life about him to meet his needs. New chemical products or mechanical inventions can be made, tested, and improved as rapidly as the chemist or inventor can work, but the breeder of plants and animals is seriously limited by the time requirements of his materials. Living things must have time to grow and mature. Most plants produce only one generation a year, and in many plants and animals the period between generations is much longer. It is clear that even slight progress from one epoch to another, in a culture so handicapped by time, represents a continuity of effort and a degree of skill far greater than those required to perfect tools or weapons. The refinement of artifacts necessitated manual dexterity often of a high order, but improvements in technique increased with practice, irrespective of the introduction of new methods. Even as tools took shape under the painstaking and laborious methods of manufacture employed by primitive man, his ideas could develop, one process leading naturally to another. Success in the domestication of plants was not acquired so easily. The plant breeder needed keenness of perception to take advantage of the small variations by which plants differ from one another, and a degree of intelligence capable of correlating remote causes with their ultimate effects. Mental development must have reached the stage of foresight and concern for the future as well as hindsight and interpretation of the past. Primitive peoples of the present day who have these qualities imperfectly developed occupy a correspondingly low position agriculturally and economically.

The short span of human life was a further handicap to agricultural advancement, since the skill of any one man could at best extend over but twenty or thirty plant generations.

The early agriculturists, then, did not find their crop plants ready to hand, merely awaiting human care to blossom forth in abundant fruitfulness. On the contrary the first tillers of the soil could but choose the most promising sorts from among the vast welter of wild plants, all ill adapted to man's wants. These wild plants, no less than the ancestors of our farm animals, had to be caught, tamed, and slowly domesticated through the centuries. Modern plant breeders may well be disheartened when they stop to survey the wide gaps between our present-day crops and the wild plants from which these were derived.

Our admiration for the abilities of the early agriculturists is further enhanced when we realize that not within historic times has a single important food plant been added to the heritage received from the ancients. We have remained content to increase the acreage and to attempt the improvement of the plants tamed for us by prehistoric man. This is at once a criticism of our abilities and a tribute to the excellence of the plant culture of early man. It might even be urged that, viewed strictly from an agricultural angle, modern man has retrogressed from the position of his forbears of thousands of years ago. For although he needs new crops suitable to lands which can not successfully compete with lands of higher productivity in the growing of our present food crops, yet he lacks the vision and the magic touch which enabled the ancients to supply their wants with new domesticated plants.

Where Agriculture Began

Where agriculture first began is a subject of some difference of opinion. Unquestionably there was an early Old World center of dawning civilization in Western Asia. Most scholars credit the peoples of this region with having been the first to sow seeds, and estimate the probable time of that momentous event as 10,000 years ago. So long as the origin of agriculture is approached from the historical standpoint the claims of regions other than western Asia and adjoining lands stand scant chance of being considered, and we are forced to agree that tillage began either in Mesopotamia or Egypt. When, however, the botanical evidence is reviewed, there is seen to be strong reason for believing, if not in an American origin, at least in an independent development of agriculture by the aborigines of America.

Anthropologists are loath to concede that man existed in America more than 20,000 years ago, a period far too short to permit an independent initiation of cultivation reaching the degree of excellence found by the white discoverers of the Western Hemisphere. Yet they have been gradually increasing their estimates of man's years in the Americas, and though the process has been slow—the estimates having barely doubled in the last ten years—there are gathering signs that its speed will be accelerated in the next few decades. Anthropological reasoning is defective in ignoring the evidence afforded by plants as to man's long residence in America. Nursed on a diet of stone and metal implements, these students of early man seem to regard the plant remains exhumed from every burial cist as lacking substance on which to construct theories of past habitation. Yet the differences between American and Old World agriculture are so fundamental that no agriculturist would consider the former to have arisen from the latter. The counter-assumption, that the Old World agriculture is the child of the New, is much more tenable. The greater divergence between the cultivated plants of America and their wild relatives as compared with the domesticated Old World plants is exceptionally strong biological evidence that American agriculture is the more ancient. This has been pointed out by Cook. Certainly, the development of a plant like maize from any wild form can not be conceived as the work of any recent comer to America from Asia.

Agriculture in the Old World appears to have developed in a nonforested region and may have been an outgrowth of the pastoral life. Plowing was an essential part of the technique and at an early date animals to pull the plow were used, but the herdsman-farmer was not forced to nurse his crop from planting to harvest. All the cultivated plants were grown in mass culture, whereby the individuality of the plant was lost among the thousands of its fellows. The New World system, on the other hand, accorded each plant individual attention. The plants were grown in hills, each plant widely separated from its fellows and subject, as a result, to the closer scrutiny of the husbandman. Animals were not used and the grower was kept in intimate contact with his plants throughout the entire season. The American Indians were wholly plant-minded, and this fact is accurately reflected in the plants they domesticated.

The Old World system is typified by wheat and the New World system by Indian corn. Each of these cereals was confined to the hemisphere in which it had been domesticated, until the discovery of America by Columbus; after that event maize spread rapidly through Europe and seems to have reached China early in the 16th century, while wheat gradually found a secure foothold in the New World.

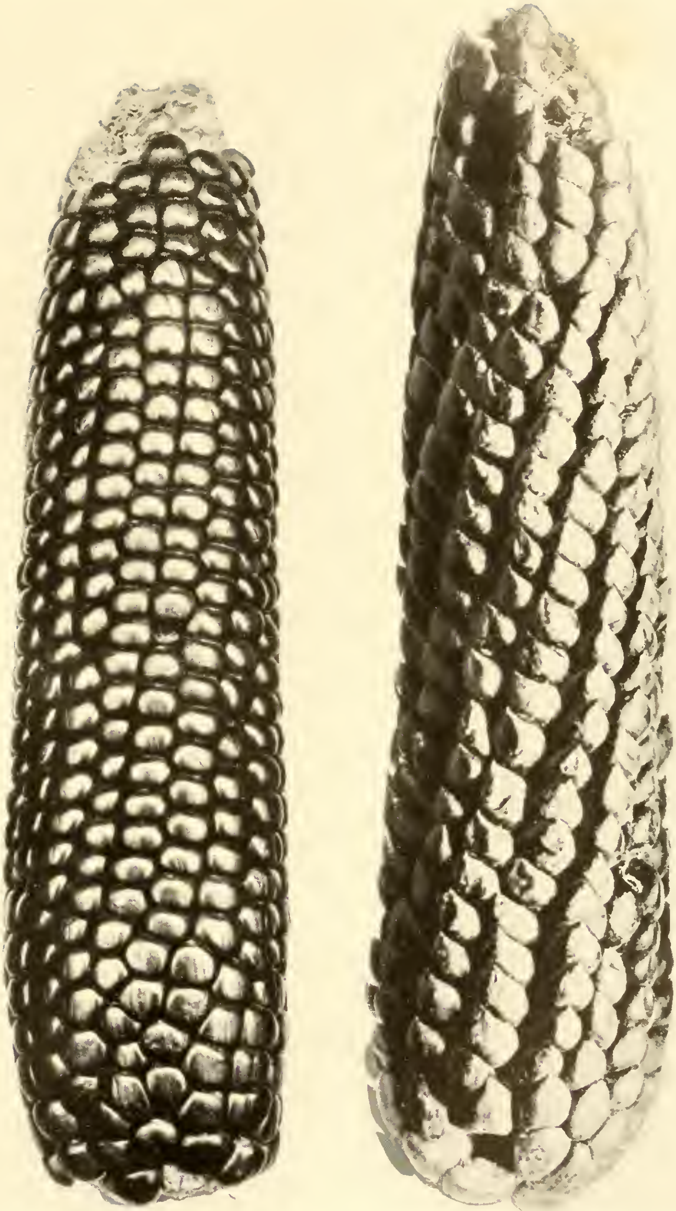
The people of the Old World developed a crop which gave the greatest food value per man-hour, while the aborigines of America achieved in Indian corn a crop which produced the greatest food value per unit area. The basic differences between the agricultural operations of the two regions would be expected to produce just this result.

While the mass system offers many advantages for a mechanized agriculture, it must be kept in mind that both the American and Old World systems were evolved during the period of hand labor; for machinery entered the agricultural field only in modern times. Undoubtedly the American type of agriculture, in which the Indian maintained close association with his individual plants, was more conducive to their improvement and to profound alteration in their characteristics. In conformity with this expectation, the cultivated plants of America are found to be much more highly specialized in comparison with their wild relatives than are those of the Old World. Wheat, barley, oats, and rye have living wild relatives readily recognized as the ancestors of the cultivated forms; but the American crops, of corn, potatoes, tomatoes, and beans, are so highly developed that the wild plants from which they originated can not be identified with certainty. Indeed, so far removed are the American crop plants from their undomesticated cousins that the direct path of their descent is shrouded in mystery. Human deposits afford no clue to their origin, such as they supply to the origin of the Old World cereals, and the botanist is forced to hypothesize for American plants an exceptionally long past beginning far earlier than 10,000 years ago, the date assigned as the beginning of tillage in the Old World.

The Most Ancient Cultivated Plant

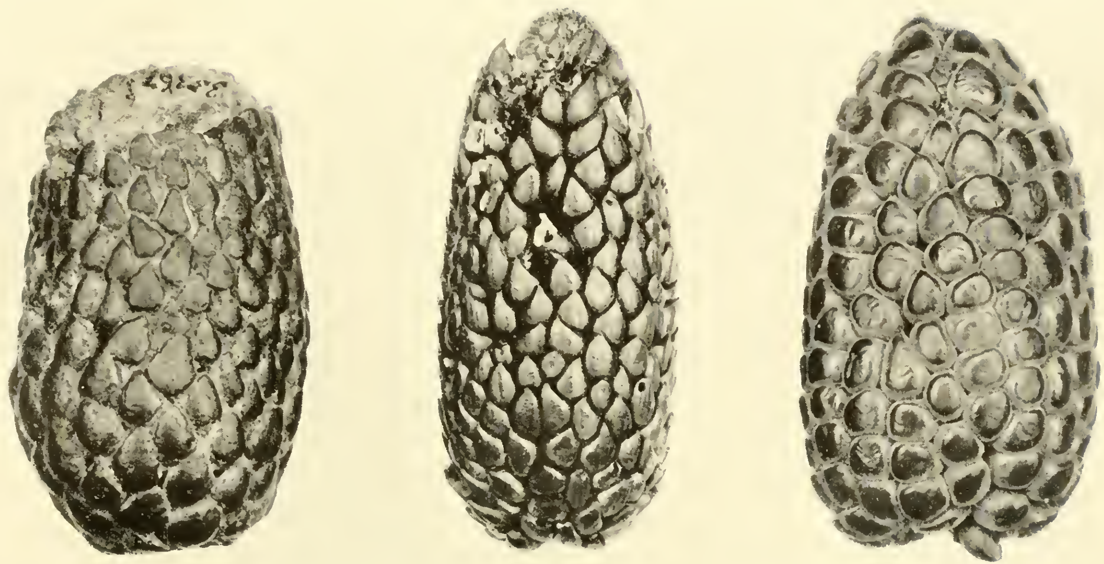
From purely botanical reasoning, based on a detailed comparison of maize with its wild relatives, Indian corn may confidently be proclaimed the most ancient of the cultivated cereals, if not of all cultivated plants. The botanical evidence is clear and unmistakable, however defective the historical and anthropological record may

PLATE 74



Prehistoric ears of corn (natural size). Left, from grave of a Basket Maker Indian in Utah; right, from a pre-Inca grave in Peru. Courtesy of the Museum of the American Indian, Heye Foundation, and W. E. Safford

PLATE 75



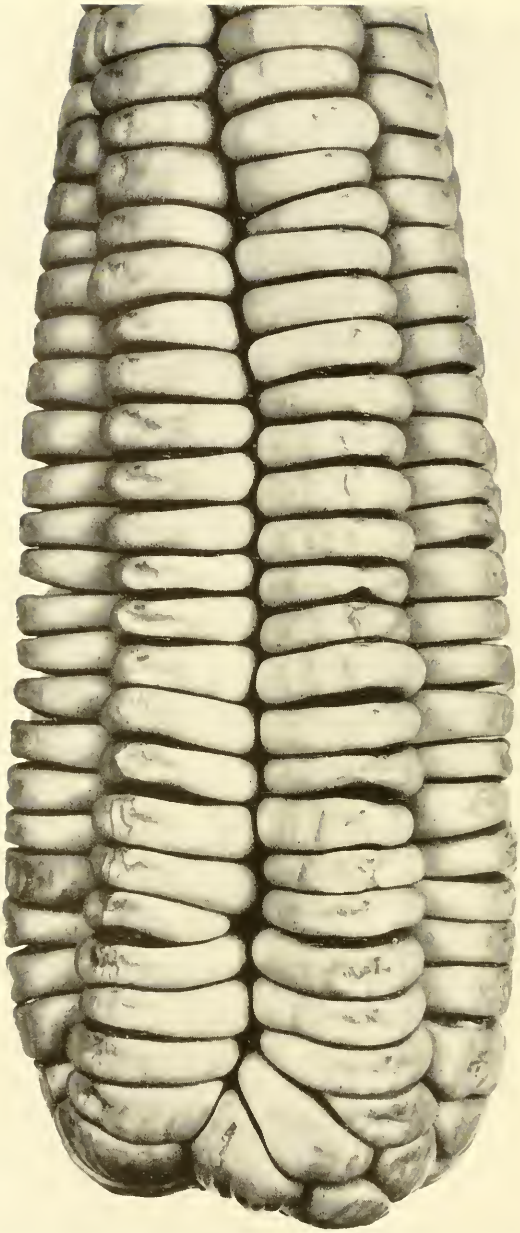
Peruvian ears of corn (natural size). Left, fossil; center, exhumed from a pre-Inca grave; right, grown by the Peruvian Indians in 1925. Courtesy of the U. S. Bureau of Plant Industry be. Indian corn represents the supreme achievement in the domestication of plants.

Of all the crop plants the cereals presented the greatest obstacle to domestication. The flowering heads, or inflorescences, of the wild grasses are jointed in various ways, and when mature they completely disintegrate in the wind, thus permitting the seed to blow about and fall upon the ground. Before plants of this sort could be domesticated it was essential to eliminate the features which led to the natural scattering of the seeds. To accomplish this was no simple matter, for the very existence of the plants in the wild state meant that they had developed an efficient means of sowing the succeeding generations. It is not likely that the early domesticators were actuated by the intelligent purpose their accomplishments seem to demand. Unquestionably, however, they were keenly observant and took advantage of the improvement (from their point of view) in their plants that resulted from lucky "accidents," or mutations.

In some of the cereals, such as wheat and all the other Old World grains, shattering, or the loss of seed from the head when fully ripe, is still a problem for the plant breeder. In Indian corn this difficulty has been overcome in a manner that constitutes one of the marvels of the plant world. The familiar ear of corn, with its regular arrangements of seeds in even rows, is a vegetable monstrosity at once grotesque and supremely useful. From the standpoint of primitive man it is difficult to imagine how food could be grown in more perfect packages. The seeds, securely packed on sturdy spikes, provide a delectable and easily handled food long before they are mature. This advantage, not possessed by any other cereal, is one which many times sustained the famished Indians when the previous year's harvest had been scanty. Storage, too, is simple, for the ears can be corded in stacks and artificially dried in wet seasons—the smoke from the drying fires of the Indians affording a satisfactory protection against the grain weevils. In dry seasons the harvested crop can be placed in the sun and moved about with facility. The husks furnish ideal string and were often used to braid together whole bunches of ears which then were hung out of reach of the grain-devouring animals. Seed properly stored will remain viable for a decade and seed stocks can be accumulated as an insurance against bad years. Since corn plants depend on the wind to effect the union of male and female gametes, they produce a superabundance of golden-yellow pollen; weeks before the ears are fit for food, the Indians gather this pollen in baskets and make of it a very palatable and nourishing soup. And this is not all, for even the parasites of maize are edible; the natives of Mexico regard corn smut as a delicacy, as desirable as our edible mushrooms are to us.

If ever a plant could be said to be designed for the use of man that plant is Indian corn. And in accordance with this seemingly providential plan, maize and man are inseparably associated in America as far back as human remains are found. Nowhere does maize grow without man's aid, nor can it. Unlike the other cereals, which, highly domesticated though they are, will sow themselves and persist for a few generations without the intervention of man, maize has lost all power of distributing seeds and maintaining itself. The ear of corn accidentally covered with soil retains the seeds intact, and if it does not rot the seeds may germinate in a mass, but the young plants are choked off long before they can produce the next generation. Furthermore, the Old World cereals, developed under a system of mass planting, have not lost the ability to grow normally in competition with weeds; but maize, the product of individual plant culture, can not long survive when forced to compete with weeds and other grasses. The whole behavior of the plant bespeaks an extensive period of human care not accorded the plants of the Old World.

Seeds of corn showing five patterns of color distribution. Twice natural size. Courtesy of the U. S. Bureau of Plant Industry



Ear of Cuzco corn (natural size). This type of corn is peculiar to Peru. After boiling the kernels are eaten one at a time as are grapes. Courtesy of the U. S. Bureau of Plant Industry

Clearly maize is far removed from a wild plant, and no wild plant resembling it has ever been discovered. When Columbus reached America he found the plant as we know it today, and the colonists of Virginia and Massachusetts were supported by varieties of maize, the counterparts of which are commercial crops in the same regions at the present time. The four hundred years of historical record show little change in the plant; this is true also of the many centuries preceding, the record of which is gradually being uncovered by archeologists. Burials of the so-called Basket Maker Indians (who were the earliest occupants of the American Southwest of whom we have record) in Utah yield ears of corn indistinguishable from the varieties grown by successors of the original growers in the same area. From the United States through Mexico to Peru, everywhere the story is the same—maize taken from the most ancient exhumations is fully developed. Indeed a small fossil ear has been discovered in Peru which resembles perfectly an ear exhumed from a pre-Inca grave, and both are beautifully matched by ears grown in the same region by the present inhabitants (Plate 75). Yet there can be no reasonable doubt that human hands planted the seed from which the fossilized ear was produced.

Thus the known record of maize in its present form embraces a period of many thousand years, and the plant probably underwent a previous period of development fully as long before it reached the perfection shown by the fossil ear.

That the artificial development of maize had attained a high level in very early times is attested not only by the size of the prehistoric ears but also by their coloration. It is surely no accident that maize is the most decorative of all crop plants, and clearly the element of art had entered into its breeding more than 2,000 years ago. No other plant grown for food can claim the variety of colors or the complexity of color patterns that are found in maize. Our modern Corn Belt varieties of the plant are restricted to white and yellow seeds, but most of the varieties grown by the Indians in the two Americas, even today, are highly colored. Not only are the seeds red, blue, black, brown, pink, purple, variegated, and spotted, but the tassels, leaves, silks, and cobs are found in several colors.

These colors were not preserved by chance; on the contrary, at least in what is now the southwestern United States, certain families were charged with the duty of maintaining them. At planting time, as Cushing has shown, care was taken to insure the presence of certain colors in each hill. There can be little doubt that the wide range of colors is the result of man's desire to maintain them. Certain it is that in our corn culture, where color other than yellow or white is not a factor, the vivid colors characteristic of squaw corn have disappeared. The same holds true for the corn now grown in Spain, Italy, and Central Europe. With the exception of an occasional red ear, all the European varieties are either white or yellow. In conformity with their disregard of colors modern maize growers recognize only the three general types—sweet, pop, and field corn. The native Americans make more subtle distinctions and prefer a certain variety for each of many different forms of food. The Peruvians even have a variety with such extremely large seeds that after being boiled they are eaten singly like grapes (Plate 77).

CHAPTER II

THE ORIGIN OF MAIZE

MAIZE, then, is a plant which has been cultivated for thousands of years, meeting the food requirements of man and beast and providing the foundations for the three elaborate American Indian civilizations—those of the Mayas, Incas, and Aztecs. Well may we ask where and how this gigantic grass as we know it originated; but its birthplace and parentage are a mystery. The wild prototypes of most crop plants are still in existence; maize, however, appears to be a botanical orphan and its original home is a matter for speculation. What little is known of the antecedents of this plant is the result of fitting together an intricate morphological and genetic puzzle lacking many of the major pieces.

THE PLACE OF ORIGIN

Curiously enough, the place of origin can be more definitely determined than the manner. In fixing on the original home of a cultivated plant, we have a choice between two avenues of approach—one, through the diversity of types of the cultivated plant; the other, through its wild relatives. Vavilov, the distinguished Russian botanist, holds that the center of domestication of cultivated plants is the region having the greatest diversity of types. If this hypothesis is adopted, Peru must be accepted as the original home of maize. This conclusion is supported by the remarkable achievements of the pre-Incas in the domestication of plants. These ancient peoples have to their uncontested credit the potato, tomato, and peanut, to mention only three crops now widely cultivated, and in pre-Spanish times they regularly grew some seventy species of plants. With this evidence of their capability in domesticating plants, it would seem reasonable to accept the contention that maize also was a product of their talents.

However, to conclude that the pre-Incas developed maize would be to ignore the very important fact that none of the existing wild relatives of maize grow in Peru. The absence of wild relatives in any region is a very serious objection to its choice as the center of domestication, for obviously the ancient breeders must have had a wild plant on which to start improvement. It is possible, of course, that maize developed from some closely related species, now extinct, which existed at one time in western South America. But as there is no evidence of any such species, current botanical opinion places the original home of maize in North America. For it is chiefly on the plateau of Mexico that all the close wild relatives of maize are now found. Furthermore, Mexico has a wide diversity of types of maize, being second only to Peru in this respect. Finally, Peru's superiority in diversity of types may be explained in a manner helpful to the Mexican-origin hypothesis. Geographically Peru is distinguished by deep narrow valleys exhibiting a climatic range that extends from tropical to arctic; this would naturally result in the isolation of diverse types. All in all, therefore, it would seem more logical to select the plateau of Mexico, probably not far from the region of Mexico City, as the birthplace of Indian corn; most botanists are agreed on this locality.

The Manner of Origin

Having chosen a place we may next consider the possible manner of origin. Maize, known to botanists as *Zea mays*, belongs to the tribe of grasses designated Tripsaceae. This tribe is characterized by having the male and female

Color patterns in corn ears grown by (from left to right) the Osage, Hopi, Navajo, and Uintah Ute Indians. Clay-colored ears are found only among the Hopi; solid black ears are rare in North America, though common in Peru and Bolivia. About half natural size

flowers borne on separate flowering heads, or inflorescences, or on separate parts of the same inflorescence. This separation of the sexes is a fundamental botanical distinction and indicates that the genera which comprise the Tripsaceae are closely related. There are three genera of American plants which belong to the Tripsaceae: *Tripsacum*—from which the tribe takes its name—*Euchlaena*, and *Zea*, the two former occurring as wild plants in North America and the latter being our cultivated Indian corn. There are numerous species of *Tripsacum*, two or possibly three species of *Euchlaena*, and only one species of *Zea*—namely, *mays*.

In the species of *Tripsacum* the male and female flowers are in the same panicle or inflorescence, the female flowers being borne on the lower and the male flowers on the upper sections of the branches (Fig. 53). In *Zea mays*, or Indian corn, the two sexes are in separate inflorescences. The male flowers are confined to the terminal inflorescence, or tassel (except in certain abnormal forms), and the female flowers are borne on the ear, half way down the plant. The plants of *Euchlaena* fall midway between those of *Tripsacum* and *Zea* with respect to the separation of the sexes. In *Euchlaena* the terminal panicles of the main plant and of the primary lateral branches bear only male flowers, as in *Zea;* but the female flowers, which are borne on secondary lateral branches, often terminate in a male spike, thus closely approximating the arrangement found in *Tripsacum*.

In general appearance *Euchlaena* more closely resembles *Zea* than *Tripsacum*, and since both *Zea* and *Euchlaena* are more highly specialized than *Tripsacum*, the latter is considered to be farther back in the evolutionary scale.

All the botanical evidence shows that the closest wild relatives of maize are the two species of *Euchlaena*, one an annual, the other a perennial. Both species are now known under the Aztec name of *teosinte*, translatable as god grass

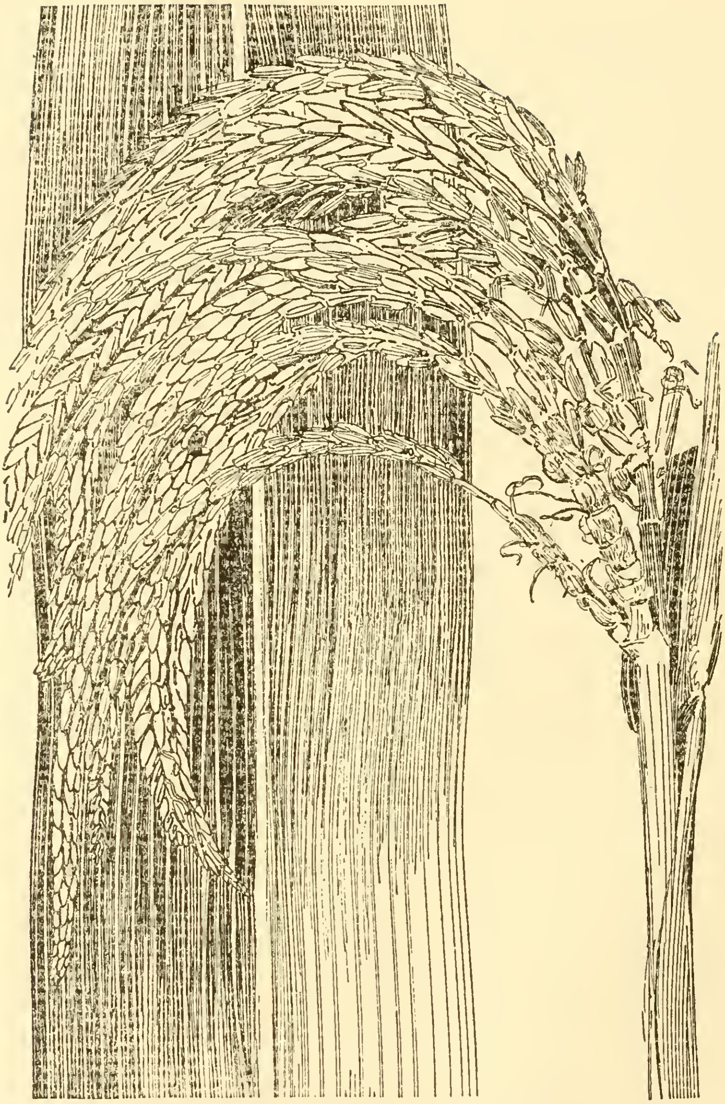


Fig. 53. Inflorescence and section of a leaf of *Tripsacum pilosum.* The female flowers are borne at the base of the tassel, which resembles that of corn

PLATE 79

Two relatives of maize

Tripsacum pilosum, growing naturally on the west coast of Mexico

Euchlaena mexicana, growing under cultivation in the United States

Courtesy of the U. S. Bureau of Plant Industry

A normal corn plant. Courtesy of the U. S. Bureau of Plant Industry or god grain. The annual form has gained, within the last fifty years, some importance as a forage crop in the southern United States. Like their cultivated cousin, maize, these two wild relatives provide some baffling problems for the botanist. The annual species (*Euchlaena mexicana*) became known through an introduction of seed to Paris. This seed was supposed to have come from Santa Rosa, Guatemala, yet diligent inquiry and several explorations have failed to discover either species of *Euchlaena* growing wild in Guatemala. The evidence for the occurrence of *Euchlaena* anywhere outside of Mexico is purely literary and is confused by attaching to this species the name *teosinte*, which is everywhere used by the natives of Mexico and Guatemala for various species of *Tripsacum*. The confusion of names and the entrance of *Euchlaena* into commerce need not concern us in our inquiry as to the origin of maize, but they serve to illustrate the involved evidence with which we must deal.

The perennial species of *Euchlaena* (*E. perennis*) is known only from a very restricted region west of Guadalajara, Mexico, in the vicinity of Ciudad Guzman, while the annual species (*E. mexicana*) extends from southwestern Chihuahua to the region about Mexico City. *Euchlaena* has been reported also from western Oaxaca and possibly Chiapas, but no authentic specimens from wild plants have been collected from either of these regions.

Both species of *Euchlaena* occur as weeds on the margins of cultivated maize fields, and indeed can hardly be expected anywhere else, as corn is now grown in practically every location that would provide a suitable habitat for these plants. Thus even the wild relatives of maize are forced into intimate association with man. Most of the present growers of Indian corn in Mexico are unaware of the close affinity of *Euchlaena* and maize, though a few recognize that *Euchlaena* hybridizes with corn and is therefore detrimental.

Neither species of *Euchlaena* is at all adapted for human food and there is no historical or archaeological evidence that either was ever so used. The seeds are embedded

FIG. 54. Left, inflorescence of *Tripsacum dactyloides*, with female spikelets below paired male spikelets; right, separate male and female inflorescences of *Euchlaena mexicana;* the spikes at the left of the tassel of *E. mexicana* have been dissected from an "ear" similar to that on the right

in a hardened segmented rachis, or stem, closed by a shell-like outer glume, or bract (Fig. 54). The segments are arranged end to end, each containing a single seed, and an inflorescence consists of from six to ten segments. When ripe the rachis is very brittle and the segments break apart scattering the seed on the ground. Although the segments of the rachis are about the size of a seed of pop corn, the actual seed of *Euchlaena*, inclosed in the segment, is much smaller than a grain of wheat. From the standpoint of primitive man, *Euchlaena* offers a very poor source of food. To separate the seeds from their outer covering is a laborious process and to gather seeds in any quantity requires an almost daily harvest during the ripening period of at least two months.

Both species of *Euchlaena* hybridize with maize. (Among plants no less than among animals related species sometimes cross.) When the hybrids are fertile the relationship of the parents is thought to be close, whereas sterile hybrids furnish strong presumptive evidence of a more remote relationship. Hybrids between genera are extremely rare and only a few examples are known among plants, one being the *Euchlaena*-maize cross.

The annual species (*E. mexicana*) crosses freely with corn, and the various hybrid generations are perfectly fertile (Plate 81). Indeed, in all the regions in Mexico where *E. mexicana* is found, maize-*Euchlaena* hybrids are common. So general is the hybridization between these two species that it is doubtful whether a pure form of *E. mexicana*, uncontaminated with corn, exists in Mexico. In the lake region, south of Mexico City, the various grades of hybrids occupy whole fields and are prominent plants in the landscape. Such natural mongrelizing is excellent evidence of the very close relationship between *Zea* and *Euchlaena* but affords no basis for the assumption that Indian corn was derived from *Euchlaena* by selection.

Hybrids between the perennial species (*E. perennis*) and maize are much less common. In the fields of *E. perennis* and maize, west of Guadalajara, we found but a single hybrid plant, a very decided contrast to the fields of *E. mexicana* and maize elsewhere in Mexico. Controlled hybrids between *E. perennis* and maize have been made in this country with plants of *Euchlaena* imported for the purpose. The cross is made with difficulty and the hybrid plants, except under unusually favorable conditions, are sterile. This sterility, fundamental in nature, is explained by the wide cytological differences between *Zea* and *E. perennis*.

The whole question of the derivation of maize from either or both of the two species of *Euchlaena* is highly involved and is one on which botanists are not agreed. Early investigators accepted the numerous natural hybrids between maize and *E. mexicana* as representing transitions from *Euchlaena* to maize, and even in more recent times Burbank fell into the same error. This assumption that the steps in the evolution of maize are being continuously repeated before our eyes is now recognized as wholly incorrect and in fact modern genetic experiments suggest that the whole picture should be reversed. There are many indications that *E. mexicana* has been derived from hybrids between *E. perennis* and maize—an hypothesis which if substantiated will remove *E. mexicana* from all consideration as one of the probable ancestors of maize.

Although there is a fundamental botanical relationship between *Euchlaena* and maize it is difficult to see how the latter could be developed from the former by means of selection. The salient characteristics of Indian corn, which make it so useful to man, are not found even in rudimentary form in *Euchlaena*.

The ear of corn remains a botanical conundrum with no counterpart in any other grass. There is no difficulty in tracing the successive stages in the alteration of the wild relatives of most cultivated plants which made them suitable for cultivation. There is no element of uncertainty as to how the head of wheat developed, for in its essential features it is the inflorescence of wild wheat; and as with wheat so with the other Old World cereals—no profound morphological changes from their wild proto-

Pistillate inflorescences of *Euchlaena mexicana* (upper left) and of *Euchlaena*-maize hybrids as they are found on the margins of Mexican corn fields. Slightly reduced. Courtesy of the U. S. Bureau of Plant Industry

Evidence for fusion as origin of corn ear

Section of an eight-row ear of corn showing separation at the top into two four-row branches. Natural size

Tassel of corn showing bifurcated central spike suggesting origin by fusion of lateral branches. About half natural size

Courtesy of the U. S. Bureau of Plant Industry

types have taken place. Maize, on the other hand, presents a baffling mystery, for the ear of corn is not foreshadowed by any simpler organ in its relatives. Nothing resembling the ear of maize is found in any other of the grasses, nor are there any rudimentary organs in this great family of plants that can be conceived to contain the germ of an ear. It is known, of course, that the ear developed from a branched structure similar in form to the tassels of maize and *Euchlaena*. But how such a branched inflorescence was changed to bring about the many-rowed ear is still a matter of speculation.

Not the least of the difficulties encountered in attempting to derive a single spike from a complex inflorescence is the contradictory evidence afforded by the ear itself. At first thought it would seem a simple matter to reduce a ramified panicle to a spike by suppressing the branches, and this hypothesis early was advanced to explain the ear. Support for this view was derived from the obvious homology of the ear with the central spike of the tassel and by the various stages between ears and tassels found on the terminal inflorescences of tillers or lateral branches. The objection to this explanation lies in the fact that the central spike of the maize tassel is as much in need of an explanation as the ear. None of the relatives of maize has tassels terminating in many-rowed central spikes. The uppermost branch, or spike, in the tassel of *Euchlaena* and of *Tripsacum* is exactly like all the other branches in having only four rows of spikelets on a flattened axis, whereas the terminal spike of a maize tassel is a cylindrical affair with eight or more rows of spikelets arranged in groups of two around the entire axis (Fig. 55).

Granting that the ear of corn is the homologue of the central spike of the tassel, differing from it chiefly in having only female flowers and membranaceous glumes, the problem of the formation of the ear is not solved but becomes one of explaining the central spike. Three theories have been advanced as to how this organ could

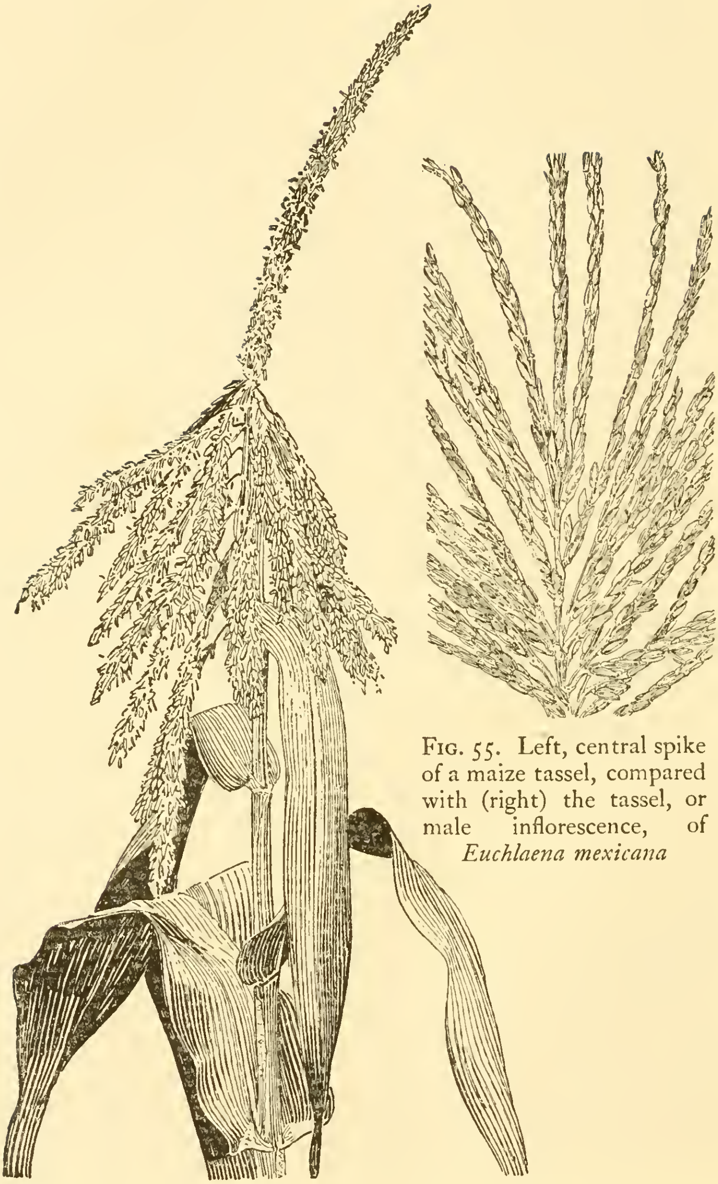


Fig. 55. Left, central spike of a maize tassel, compared with (right) the tassel, or male inflorescence, of *Euchlaena mexicana*

be derived. These may be designated briefly as fasciation, branch suppression, and twisting. All three are in good standing at the present time and have reputable adherents.

The theory that the central spike, and hence the ear, arose as the result of the fasciation, or growing together, of two four-rowed branches is beautifully supported by many examples of obviously fasciated ears and central spikes. Eight-rowed ears of corn which are divided for half their length into two four-rowed segments are found frequently and a similar condition is often met with in central spikes (Plate 82). Furthermore, true-breeding races with fasciated ears, and central spikes as well, have been isolated by geneticists, showing that fasciation is not only possible but is hereditary in maize.

The hypothesis of branch suppression is equally well supported by a true-breeding type of maize known to geneticists as ramose. In this type both the ear and tassel are very much branched inflorescences which in extreme cases lack central spikes (Plate 83). The various degrees in the expression of this branched-ear character show clearly that branches often are reduced to paired spikelets and when such a reduction occurs a central spike is formed. The ramose type of maize arose as a mutation from the normal form and behaves as a simple Mendelian recessive in inheritance. In crosses with *Euchlaena* the character reappears in the second generation in approximately the expected proportions but greatly modified in expression.

The third method proposed for deriving the ear, that is, by twisting the axis of a simple inflorescence, is suggested and supported by *Euchlaena*-maize hybrids. In the second generation of these hybrids all stages are found from the simple two-rowed spike of *Euchlaena* with segmented rachis to the multiple-rowed unsegmented rachis of the maize ear (Plate 84). These stages afford clear-cut examples of how an ear can be built up by twisting a two-rowed axis and solidifying the rachis. The first stage of twisting results in a four-rowed ear, which passes by imperceptible stages to ears with higher multiples of rows. It is apparent from these hybrids that there is no insurmountable obstacle to combining the widely different characteristics of the pistillate inflorescences of *Euchlaena* and maize; and the inference is that a comparable combination may have taken place in the development of maize.

In the present stage of our knowledge these three hypotheses as to how ears were formed stand on an equal footing of credibility and no decision can be rendered as to which is the one most likely to have occurred.

Even with a moderately satisfactory picture of how an ear of corn could be built up from a branched inflorescence similar to a tassel of *Euchlaena*, we have gained little or no knowledge of how the process came about.

Since *Euchlaena* hybridizes with *Zea* and closely resembles it in many respects, there can be little doubt that the relationship between these two genera is very close. *Euchlaena*, being a wild plant fully capable of self-propagation, would seem at first glance to be the logical ancestor of maize; but whether the relationship is one of parent and offspring is not so certain. The detailed botanical and morphological evidence affords serious objections to such an hypothesis.

The flowering unit of the grasses is the spikelet, which in normal maize and *Euchlaena* bears flowers of only one sex. The staminate, or male, spikelets contain two flowers, each with three stamens; but the pistillate, or female, spikelets normally have only a single flower. In *Euchlaena* the spikelets rarely develop flowers of both sexes, but maize frequently produces bisexual spikelets both in the staminate and pistillate inflorescences. This evidence indicates that the separation of the sexes occurred later and is less complete in *Zea* than in *Euchlaena*. Such a conclusion is further supported by the greatly modified rachis, or flowering stem, and outer glumes of the female inflorescence of *Euchlaena*. In maize the bracts, or glumes, surrounding each seed are not greatly differentiated from those inclosing the staminate flowers of the tassel, whereas in *Euchlaena* the outer glume of the pistillate spikelet has become thickened and hardened. Furthermore, in maize the spikelets are borne in pairs—one, pediceled, or stalked, the other, sessile—and this pairing is normal for both male and female inflorescences. In *Euchlaena* the staminate spikelets are paired as in maize but the pistillate spikelets are borne singly—the pediceled spikelet being aborted.

These differences between maize and *Euchlaena* in the separation of the sexes and development of the flowering parts show that maize is less highly specialized in an evolutionary sense than is *Euchlaena*.

The customary explanation that maize evolved from *Euchlaena* by gradual changes aided by human selection ignores the point that neither species of *Euchlaena*, as growing at present, could be considered as furnishing a basis from which to start selection toward maize. The male and female inflorescences of *Euchlaena* are already more highly differentiated in many respects than the staminate and pistillate inflorescences of maize. Therefore, to derive maize from *Euchlaena* by selection would be to pass from the specialized to the unspecialized—a reversal of the usual direction of evolution. Furthermore, if it is assumed that the change was gradual, it is hard to believe that some of the intermediate stages would not have been preserved, at least in the ancient tombs of man, if not as living plants.

Hybrid Origin or Development by Selection

There is still another hypothesis for the origin of maize. Collins having noted the many resemblances between maize and the Andropogoneae, a very large family of grasses, which includes the broom sedge, suggested that the former may have arisen as the result of natural hybridization between *Euchlaena* and some grass similar to a species of the subgenus *Sorghum* of the genus *Andropogon.* This genus in the Old World has furnished a series of domesticated forms grown for grain, syrup, and broom material. In many respects it is similar to *Zea,* the genus to which maize belongs, the two genera being parallel cytologically and having several inherited characteristics in common. Some of the true-breeding abnormal forms of maize so closely resemble those of the cultivated Andropogoneae as to be botanically indistinguishable from them.

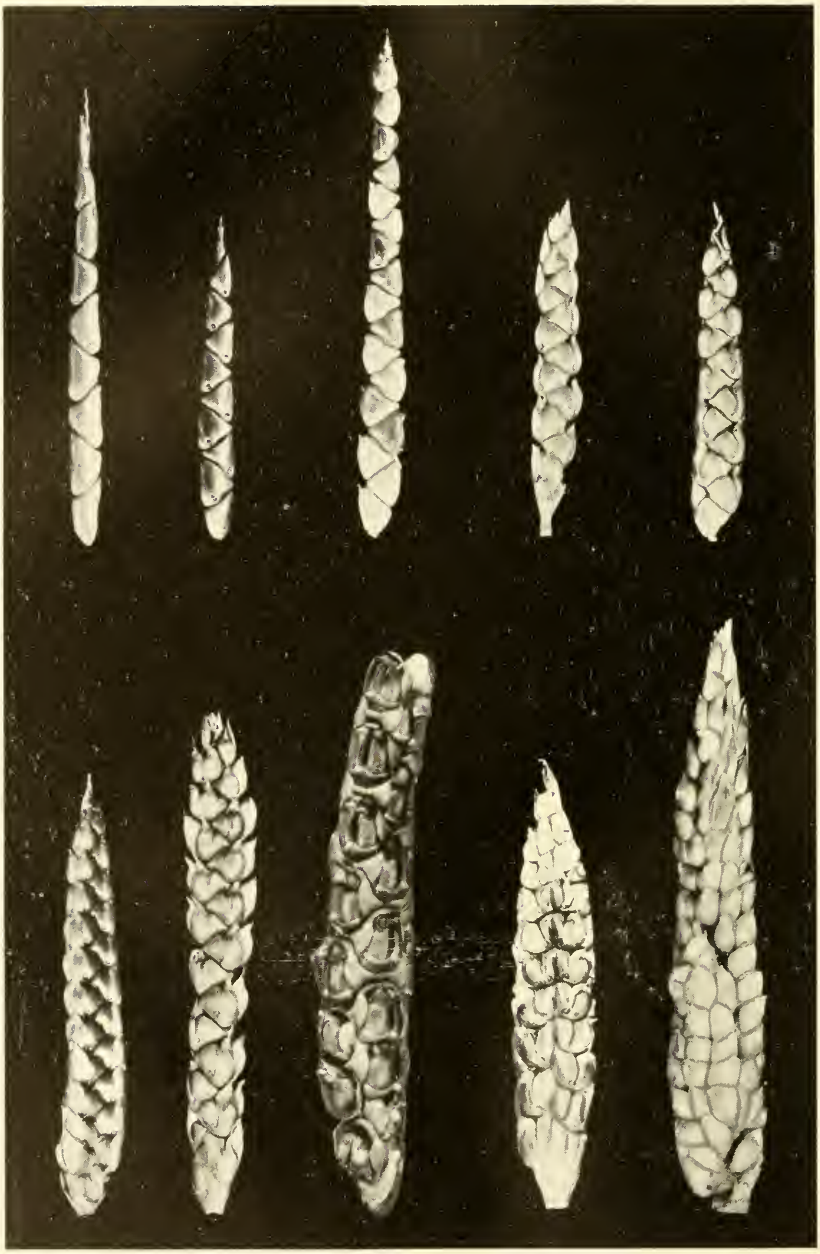
Numerous attempts have been made to cross maize and members of the Andropogoneae, but without success. It is true that Burbank claimed to have made the cross, but investigation showed this to be an error arising from some close resemblances between a variety of pop corn and one of the grain sorghums.

None of the Andropogoneae which would logically be chosen as the mate for *Euchlaena* to produce a hybrid from which maize might descend are indigenous to the New World. However, in view of the intermediate position of maize between *Euchlaena* and the andropogons, the idea of the cross having been made with a New World species may be entertained. Not only does this hypothesis harmonize with the known morphological facts but it reduces very materially the length of time necessary to produce such a plant as maize.

When the hypothesis of hybrid origin was first put forth the idea was considered as a novel one to be invoked only as a last resort. Since that time, however, claims have been made for a hybrid origin of wheat, barley, apples, and grapes among our crop plants, and cattle, swine, sheep, and chickens among our domestic animals.

The alternative to hybrid origin is development by selection. No two plants are just alike, for all organisms are subject to variation. When the variations are heritable in nature it is possible to change, within limits, the type of organism by selecting for propagation only those

Longitudinal section through an ear of ramose corn, showing how the normally sessile spikelets have developed into branches. Natural size. Courtesy of the U. S. Bureau of Plant Industry



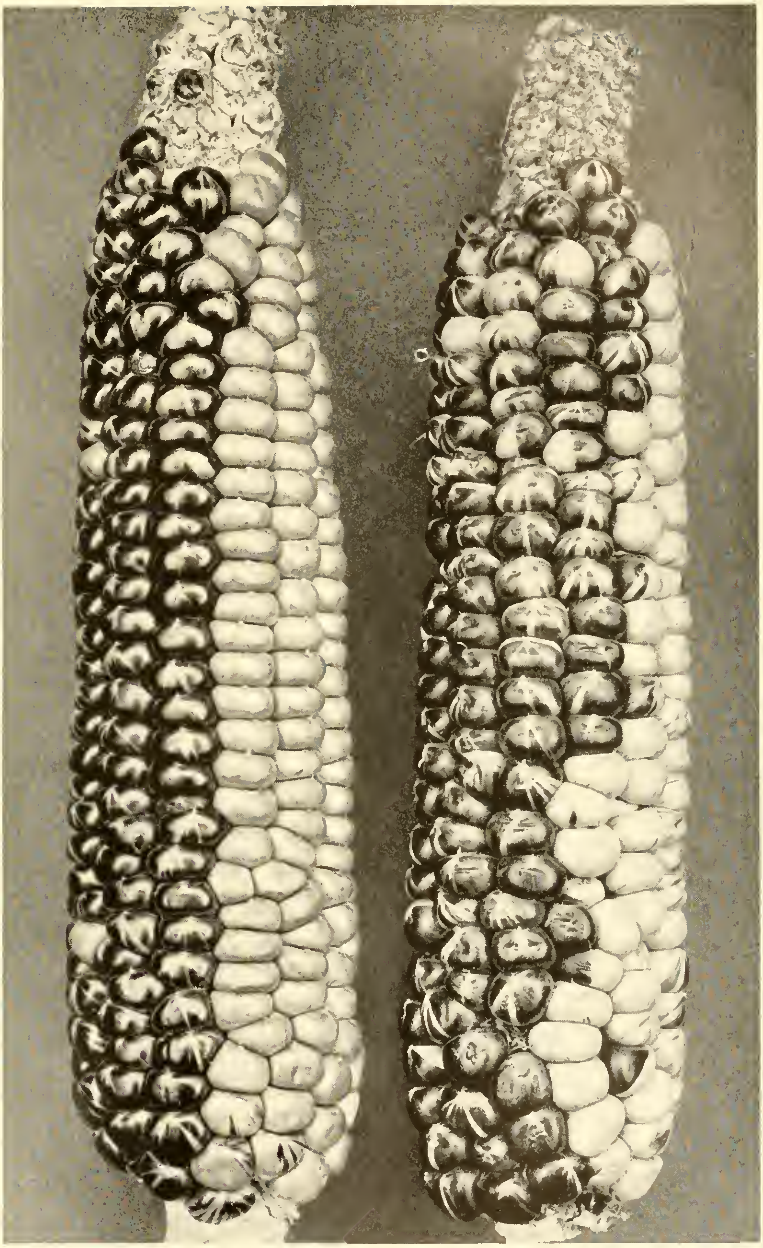
Inflorescences from *Euchlaena* and *Euchlaena*-maize hybrids, showing the stages between a *Euchlaena* spike and an ear of corn (natural size). Spike at upper left is the commercial type of *E. mexicana*, and adjacent spike is the native Mexican form. Courtesy of the U. S. Bureau of Plant Industry individuals which have the desired characteristics. This process has been employed in the development of most of our improved varieties of crop plants and animals. Modern breeding experiments show that the procedure does not stimulate the organisms to vary further in the direction of selection, but that the breeder is limited to a choice of individuals which happen to change toward the desired ideal. Thus the breeder of race horses uses for parents the fastest animals; the dairyman, the highest milk producers; the poultryman, the best layers. Similarly with plants—those with the highest yield, finest quality, or greatest resistance to disease are chosen, whenever they appear, as parents for the succeeding generations.

Many botanists of the formal school prefer the hypothesis that the crop plants were developed from their wild ancestors by this very gradual process of selection, and they still view hybridization as a rare event not to be seriously considered as a factor in the development of our present-day crops. Maize and *Euchlaena* are held to have developed by gradual evolution from a common ancestor probably closely resembling *Tripsacum*, of which several species are indigenous to North America. The presumption is that the direction of evolution of maize was controlled, at least in the later stages, by human selection. Such a process would require a lapse of time far beyond that available on even the most liberal estimates for the beginnings of agriculture.

If selection is deemed to be too slow, the phenomenon of mutation, or sudden large changes in type, is suggested. By hypothesizing mutation in the gross sense it is possible to form any sort of plant almost over night, as it were, and one need not be restricted as to ancestry. Thus it could be claimed that the present-day maize plant arose as an abrupt change or mutation either from *Euchlaena* or almost any other grass. Such large-scale mutations are unknown in any organisms and are hardly to be expected.

It is possible, of course, to conceive of several rather large mutations which together resulted in maize, but if they occurred from existing wild plants it would be expected that they would recur from time to time.

Mutations in maize as in most other organisms intensively studied are, of course, far from rare. Within the past few years several hundred such changes have been noted affecting many parts of the plant. The color of the seeds may mutate from red to variegated or the reverse, green plants may give rise to white ones, normal seeds to defectives, tall plants to dwarfs, and so on through the whole range of plant parts. For the most part these changes or mutations are undesirable in that they result in weak plants that are not as productive as the normal form, and their elimination from seed stocks is the aim of modern maize breeders. The observed mutations affect single characters or small groups of characters and are of a different degree of magnitude from those necessary to account for the origin of a plant like maize from its wild relatives. They represent changes in single hereditary units and behave as simple Mendelian characters. When crossed with the forms from which they arose they always reappear unaltered in subsequent generations. Crosses between maize and *Euchlaena* exhibit a complete blending of the characteristics of both species. There is no alternative segregation into the parental forms, and the evidence clearly shows that these species differ from one another not by a single hereditary unit but by literally hundreds of genes. If we are to derive maize from *Euchlaena* by mutation we must accept the evidence and conclude that not one but hundreds of mutations have occurred, and that is in effect a return to the hypothesis of selection. That maize differs so widely genetically from *Euchlaena*, its closest relative, does not preclude their both having arisen by mutation from some distant ancestor; but if the relationship between these two species is as remote as this, it is difficult to explain their fertility when crossed.



Examples of a color mutation in corn. The large colorless areas result from an abrupt change in the gene that controls the development of variegated pericarp. Courtesy of the U. S. Bureau of Plant Industry

Curiously enough, in comparison with maize its wild relatives are remarkably stable—a stability that affords additional evidence that maize is in fact a hybrid. Thus normal maize plants range in height from six inches to twenty feet; the leaves vary in length from six inches to four feet, and in width from a half inch to six inches; the ears range in length from one inch to twenty inches; the number of seeds vary from less than one hundred to over a thousand; the weight of the seeds may vary from one-tenth of a gram to more than a gram, and they may range in length from three millimeters to two centimeters. These are only a few examples of the variability of this species, for practically every organ is found under a wide range of sizes, shapes, and colors. Nothing approaching this degree of variability is found in any of the maize relatives. Indeed the entire range of characters in all the other New World members of the Tripsaceae tribe combined does not equal that of *Zea* alone.

The chief objection to the mutation hypothesis—aside from the facts that large mutations are extremely rare and that the relatives of maize are stable—is the remarkable parallelism between the types of maize wherever found. All forms and sizes of maize are perfectly fertile in crosses. Only an expert can distinguish many of the Peruvian varieties from those of our southwestern Indians, a fact which indicates clearly that the distribution of this important food plant did not take place until it was a finished product morphologically speaking. Further evidence for this point is found in the wide distribution of colors, seed types, and plant forms. Some differences exist, it is true, but these are insignificant in comparison with the large number of similar types grown in widely separated and remote regions.

On the mutation hypothesis one would expect that the first change in form that resulted in a plant of economic usefulness would have started the chain of distribution so that the farther ends of this hemisphere would have had a cereal crop descended from pre-maize plants of this sort. The subsequent mutations would have occurred in widely separated regions, and it is extremely doubtful whether trade conditions among the aborigines would ever have brought all the stages together. Unless the intermediate forms were assembled and intercrossed, various degrees of maizelike plants should be found throughout the New World. But nothing like this occurs, and maize, exactly as we know it today, appears to have been distributed from Peru to New Mexico thousands of years ago.

The Crowning Achievement of the American Indian

Whether selection, hybridization, mutation, or a combination of all three is eventually settled upon as the answer to the origin of maize, botanists are agreed that the American Indian played the largest part in the development of this remarkable grass. To him and to him alone belongs the credit for bringing this cereal to its present high stage of development. He it was who distributed it throughout the New World and, with a patience only equaled by the Chinese, slowly pushed the frontiers of maize culture across the deserts to the fertile plains of the north, and through the tropical jungles to the temperate south. To his efforts the world owes the only cereal which can be cultivated from Canada to Chile, producing food almost equally well in the short seasons of the far north and extreme south and in the twelve-month season of the Tropics.

Thus, for unknown centuries maize has been intimately associated with the life of man in the Western Hemisphere. From the plains of southern Canada, across the tablelands of Mexico, through the deep valleys of the Andes, to southern Argentine this splendid grass has provided not only the chief food of the inhabitants but their artistic and literary inspiration as well. And how perfectly they saw the details of this, the crowning achievement of their plant genius. The conventionalized maize

An Aztec urn bearing facsimiles of excellent ears of corn. Courtesy of W. E. Safford

plants drawn as decorative motifs on the pottery of Peru (Fig. 56) at once attest the artistic ability of the ancient Peruvians and show a familiarity with their subject far superior to that of the early Caucasian illustrators. Ears

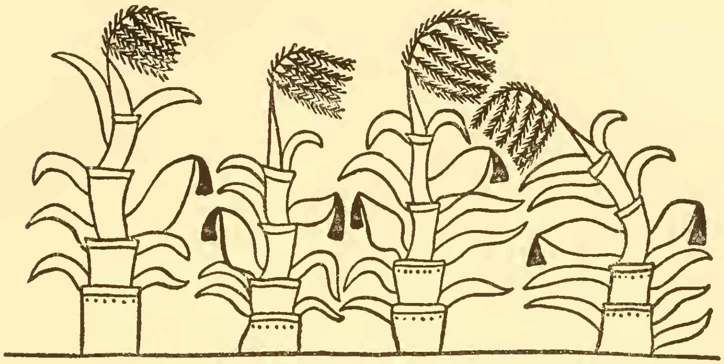


Fig. 56. Conventionalized corn plants drawn on a clay vessel by the people who preceded the Incas in Peru. After Lehmann

of corn, skillfully molded, adorn ceramics from Mexico and Peru, furnishing imperishable records of the high level of the ancient maize culture.

Following the return of Columbus, maize spread rapidly across southern Europe, through Burma, and seems to have reached China in the 16th century. At the present time it is found in the most remote and inaccessible regions of Asia and the islands adjoining that continent. Although this majestic emigrant did not supplant the Old World cereals—wheat, rice, and barley—as a basic food, it found a dignified place in the agriculture of the great plains of central Europe. In the picturesque province of Burma it contributed to the popularity of that other great American traveler—tobacco—by furnishing the wrappers for the "whacking white cheroots."

The Orientals, like the American Indians, early appreciated the artistic possibilities of maize, as is shown by a beautifully executed 16th century screen now in the Freer Gallery of Art, at Washington. No more pleasing reproduction of the maize plant can be found than in this four-hundred-year-old garden scene (including, by the way, the Peruvian-bred *Amaranthus*), for not only have the plants been balanced skillfully but they have been reproduced with a fidelity to nature superior to contemporaneous European attempts.

Though banished from the arts when our industrial civilization submerged our agricultural antecedents, maize has found a place in the halls of science by providing a valuable tool for the study of heredity. It is on this score that we are now concerned with the origin of this plant. The American Indians no less than we moderns were sorely perplexed over the genesis of their majestic plant, but where we debate the merits of this or that botanical hypothesis they had recourse to chanted sagas recounting godly gifts and the intervention of the immortals. And who can say where lies the truth? For as the Zuñi have said "Men, our children, are poorer than the beasts, their enemies; for each creature has a special gift of strength and sagacity, while to men has been given only the power of guessing."

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Part VIII

BOTANICAL EXPLORATION IN SOUTH AMERICA

By

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Vegetation of the subtropical zone in Colombia. The epiphytic growth includes filmy ferns, bromeliads, aroids, and orchids. Ropelike lianas swing from the trees. By E. Cheverlange

CHAPTER I

A NEW FIELD FOR AMERICAN BOTANISTS

The territorial expansion of the United States, with a corresponding development of means of transportation, gave the American botanist of the last century wonderful opportunities for exploration. Confined at the beginning of the century to the Atlantic seaboard, he saw the West rapidly open up to him, and by the time the hundred years had run out, he had collected substantially all the kinds of plants growing within the continental United States. True, certain areas required further intensive study, and a vast amount of information had to be assorted and put into intelligible form; but the eyes of the ever-curious explorer were turned toward our island possessions and to the little-known parts of the New World.

It was to Mexico that the American botanical collectors first went. The appeal of that vast republic, lying so extensively within the Tropics and having an altitudinal range of thousands of feet, was especially great. Pringle, Rose, Palmer, and Nelson traversed Mexico from the northern boundary to Yucatan and from the Atlantic to the Pacific, and upon their collections is based a large part of our present knowledge of the flora of Mexico. American botanists have found their way, also, to all the countries of Central America and to the Bahamas, Cuba, Porto Rico, Haiti, the Dominican Republic, Jamaica, and the Lesser Antilles, and descriptive accounts of the vegetation of several of these regions have been published.

But until very recent years the great South American continent has remained almost wholly unknown to the botanical explorers of the United States. And when about thirteen years ago certain American scientific institutions seriously commenced the exploration of South America, they found that much work had already been done by European explorers. Thousands of specimens had been collected and deposited in European herbaria. South American botanists had explored their countries extensively, but they, too, had sent their collections to Europe, not to the United States.

The earliest pressed plants to reach Europe from South America were doubtless those sent by missionaries or casual travelers. Some attribute of the plant, perhaps some medicinal property, aroused the visitor's interest, and he sought to make vivid his description to those at home by sending a sample of the plant. Some of these specimens eventually reached botanical students, who wrote about them. Then the botanists themselves went to South America, often attached to general exploration parties. Horticulture gave a decided impetus to botanical exploration. The sovereign or the large landowner would desire to grow the gorgeous tropical plants in his gardens, and would commission a collector to go to South America and gather seeds, bulbs, and young plants. For many years the large horticultural houses of Europe maintained explorers in various parts of South America.

It is not possible here to give even a brief summary of the work done by all these men. The accounts of their travels and adventures, their comments on the life of the people they met with, their observations on the plants and animals make fascinating reading. In these men one sees little resemblance to the conventional portrayal of the botanist as a shriveled old man, wandering about abstractedly, peering intently through a little lens at some dainty flower.

Except for the expedition under the leadership of Commander Wilkes, sent around the world by the United States Navy in 1838 to perform a general scientific survey, we find no record of important exploration in South America by North Americans until the latter years of the century. Then came Rusby's expeditions to Bolivia and Morong's to the more southerly countries. Finally in 1918 a plan was formulated by the New York Botanical Garden, the Gray Herbarium of Harvard University, and the Smithsonian Institution for the cooperative exploration of the northern part of South America. The plan contemplated the sending of expeditions into the field whenever practicable; regions already explored by earlier collectors were to be revisited and efforts made to recollect the species little known to American botanists; regions wholly unknown botanically were to be explored for the first time; finally, when a sufficiently large amount of material had been collected descriptive accounts of the vegetation of these northern countries were to be prepared.

In the carrying out of the project other institutions have given assistance at various times, and as a result two expeditions have gone to British Guiana, one to Venezuela, two to Ecuador, and three to Colombia. Although these parties penetrated far inland from the coast, of such absorbing interest was the collecting that time permitted only a view of the vast Amazonian basin from the mountain heights. So, except for the recent work about Mount Roraima and Mount Duida of G. H. H. Tate, of the American Museum of Natural History, the southern portions of British Guiana and Venezuela, southeastern Colombia, and eastern Ecuador still remain unexplored. Although not directly connected with the cooperative program for exploration in northern South America, an expedition was recently (1929) sent by the Smithsonian Institution into northeastern, or Amazonian, Peru, and the collections obtained on this trip give an idea of the general nature of the vegetation of the Amazonian forests on the north.

The three expeditions to Colombia and the recent one to eastern Peru serve well to illustrate the whole subject of the botanical survey of South America. For Colombia —with a frontage on both oceans and with three great mountain ranges, peaks of which exceed 18,000 feet in height—offers nearly every type of coastal or mountain collecting that is to be encountered anywhere in South America; and eastern Peru is representative of the vast forested area occupying the central part of the continent. The problems which confront the explorer of Colombia and of eastern Peru are essentially the same as those which must be met by the explorer of the ocean strip of Venezuela, of the mountains of Ecuador and Chile, or of the rivers of British Guiana and Brazil.

Topography and Vegetation of Colombia

Colombia is the fourth largest of the South American republics and the only one with long coast lines on both the Atlantic and Pacific oceans. If superimposed on a map of the United States it would reach approximately from Lake Ontario to central Georgia and from the Atlantic Ocean to Illinois. In latitude it extends from a little beyond 12 degrees north of the equator to about 2 degrees south of the equator. In altitude it ranges from sea level to some 18,500 feet above sea level. At the border between Ecuador and Colombia the Andes mountain chain divides into three branches, known as the Western, Central, and Eastern cordilleras. Between the Western and the Central cordilleras lies the Cauca Valley; between the Central cordillera and the Eastern cordillera the Magdalena Valley. To the southeast is a vast region, constituting nearly half the area of the republic, of low elevation, forming a part of the Amazon and Orinoco drainage basins. Then there are the Atlantic and Pacific coastal strips, respectively, at the extreme north and west.

Except at their southern extremity the three great mountain ranges are distinct from each other, though near

The wax palms of the Quindío trail, Colombia; in many ways the most striking plant of that country.
Photograph by Killip

A lupine from the Páramo del Quindío, Colombia. Note the dense woolly covering of the plant. Photograph by T. E. Hazen

Medellín, in the Department of Antioquía, the distance between the Western and Central ranges is only the width of the Cauca River itself. Elsewhere the Cauca Valley is twenty to thirty miles wide, and the Magdalena Valley at most points even wider. Both the Western and the Central cordilleras terminate in northern Colombia; the Eastern range divides near the city of Bucaramanga, one branch extending northward a few hundred miles, the other passing on into Venezuela. Isolated from these great cordilleras, the Santa Marta mountains occupy a small area in northern Colombia, rising directly from the sea to a height of more than 18,000 feet.

This remarkable topography at once gives rise to several questions as to the distribution of plants. Are the plants on each of the cordilleras essentially the same or strikingly different? Do Ecuadorean species extend northward, and if so, do they follow all the ranges? Is there any similarity between the plants of the Western cordillera and those of the mountains of Central America? If so, this might indicate that a connecting link between the two once existed. Do the plants of the Cauca Valley "jump" over the mountains to the Magdalena Valley? How does the flora of the Pacific slope compare with that of the Atlantic coastal area? Is the vegetation of the Amazon basin of southeastern Colombia like that of the Magdalena Valley and other low-lying parts of the country? Other questions concern the influence of altitude. How do the plants at the base of a mountain range compare with those at 8,000 feet and those at 15,000 feet? Are there well-marked zones of vegetation dependent on altitude? Are the plants of the cool-temperate altitudes closely related to the plants of the north temperate zone of the latitude of New York, for example, or are they modifications of the tropical plants occurring within a few miles of them, though lower by several thousand feet?

To assemble data for answering these questions, plans for the exploration of Colombia were made, which called for work in each of the cordilleras at southern, central, and northern points and at various altitudes; in the Cauca and Magdalena valleys; in the Amazon and Orinoco basins; and on the Pacific slope and the Atlantic seaboard. A part of this work has been accomplished; much remains to be done. Some general observations may be made upon the distribution of plant life in Colombia, but definite answers to many of the questions must await careful study of the vast amount of herbarium material collected.

In going from sea level to the snow line in Colombia the traveler passes through various zones of vegetation, much as he would if traveling from the Equator to the North Pole near sea level. The boundary line between the zones is not always a sharp one, nor is it always at the same altitude. But with little difficulty one may recognize four distinct belts.[1]

The tropical zone lies between sea level and an altitude varying from 4,500 to 6,000 feet. Where there is heavy rainfall and high humidity, as on the Pacific slope and in the central part of the Magdalena Valley, there are dense forests, the great trees spreading their branches to form a canopy far above the forest floor. Within these forests underbrush usually is not profuse, but at their edges dense masses of low bushes and intertwined vines compete for light. Palms—tall species and short ones—throng these jungles, and many plants have long spines that make travel uncomfortable. Ferns, cannas, and various banana-like plants also abound. Sometimes the explorer will find hunting trails or lumber paths leading into the jungles, but often he must wade up or down small streams if he is to penetrate them. Then there are the great arid stretches where cactuses and acacias thrive. Sometimes, due to a configuration of the mountains, rain will be shut off from

[1] F. M. Chapman, in an account of the distribution of bird life in Colombia, discusses at some length the life zones of the country, and his terminology for the different zones is here used.

a very small area, causing an arid pocket in the midst of a wooded area; such a pocket occurs in the Dagua Valley of western Colombia. A striking feature of the broad river valleys are the graceful bamboos lining the stream banks.

Only a small portion of this rich tropical area has been explored. Our 1922 expedition entered Colombia by the Pacific port of Buenaventura, and made extensive collections about Buenaventura Bay and in the dense and exceedingly luxuriant forests between the ocean and the base of the Western Cordillera. This Pacific tropical area was later explored at a point much farther south, toward the Ecuadorean boundary, west of Popayán. In connection with the study of the birds of this region Chapman notes: "The Colombian-Pacific fauna . . . is one of the most circumscribed and sharply defined, and possibly the most strongly characterized of any fauna of South America. Certainly no other area of similar extent in the tropical zone has so many birds which are peculiar to it." A similar statement might be made in regard to the flora. Of the plants of our collections so far studied a surprisingly large proportion have proved to represent undescribed species.

The subtropical zone extends from the upper limit of the tropical—which varies between 4,500 and 6,000 feet depending on temperature and humidity—to an altitude of about 9,500 feet. In this zone, also, there are dense forests as well as arid hillsides and plateaus. In these forests there is nearly always a dense undergrowth, and the trees and shrubs are literally plastered with a profuse growth of parasites and epiphytes—orchids, aroids, bromeliads, mistletoe, mosses, and ferns. The subtropical ferns are of all kinds, varying from dainty mosslike "filmies" to large palmlike trees. What is in many ways the most striking plant in Colombia occurs at the upper limit of this zone, almost in the temperate zone—the wax palm of the Quindío trail (Plate 88). It reaches a height of 200 feet, towering high above other trees, its long slender white trunk, ringed with black bands and crowned with graceful foliage, making an unforgettable sight. Viewing this region from an eminence, one can well appreciate Humboldt's characterization of it as a forest above a forest. It is in the subtropical zone that the botanist finds the most profitable collecting, and much of the time of the three expeditions has been spent at these elevations.

Above this zone comes the temperate, reaching to 11,000 or 12,000 feet altitude. The woods here are characterized by much-gnarled, though usually compact, low trees, densely covered with moss and lichens. Brilliant fuchsias, passion flowers, and tropaeolums (our garden nasturtiums) make a striking display. Here, too, are many plants familiar to inhabitants of the north-temperate regions—violets, blackberries, strawberries, mustards, buttercups, lupines, and asters. One family of plants, the Melastomaceae, only scantily represented in the United States, makes a fine show of large magenta flowers. Yellow is given to the landscape by festoons of oncidiums and odontoglossums (both orchids), and pink by plants of the blueberry and lobelia families.

Finally the explorer comes to the paramo zone, the bleak region lying above timber line. Often the entrance to a paramo is abrupt; the trail will lead up a gulley through a growth of stunted trees; a dense foggy mist will blanket everything; the stream becomes a mere trickle; and you pass over the edge.

There before you stretches a vast undulating plain, sometimes broken by domelike rocky eminences. Through the mist you see a number of tall, straight, dark figures, the frailejones (little priests), curious wool-clothed plants related to our sunflower (Plate 90). There are many kinds of frailejones, some scarcely a foot high, others fully twelve feet; even the small ones, with their dense rosettes of leaves, and covered with a thick white or golden-yellow

Frailejones (little friars) on the Páramo del Quindío, Colombia. Photograph by T. E. Hazen

PLATE 91

A cushion of *Distichia tolimensis* on the Páramo del Quindío, Colombia. Photograph by T. E. Hazen wool, make a striking effect on the paramos. On the paramo floor are cushions of plants—some are soft moss, and some have sharp needlelike points, which easily penetrate clothing. Of the latter kind are *Distichia* (Plate 91), an Andean plant of the rush family, and *Aciachne*, a matted grass. Here, too, are plants strongly suggestive of northern asters, daisies, and black-eyed Susans, though sometimes the woolly coating of the plant is so dense that it is difficult to see of what northern plant it is a counterpart. Gentians—blue, yellow, and white—are everywhere; blackberries and representatives of the heath family abound. Occasionally a plant of blue-eyed grass, though usually with a yellow "eye," is found. For the most part the ferns are either of the club-moss type or are stiff straight fronds growing out of a stout rootstock. There may be depressions or even gulleys in the paramo where the soil is sufficient to permit the growth of shrubs or very low trees, and these, sometimes covered over with fuchsias and passion flowers, add to the general picturesqueness.

So far as is known there is little true paramo in the Western Cordillera. F. W. Pennell reached an area of some five or six acres in the northern part of this range in 1917. In the Central Cordillera the 1917 and 1922 expeditions did extensive collecting on the paramos of Ruiz and Santa Izabel, respectively. We had hoped to find a rich paramo vegetation on Mount Puracé, near Popayán, but this had been almost completely obliterated by thick layers of ashes from this active volcano. In the Eastern Cordillera A. C. Smith and the writer, together or separately, visited ten different paramos.

Such, then, is the general vegetation of Colombia. To find out what particular species inhabit these zones—whether they are already known or new to science—involves more than merely passing through the locality and observing its flora. Descriptions of the known plants of Colombia are not to be found in a single compact work, as are those of many areas in the United States, but are scattered through a large number of books, which obviously can not be transported into the wildernesses. Samples must be taken from the plants, preserved, and brought back to institutions where facilities are available for their careful study. It is possible to collect seeds of a few plants, germinate them in the United States, and make studies from living material, and sometimes bulbs or other portions of the plant may be brought back and grown. But the great mass of taxonomic botanical knowledge is based upon pressed and dried specimens, supplemented by notes on the character of the living plant. Low herbs, of course, can be collected entire, so that when they are studied a nearly complete picture of their natural appearance can be had. But of larger plants, which obviously can not be pressed and dried as a whole, it is necessary to select portions showing their essential parts—the flowers, fruit, and foliage.

CHAPTER II

WORK IN THE FIELD

There are two main tasks in the making of herbarium specimens: the actual collecting of the plants, and—as soon after the collecting as possible—the drying of the specimens. It is a far cry from the nature lover's act in picking a violet and pressing it flat between the pages of a book to the work of an expedition to the Tropics which gathers some 7,000 "numbers" in the course of six months. The cooperative work in Colombia has made necessary the collecting of three or four specimens of each "number," and the gathering and drying of these specimens and the transportation of the necessary equipment constitute serious problems. The methods of botanical exploration may best be illustrated by the description of a typical month spent by the members of the last expedition to Colombia in the mountainous region north of Bucaramanga.

Bucaramanga was our principal headquarters in the Eastern Cordillera. Leaving the greater part of our baggage at a school building placed at our disposal by the government authorities, we proceeded north to the small village of California, distant about two days of mule travel. Here we rented a house and, after making the necessary calls upon local officials, we were ready to begin work. Our first excursion was to La Baja, a few miles distant. This place, indeed, had been the principal factor in determining to what part of Colombia we should go on this trip. A mining town of some importance at the middle of the last century, La Baja had become botanically famous as the locality at which Linden, Funck, and

Schlim had found a large number of new plants, apparently of limited distribution. Today the town is a mass of ruins, only three or four houses remaining intact.

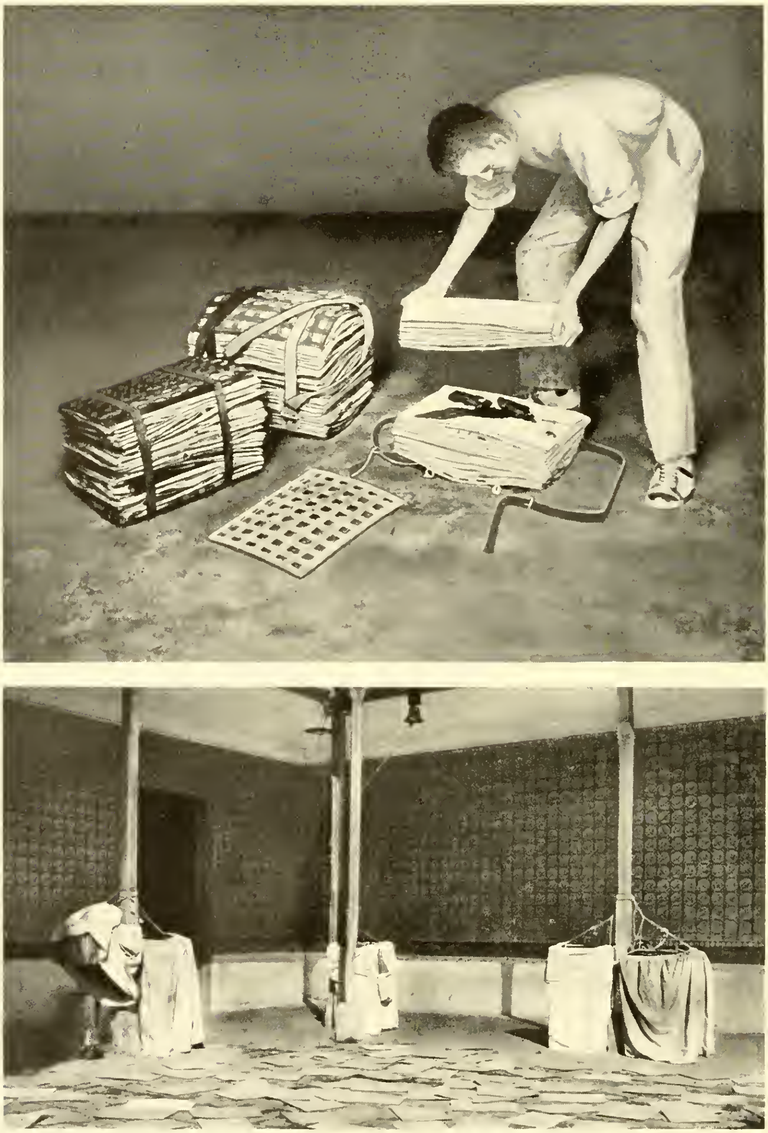
The mule trail ascended the La Baja River valley, passing sometimes through grassy country and sometimes through deep woods. The equipment which each of us carried consisted of a pair of pruning shears, a hunting knife with a saw-toothed edge, and a collecting portfolio, made of two wooden frames about seventeen inches long and twelve inches wide, held together by leather straps. The portfolio contained a number of sheets of white paper on which to lay the plant specimens.

As this was our first field work in this locality, we collected specimens of every plant that was either in flower or in fruit. Shrubs were often more easily reached from the mule's back, but usually we dismounted to get a specimen. The specimens were laid in the portfolios, accompanied by notes on the size and habit of the plants. When a portfolio became inconveniently full, a situation which arose every few minutes, we made up a bundle and cached it beside the trail, to be retrieved on the return trip.

The leading citizen of La Baja guided us on a short trip into the mountains, and we made arrangements with him for a week of collecting later. At the end of the day we hurried back to our house in California. The bundles of fresh plants were hung for the night high out of reach of marauding ants.

There is little advantage in two botanists doing the actual work of collecting together, so we planned to take turns in the field, Mr. Smith to spend ten days in the high mountains to the east while I dried and prepared the specimens he collected. Then I was to return to La Baja while he worked at the California headquarters. In the company of the village priest, whose guest he was to be at one of the "highest" towns in Colombia—Vetas—and of our native helper, Mr. Smith made the steep ascent of

Indian carriers bringing fresh plant specimens to headquarters at Yurimaguas, Peru. Photograph by A. C. Smith



Preparing plant specimens. Upper: Making bundles for drying. Lower: Drying plants over oil burners. Photographs by Killip the Páramo Rico to Vetas. Using this village as a base, he made daily trips to neighboring paramos. Each evening the bundles of fresh plants were turned over to an Indian messenger, who made a moonlight trip across the mountains to our little house at California. This Indian packer arrived at about five o'clock each morning, bent over with a load of some fifteen or twenty small bundles well lashed together. His pay for the trip—fifty cents—seemed small recompense.

Each bundle bore a number so that the plants could be arranged in chronological sequence. The specimens were unpacked, all dirt washed off the roots, loose flowers or leaves placed in small envelopes, and each specimen laid out carefully on clean white paper of standard herbarium size. Extremely succulent plants were first put in boiling water to insure quick death and forestall decay while drying. Next each sheet was given a number and a corresponding entry was made in a notebook, giving the probable generic name of the plant, its habitat, the place of collection, the coloring of the flower, and a transcript of additional field notes made by the collector.

A sheet of blotting paper was laid between each pair of specimens and when a bundle became large enough it was inclosed between two slat frames and cinched tightly with web straps. A large part of the moisture in the plants would thus be absorbed by the blotting paper, and the next day the specimens were ready for drying over heaters. For this operation the wet blotting paper was removed and replaced by dry sheets of blotting paper and corrugated cardboard in alternation. The packages were then lashed to the posts and railing of the patio about three feet above the ground. There are patios, or courtyards, in all Colombian houses, and they all have posts or railings. This furnishes an additional reason for doing this part of the work in a substantial habitation whenever possible, rather than in a tent. Under each package was placed a small kerosene stove, and around each bundle a curtain was draped so that the heat might all pass up through the corrugated boards and dry the plants more speedily. Sad experience had taught us the danger of fires resulting from the curtain being blown into the flame, so we had constructed protecting shields from ordinary chicken wire, and these were placed around the stoves.

This drying apparatus required little attention; twice a day the bundles were reversed and the stoves refilled. The length of time needed to dry plants obviously depends on the nature of the individual plants. Ferns, grasses, and slender herbs will usually dry within twenty-four hours; most plants will dry within forty-eight hours; orchids, aroids, cacti, and similar fleshy plants may require as long as a week to dry thoroughly. Fortunately kerosene is obtainable at all important places in Colombia, though at exorbitant prices in regions where the cost of transportation is high. However, we have found no satisfactory substitute. Charcoal was used on one trip but the difficulty of maintaining an even heat led to several destructive fires, one of which required the summoning of the entire village fire department to save the building; as a further disadvantage, charcoal makes necessary the continued presence of a man to feed fuel. The kerosene stoves, on the other hand, require no attention for twelve-hour intervals. It is, of course, possible to dry plants without artificial heat by changing the blotting paper repeatedly and drying the wet paper in the sun or near a stove. But this method is slow and is scarcely practicable when large collections are being made. We averaged 150 collecting numbers, or about 400 individual specimens, a day.

Once the plants are thoroughly dried they are made into small packages and are ready for shipment to the United States. A quantity of naphthaline is placed with the specimens to prevent molding.

The collecting and drying of plants at the little Colombian town of California was done under ideal conditions. When a long journey by mule through a sparsely settled country is undertaken additional problems arise. If an expedition moves over a trail rapidly to reach at night a satisfactory domicile where adequate preparation of the specimens can be made, it will overlook many rare plants en route. If the party moves slowly, collecting abundantly, camp may have to be made at a point where the material can not be well assorted and dried. We usually traveled slowly, collecting all but the most common plants. At night we laid the specimens between driers, changed the driers the following day, and then, when a satisfactory stopping place was reached, spent three or four days in drying the specimens over the heaters.

The equipment for a six months' botanical trip is necessarily large. In addition to the usual articles such as tents, folding cots, hammocks, cooking utensils, mosquito netting, common tools, and medicines, we took as special equipment for the botanical work 15,000 sheets of white paper of standard herbarium size, 2,500 sheets twice as wide and folded once lengthwise, 1,800 sheets of blotting paper, 700 corrugated cardboards, 20 wooden frames to serve as press ends and an equal number of web straps, 3 collecting portfolios, 5 kerosene heaters with curtains to drape about them, several pounds of naphthaline, pruning shears, notebooks, and sundry articles such as twine, rope, and tags.

To the parts of Colombia visited by the recent expeditions it is unnecessary to carry large quantities of provisions. In the mountains bread and cheese, chickens and eggs, meats, potatoes, and sweets may be obtained nearly everywhere, and, of course, in the lowlands a great variety of food can be had. The main problem in the matter of provender is pasturage for the mule caravan; and frequently the stopping place of an expedition is determined not by the rare botanical specimens available but by the common fodder crops for the mules.

Our equipment was packed in twelve light but strong fiber cases two and a half feet long, one and a half feet wide, and one foot deep. This size is well adapted to the economic packing of the paper supplies, and, moreover, such cases are easily adjustable to a mule's back.

Nearly all travel in the Colombian mountains is done by horse or mule—the horse for the more dignified voyager on the well-beaten roads, the mule for cargo and the less-used trails. Although agencies will transport baggage at a variable rate, often quite high, a better method is to purchase the mules or to rent them by the week or month, engaging a muleteer, or *arriero*, to have charge of the loading and driving of the caravan. Two fiber cases are secured to each mule by an elaborate system of roping, during which cloth is placed over the animal's head lest he take fright and run. The *arriero* well appreciates the need for care in this loading, for if the pack should become loose and unbalanced, the mule might easily slip over a precipice, and mule and cargo be permanently lost. Often on the road the pack slips and then the muleteer hastens to throw a cloth over the mule's head and adjust the cargo. At night the good *arriero* never thinks of resting or of eating until the mules have been unloaded, their backs massaged, and the animals led to pasture—often a long distance from the inn.

The complex task of drying specimens makes a substantial headquarters for the night almost a necessity, and consequently tenting has been avoided on these botanical trips as far as possible. In the larger cities that served as main bases, the local authorities generously placed at our disposal some public building, which served as workshop, storehouse, and eating and sleeping quarters in one. In Popayán the building given us had formerly housed a convent. It was a beautiful two-storied example of early Spanish-American architecture with large patios. Comfortable beds had thoughtfully been provided; meals were served in a spacious dining room; and a reception room

PLATE 94

The expedition crossing the Páramo de Santurbán, Colombia, at an altitude of 12,000 feet.
Photograph by Killip

A caravan of mules arriving at Popayán, Colombia. Photograph taken from the expedition's headquarters by Killip had been set apart, to which the important citizens came immediately on our arrival with every offer of assistance. In Bucaramanga we were given a nineteen-room school building. In Salento, as in California, we rented a house. In a few large cities we lived at hotels, though the interruption our work offered to the normal quietness of these more pretentious hostelries was not always welcome. Rooms in a modern flour mill at Suratá, a village near California, were given us free of charge. At La Cumbre, on the crest of the Western Cordillera, in a region unusually rich in dense vegetation, quarters were found in an American hospital. Several times hunting lodges in virgin wilderness were turned over to us by their generous owners.

Often, especially on long trips, we stopped at any inn or hut which might conveniently come into view about three o'clock in the afternoon. Considerable persuasion was frequently necessary to gain permission to remain if the spot were not a regular stopping place for distinguished *caballeros*. Though a caravan of cargo mules might well have arrived there already, the innkeeper, usually a woman, would protest that she had not the right kind of food for such as we and that certainly we would not wish to crowd into the one room already occupied by several muleteers. Once we suggested that we sleep on our cots on the porch; a horrible suggestion, apparently, for, she protested, "You will die. The night air is filled with disease and evil spirits." And when in the morning she found us still alive, it was hard to say whether relief that we were not dead or chagrin at the nonfulfillment of her predictions predominated.

Our full complement of baggage required six mules, and the loading of these in the morning took much time. My companion and I usually started off on the trail well in advance of the cargo, and, traveling slowly, we made a thorough job of collecting. In time the cargo caravan caught up with us, and then inevitably much confusion ensued as the burdened animals tried to pass our riding mules; for the Andean mule is a wise beast and has learned always to strive for the inside track on the narrow trails where a misstep on the outside track means a plunge over a precipice. To the already well-laden mules we would add our morning's collections and allow the caravan to pass on to a satisfactory halting place for the night.

In the lowlands travel by mule is supplementary to travel by boat, railroad, and auto. The two main arteries of Colombia are the Magdalena and Cauca rivers, though neither is navigable its entire length and detours must be made around rapids. The boats are oil-burning or wood-burning side-wheelers and on the whole quite comfortable. The few staterooms are usually reserved for women passengers, the men sleeping on cots on the decks. Oil-burners are preferable because their stops for fuel are infrequent. Small gasoline launches or canoes can be used profitably by the botanist for the exploration of coastal strips and river valleys. Skirting the low shores of Buenaventura Bay or Cartagena Bay in a canoe gives a wonderful opportunity to collect interesting plants. The natives climb the overhanging trees and throw into the canoe rare orchids, aroids, and bromeliads. Only by canoes may the narrow water passages among the mangroves be explored.

The heavy seasonal rains and the loose, shifting character of the soil often cause the destruction of long stretches of railroad and highway. The fine new road along the Pamplona Valley from Pamplona to Cúcuta, which we had planned to take toward the end of our last trip, was out of service, some portions of it nearly a mile long having been washed into the river. So we were obliged to flounder through a muddy "washerboard" trail, once abandoned. The night before we planned to go from Buenaventura to La Cumbre, in the Western Cordillera, landslides had blocked the railroad at several places. The train steamed

PLATE 96

Transporting the expedition's supplies across a river in western Colombia. Photograph by T. E. Hazen

PLATE 97

Epiphytic orchids brought from the mountains to adorn the walls of a home at Piedecuesta, Colombia.
Photograph by Killip

to the first blockade, waited till the débris had been removed, then went on to the second. At one obstruction, too great to be cleared away in a day, the passengers were transferred to a small flat car and an exciting ride ensued, two natives pushing the car to the top of a grade, then letting it race madly down the winding track at the edge of the gorge, with no brake other than a crowbar pressed against a rapidly revolving wheel. With the development of modern means of transportation in Colombia, as well as in other South American countries, the work of the botanical explorer will be greatly simplified. Less time will be consumed in reaching the area to be explored; equipment can be transported more safely; and the specimens collected can be shipped out with a greater chance of eventual arrival in the United States.

Exploring Beyond the Peruvian Mountains

From Colombia the Andes extend for nearly 4,500 miles almost to the southern tip of the continent, a great mass of mountains, many of them snow capped, cleft here and there by passes through which travel moves into the interior. The proximity of the cordillera to the ocean has resulted in a curious, uneven development of these western countries. Cities have sprung up on the coast or on the nearby mountain slopes, where trade with the outside world might more easily be carried on. Other cities have grown up in the cooler, more invigorating climate of the higher altitudes. Caravans of trade have passed from the mountains to the coast and from the coast to the mountains. But across the mountains was another world, a world seldom or never visited. Roads leading to it, even the narrowest of mule trails, were few. The friendliness of the native Indian tribes was uncertain, and living conditions were of the most primitive sort. Here and there outposts of civilization were established, mainly along the most direct routes from the mountains to the navigable portions of streams flowing toward the Atlantic, and along the Amazon and its larger tributaries. But even today there are vast, almost wholly unexplored regions in southeastern Colombia, eastern Ecuador, northeastern Peru, eastern Bolivia, and northeastern Chile. All this eastern country is known as the *montaña*. Most of it is dense forest, though in Colombia there are long stretches of grassland. Rainfall is heavy, though usually there are two well-marked seasons, a dry one and a wet one. Travel is by canoe, by river steamer, by mule, and in recent years by airplane.

From Callao, the principal seaport of Peru, and Lima, the capital, seven miles inland, the main route of travel to the Amazon runs almost due eastward over the cordillera to the Chanchamayo Valley, then northeastward over a lower, rather isolated range of mountains to the Pichis River, down this and the Pachitea to the Ucayali River, which unites with the Marañón, coming from the west, to form the Amazon. The first part of the trip, from the coast to the Chanchamayo, is by rail and auto, the railroad crossing the crest of the Andes at an elevation of 15,600 feet, a marvelous feat of engineering with over sixty tunnels, numerous "switchbacks," and high bridges. From Oroya, in a valley between the main ridge and the lower, Eastern Cordillera, the route continues by an auto road over this second range, then down to San Ramón, La Merced, and the Perené Colony, the three most important places in the Chanchamayo Valley.

This descent from 14,000 feet to 2,000 feet is full of thrills, most of the "drop" coming within a few miles. The road is scarcely wider than the car and consequently for the greater part of the route one-way traffic is maintained, cars descending three days a week and ascending on alternate days. Looking ahead the road seems so narrow at places that no car can pass, but it does, scraping the jutting rocks on the inside, the wheels perilously near the outer edge. A tunnel looks like a rabbit hole—much too small for the car to enter. But you pass through safely, the top of the car brushing against the roof of the tunnel. By nature these Latin-American drivers are thrill-loving, and they make more use of the accelerator than of the brake.

At the end of the highway you have a choice of continuing your route to Iquitos on the Amazon by air, a day's flight, or by land, a three weeks' trip. The air journey, though, of course, impossible for the botanical collector, gives a wonderful view of the vast rolling Amazonian forest, streaked with the crooked silvery lines of the rivers as they make their way, steadily growing broader, to the great river. The aviators in this service relate many an adventurous tale of forced landings on river banks in the heart of the wildest Indian country, their planes bearing the marks of hostile arrows.

Few parts of Peru are more interesting to the botanist than the Pichis trail, the only portion of the land route from Lima to the Amazon that must be made by mule. Much of this is through subtropical forest between 5,000 and 6,000 feet elevation, and there is a constant change of vegetation from day to day. Color is given to the forest by red fuchsias, blue monninas (a shrub related to our northern polygalas), and yellow composites. Hidden in the jungle we found an open sphagnum swamp, much like those of our Northern States but with only one familiar species, the cinnamon fern.

One of the pleasant features of this trail is the presence of delightful *tambos*, or inns, at the end of each day's journey. Flimsily constructed though they are, and with domesticated animals ever present, sleeping accommodations are satisfactory and the meals remarkably good.

At Puerto Yessup canoes are boarded. How far one must travel by canoe depends on the depth of the water; steam launches do not go far up the Pichis River in the dry season. Canoeing down these small streams is a fascinating experience. The banks are close enough to permit the recognition of individual trees. In the profusion of vines, morning-glories, passion flowers, and plants of the pumpkin and grape families predominate. On the broader rivers the shore appears merely as a dark band between the sky and the water. Animal life, too, seems more abundant on the smaller streams. Gorgeous parrots and macaws fly screeching overhead; alligators and giant turtles bask on the beaches; monkeys swing from tree to tree, howling uncannily. Many times canoeists must disembark in the middle of the river to drag the boat over shallow stretches. Often the water is so swift that there is danger of an upset.

At length one reaches a point where navigation by larger boat is possible, and one steams slowly onward, day after day, down the Pachitea and Ucayali rivers till the Amazon is reached. These boats are wood-burners, and much time is consumed taking on wood. At convenient spots on the banks are great wood piles, and hour after hour there is a continuous procession of slow-moving natives carrying the logs to the ship. Stops may be made for the loading of cattle, cotton, or bales of balata, one of the rubber plants of the upper Amazon country. Many of these boats are trading ships, carrying a large assortment of goods to be sold to the natives or, more usually, exchanged for local products, each transaction accompanied by the customary tedious bargaining.

From the base of the Andes to the northern and eastern boundaries of Peru and across into Ecuador and Brazil there lies the vast, almost unbroken forest, penetrable only by the rivers and the narrow trails which connect the more important settlements. Here and there is an Indian *chacra*, a hut or two about which a clearing has been made for the growing of yuca (cassava), bananas, platanos, and barbasco. The first three are the main food products of the natives, and the barbasco is used in fishing. But for mile after mile there is nothing but forest.

The number of different species of plants within a given area is almost beyond estimate; certainly it is many times greater than in a similar area in a northern woods. Collecting herbarium specimens to represent even a fair number of these plants is no easy task. Often the desired flower or fruit towers high above the collector's head, to be reached only by an arduous climb up through the entanglement of vines at the river's edge. Back of this network are the trees, trees of all sizes from small shrubs to giant ceibas and mimosas, all bound together by lianas and covered with a dense epiphytic growth of orchids, bromeliads, ferns, and mosses. To get specimens from many of the trees means cutting down the tree. Often merely cutting through a trunk does not fell an Amazon tree, for the upper part may be held up by the lianas or it may lodge on another tree, which in turn has to be cleared away. The natives are adept climbers and often go up a tree trunk or a swinging liana to get the specimen. Sometimes in the less dense forest a branch of flowers may be shot off. Naturally, however, the greatest hauls are made at recent clearings. Often while walking along a trail we would hear the sound of an axe, make for it, and there where some Indian was making his home in the virgin forest spend profitable hours among the fallen treetops. An added advantage of collecting under such conditions is that the native usually volunteers information about the plants—the quality of the various timbers, the effectiveness of different drugs.

Even after they are collected, the specimens require much attention to forestall the attacks of ants and other insects, and of mold. A package of specimens left on the floor at evening will by morning have great ants' nests between nearly every pair of paper sheets. The general dampness of the Amazonian forests hastens the decay of specimens so that they must be cared for immediately, and, when dried, well sprinkled with naphthaline. All this attention, of course, is necessary anywhere in the Tropics but it is particularly so in the Amazon country.

Our almost complete lack of knowledge of the upper Amazon is amazing. One of the most commonly cultivated plants in northeastern Peru is the *barbasco*, or *cube*, the roots of which are used by the natives to stupefy fish; yet until recently its botanical name was not known, and apparently no specimens of it were to be found in American herbaria. This plant will doubtless have great commercial value as an insecticide. Another plant, *ayahuasca*, or *caapi*, used by the Indian medicine men to produce fantastic dreams, is a strong narcotic, possibly of great medicinal value; yet, it, too, is almost wholly unknown outside of its native haunts. And who has heard of the *abuta* or of the *chuchuhuasca*, two other cure-alls of the natives? What other plants are hidden in the dark recesses of this Amazon country or in the mountains to the westward that might prove of great commercial value? What gorgeous flowers that might be brought to horticulture? What fruits that might find their place beside the banana, the orange, and the avocado?

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