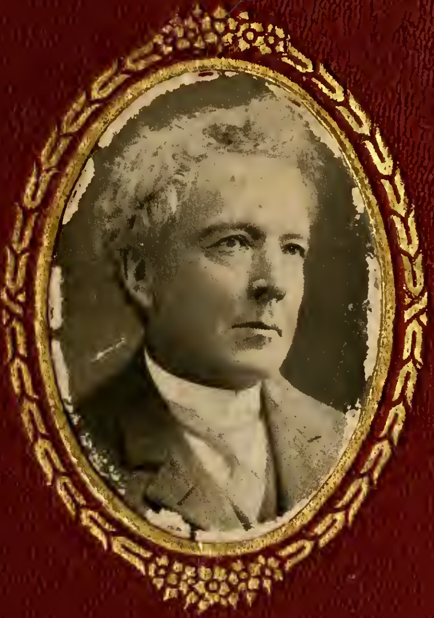

Cleft Graft

This is one of several common methods of grafting. The engrafted twigs are called cions, the branch on which they are placed is called the stock. The essential principle is that the inner bark, called the Cambium layer, of the cion should be brought into intimate contact with the corresponding layer of bark of the stock. Further details of grafting are shown in other pictures in this volume.

LUTHER BURBANK

HIS METHODS AND DISCOVERIES AND THEIR PRACTICAL APPLICATION

PREPARED FROM
HIS ORIGINAL FIELD NOTES
COVERING MORE THAN 100,000 EXPERIMENTS
MADE DURING FORTY YEARS DEVOTED
TO PLANT IMPROVEMENT

WITH THE ASSISTANCE OF
The Luther Burbank Society
AND ITS
ENTIRE MEMBERSHIP

UNDER THE EDITORIAL DIRECTION OF
John Whitson and Robert John
AND
Henry Smith Williams, M. D., LL. D.

VOLUME III

ILLUSTRATED WITH
105 DIRECT COLOR PHOTOGRAPH PRINTS PRODUCED BY A
NEW PROCESS DEVISED AND PERFECTED FOR
USE IN THESE VOLUMES

NEW YORK AND LONDON
LUTHER BURBANK PRESS
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Volume III — By Chapters

FOREWORD TO VOLUME III

With many examples of the actual work before us, Mr. Burbank now takes us into the interesting detail of method itself, treating the subjects of pollenation, grafting, plant affinities, fixing traits, selection, and spreading before us all of the processes which he has employed in his more than 100,000 separate experiments.

The purpose has been to lead the reader, by easy and interesting stages, up to a point where a delineation of the actual processes may be most readily grasped. This, the third book, completes the consideration of general method, and with the two preceding volumes gives us an intelligent survey of Mr. Burbank's work.

THE EDITORS.

A Burbank Strawberry

This picture represents a fruit that was developed in accordance with Mr. Burbank's preconception as to what a perfect strawberry would be like. It is remarkably symmetrical in shape, of just the right size, and its qualities of firmness of texture and of flavor are ideal. It is the product of a long series of experiments in selective breeding. John Burroughs pronounced it the best strawberry he had ever eaten.

PLANNING A NEW PLANT

THE FIRST STEPS IN PRACTICAL WORK

SOMEONE has said that a painter is a man who can see the picture in the landscape. In similar fashion it may be said that a successful plant experimenter is one who can see new varieties of future plants when he looks at old existing varieties.

But of course the painter, whatever his constructive imagination, does not always see at first glance every detail of form and color that will ultimately appeal to him. Nor can the plant experimenter claim, by any manner of means, to know always from the outset just what his new plant creations will be like. There are numberless instances, indeed, in which a plant experimenter who operates on a large scale may make hybridizing experiments, merely to test the possibilities of crossing certain species, without having any precise and definite goal in view.

[VOLUME III—CHAPTER I]

But, on the other hand, it is necessary in the pursuit of practical plant developments to have a tolerably precise idea in mind as to the particular direction in which progress is desirable.

Lacking such an ideal, the breeder of plants would be about as likely to produce new creations of value as an architect would be likely to construct a fine building by putting materials together at random without a carefully preconceived plan.

"In what percentage of cases have you achieved the ideal at which you aimed in the production of new varieties of flowers or fruits?" a visitor asked me.

The question is almost impossible of definite answer. When I first commenced, doubtless a very small proportion of my experiments came out as I expected. But now, with years of experience to guide me, I may say that I practically always get something not far different from what I desire. In many cases, the result comes just about as I expected. But this is because I am working with plants that I have previously tested.

With a new plant I am still sometimes in doubt. But if it is a case of poppies or walnuts or any one of a score or so of other plants that I have fully tested, I know just about what to expect.

At best, however, I am very often reminded that each species has its own individuality and that even the most familiar plant may hold surprises in store for us.

THE ROUGH SKETCH

"But just how do you start out when you are seeking to create a new form of plant life?" I am constantly asked.

And here again the answer is difficult. Everything depends upon the ultimate object. If I am seeking merely to test the possibilities of making certain crosses, or as it were feeling my way along new channels, I am more or less like a person groping in the dark.

This form of vague experimentation is often full of interest. I have already given some instances of what may come to pass when we hybridize plants of widely separated species or of different genera. The reader will recall the case of the petunia with the tobacco habit and of the dewberry crossed with such remote cousins as apple and pear and mountain-ash. These experiments were made without a clearly defined object—except to ascertain whether it was possible to hybridize plants of such diverse character.

And the results of the experiment, while of very great scientific interest, were not practically successful in a commercial sense.

I recall reading an address by the late Professor Newton, a distinguished American astronomer, on the subject of "dead work," in which he emphasized the fact that the main bulk of the experiments which any scientific worker must make will lead to no definite goal. A large part of the time of every experimenter must be given up to following trails that lead nowhere in particular or that end in blind *cul de sacs.*

The work of the plant experimenter is no exception, but there is always an incentive to further effort in the knowledge that a path that seems to lead only into impenetrable mazes may presently bring one out into the light. To make the application to one illustrative case among many, I recall that for twenty-four successive seasons I attempted to hybridize certain species of Solanum before I finally succeeded in effecting a cross that gave me a single seed from which sprang the new race of Sunberries.

But it must not be understood that the main bulk of my experiments are made in any haphazard manner.

On the contrary my most important results have been attained by continuing the experimentation along rigidly predetermined lines and by methods of hybridizing and selection that my earlier work had fully established. Having served

Strawberries Showing Variation

This picture illustrates the variation that may be shown by fruit growing on vines from the same lot of seed. By selection, each type of berry here shown might have its peculiarities accentuated, and as many new varieties developed. Mr. Burbank is always on the lookout for variation among his plants, and such variation forms the basis of his experiments in selective breeding.

a long apprenticeship and tested the usual limits of making new plant combinations, I was presently able, like any other trained technician, to apply the knowledge thus acquired toward far more definite results than were at first possible.

In the case of the Shasta daisy, the plans were all laid out beforehand as to just what type of flower I wished to produce.

The ideal of a white blackberry was also, of course, a perfectly precise and definite one.

Obviously the scented calla, the stoneless plum, the early bearing cherry, the sugar prune, and the spineless cactus are other instances in which the ideal pursued was as clearly conceived and as definitely outlined in advance of my earliest experiments as a cathedral is outlined in the mind of the architect before he commences his preliminary drawings.

In one case as in the other the details may be modified as the work progresses, but the general idea of the structure aimed at—be it new fruit or new building—must be conceived with a good deal of definiteness from the outset. My original conception of a new plant creation, in the cases outlined and in a large number of others, certainly bore as close a resemblance to the final product achieved as the first rough drawing of the architect bears to his finished plans.

"But how do you *begin?* What is the *very first thing?"* a visitor insists.

The "very first thing" I have already described —it is the conception of an ideal, a mental picture of the new plant form desired.

Clues to Be Followed

It has occurred to me, for instance, that the cherry crop is not what it might be. I have learned that there is a steady market for early cherries and that a difference of a few days in the time of marketing may make a difference of more than one hundred per cent. in the price.

And so I ask myself, why not create a new cherry that shall be ready for shipping at least two or three weeks earlier than any cherry now in the market?

Of course, I reflect that my early cherry must have a number of other desirable qualities—large size, rich color, lusciousness of flavor. I know at the outset, or I presently learn, that it is desirable also, from the standpoint of the shipper, that my cherries shall grow on short stems. I know that the tree producing them must be hardy, capable of withstanding both cold winters and dry summers, and that it must have an inherent vitality that will make it resistant to the attacks of insects and fungoid pests.

Next I ask myself what warrant there is for supposing that I can build such a fruit-structure as I have conceived.

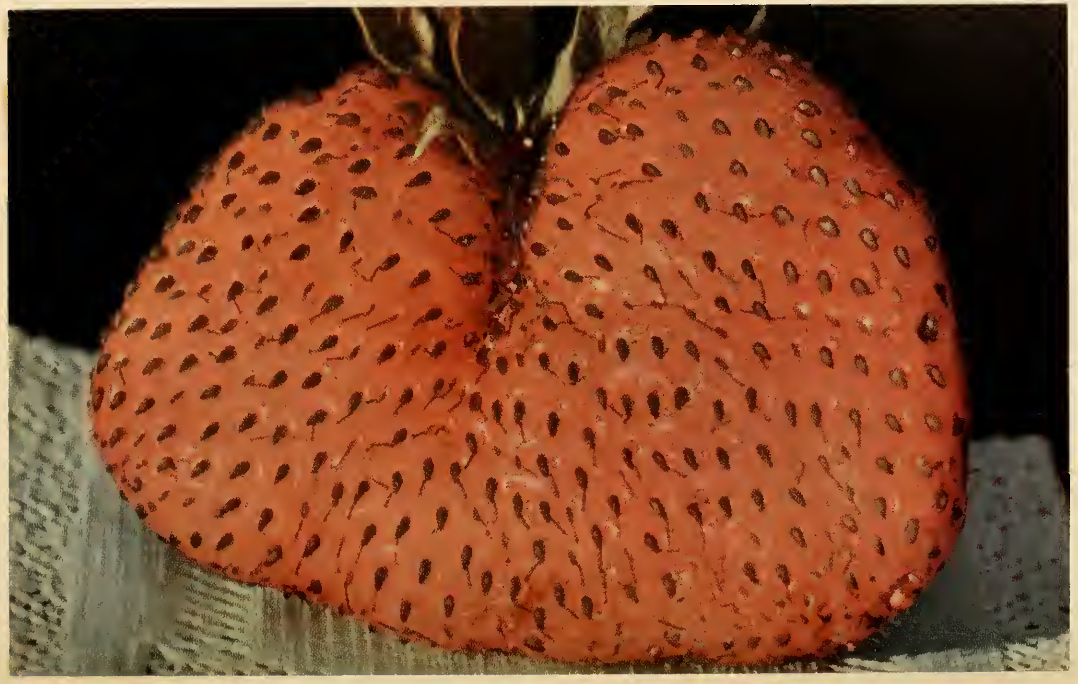
And here the answer is supplied solely by the use of imagination in connection with the inspection of existing races of cherries. I examine the best fruits already in the orchard and find that there is a large measure of variation between the cherries grown on different trees, as well as between the individual specimens on the same tree.

In imagination I look back far into the past and inquire as to the racial history of this fruit.

I am led to believe that certain among the ancestors of the cherry have grown in semi-tropical climates, and I know that even in the present day there are species, doubtless sprung from the same original stock, that grow far up into Canada.

I ask myself why it is that the cherry shows such a propensity to vary, and I find an answer in the assumption that the existing cultivated races carry in their veins, so to speak—that is to say in their germ plasm—hereditary tendencies drawn from varied strains of a mixed ancestry.

And I feel well assured that it should be possible, by accentuating the tendency to variation through further hybridizing, and by careful selection, to combine and bring out in a more or



A Giant Strawberry

Mr. Burbank considers symmetry of form more important than gigantic size in a strawberry. He has developed some varieties, however, that grow to exceptional size, it being desirable to produce fruits that meet various demands. This picture shows a variety that has been developed along the lines of one of the forms shown on Page 11.

less remote generation of progeny of the existing cherries, a race that will furnish extreme examples, through reversion, of the limits of variation in each direction—and as regards each particular quality of fruit—that any ancestor reached.

It will be obvious, then, that I am not preparing to make bricks without straw.

I am counting well the materials with which I must work, just as the architect from the first stroke of his pencil bears in mind the materials of the future cathedral.

I do not imagine that I can produce an apple from my cherry stalks, any more than the architect assumes that he can build a marble cathedral out of bricks. I know that there are sharply defined hereditary limitations beyond which the cherry cannot be made to go within any such period of time as that limiting my experiment.

In other words, I do not ask the impossible, although it has often seemed to my critics that I have asked the highly improbable.

But the results I have attained are in themselves sufficient answer to the critic. If my vision has in some cases been the clearer, it is merely that my knowledge of plant life, drawn from the school of experience, has been wider.

To the uninitiated observer it may have seemed that I set no limits to the transformations I attempted. In reality, my plan has always from the outset recognized most definite limits—although often enough the limits as I conceived them were quite different from those that had been set by theoretical botanists.

Aid From Galton's Law

In attempting to estimate the possibility of improvement in a given form of plant life, it is of value to recall the formula put forward by the late Sir Francis Galton; a formula often spoken of as Galton's law.

According to this estimate, the hereditary traits of any given organism are so intermingled that we may assume as a general rule that offspring of a given generation will inherit about half their tangible traits from their parents, one-quarter from their grandparents, one-eighth from their greatgrandparents, and so on in decreasing scale from each earlier generation.

Stated otherwise, according to this rule, we should be able by observation of the parents of any given organism, to see presented half of the traits of the offspring; but we may expect that the offspring will manifest, as the other half of their inheritance, traits that have come to them, through the process of reversion or atavism, from remoter generations of the ancestral strain.

And this obviously gives opportunity for the appearance of an enormous variety of traits in any given generation that were not manifested in the preceding generation.

Thus any given individual has normally, as a moment's reflection will show, four grandparents, eight greatgrandparents, sixteen ancestors in the generation before that, then thirty-two, sixty-four, one hundred and twenty-eight, and so on in a geometrical ratio with each remoter generation. So the normal ancestral clan of any one of us numbers more than a thousand different individuals within the relatively limited period of time compassed by ten generations.

And, according to the estimate of Galton, to which numberless cases of atavism give force, certain traits and tendencies of each and every one of these ancestors may make themselves manifest in the personality of any given descendant.

Galton's studies, upon which his formula was based, were chiefly made with reference to human beings, but we now know that the laws of heredity apply with equal force to all kinds of living organisms, including plants; and whatever the limitations of Galton's law as a precise formula, there can be little question as to the general truth of the principle that he invoked.

Hence the value of that search in imagination

A Japanese Pear

The tastes of the Japanese people are different from those of Europeans and Americans, and their fruits have been modified to meet these tastes, through long generations of conscious or unconscious selection. The Japanese and European pears have common ancestors, and they have not diverged so widely that they cannot be interbred. By such interbreeding, Mr. Burbank unites the different racial strains, and produces new varieties.

for the ancestors of our cherry in their widely separated habitats and with their widely diversified traits and habits.

But of course in making practical studies for the development of the mental blue print with its forecast of qualities of our new cherry, we must perforce be guided largely by the observed qualities of the parent stock with which we deal. Precisely what were the qualities of the remote ancestors, we can only infer. But we can see for ourselves what are the qualities of the fruit before us.

We know, then, pretty definitely what we may expect as to one-half the traits of a hybrid that will result when we cross two varieties of cherries in our orchard. The other half must be somewhat matter of conjecture, to be revealed by the actual product or, as is practically the case, by succeeding generations.

What we actually do, then, in practice, is to take flowers from a cherry tree that has been observed to bear fruit somewhat earlier than neighboring trees, and with this pollenize flowers of another tree that has been observed to produce fruit of exceptionally good quality. Pollenation accomplished, by the method elsewhere described, we can only mark the branch for future identification, and await results.

The seed thus secured will be planted next season, and in due course we shall have a seedling which, when grafted on another tree to speed its maturing, will come to blossoming time—after another period of waiting—and finally show us the first fruits of our experiment.

From this fruit we shall raise a new generation of seedlings which will reveal to us beyond peradventure a varied assortment of ancestral traits that the parental forms of our first hybridization did not show. And from among these diversified forms, we shall be able, by a long series of selections and new hybridizations, to make our way toward the attainment of our original idea.

The precise steps and the varying details through which this may be attained, will be discussed in other chapters. Here we are concerned only with the general outline, and, this having been presented, we may leave our cherry in this interesting stage of partial construction.

To be sure we have not seemingly advanced very far toward our ideal in these two generations; but in this our case is only comparable, after all, to that of the architect, who, when he has planned a building that shall ultimately tower toward the skies, must be content to see the workmen first begin digging in the opposite direction, to lay foundations far beneath the earth's surface.

This matter of the very doubtful result of the first stages of a hybridizing experiment should be emphasized, because otherwise the amateur is pretty sure to become discouraged at the outset and to proceed no farther.

Many an experimenter has given up a quest because when the two varieties of plant were crossed the offspring seemed inferior as to the desired quality to either of the parents. But the experienced plant breeder knows that this is very often to be expected and that he should not be in the least discouraged by this result. It is necessary to go on to the next generation before we can hope to discover the real possibilities of the experiment.

The simple fact is that, where varieties or species of plants that differ markedly as to certain qualities are hybridized, the offspring very frequently seems to present what has been spoken of as a mosaic of characters rather than a blending. It may and very commonly does manifest, as regards any given quality, the influence of one parent seemingly to the exclusion of the other.

A familiar illustration of the same rule may be observed when a person having black eyes marries one having blue eyes. It is obvious that no individual child of this union can have both black eyes and blue eyes. In point of fact, it is a

The Chinese Pear

The Oriental pears have not the characteristic shape of the European pear. The latter was presumably modified in shape through selection at a comparatively recent period. It is supposed that the original home of the pear was Central Asia, and that the fruit was carried into Europe in prehistoric times. The pear is characterized by having a fibrous or woody deposit in the skin, indicated by the dotted appearance of this Oriental specimen.

matter of common observation that the offspring in such a case will have dark eyes.

But it has also been observed that the blue eyes of one of the parents may reappear in the second generation.

The tendency to blue eyes was entirely subordinated or submerged in one generation, yet it was by no means eliminated, as its reappearance in the next generation clearly proves.

Similar instances without number may be studied from our plant experiments; for example, the case of the white blackberry. If flowers of this kind are fructified with pollen from flowers of a blackberry of the usual color, the hybrid progeny of the first generation will all bear black fruit.

The quality of blackness has proved prepotent or dominant, and the opposed quality of whiteness has been totally subordinated so far as this generation is concerned.

But if these black hybrid blackberries are cross-fertilized, from the seed thus produced there will spring a generation of brambles, some members of which will in due season produce white fruit precisely like that of the maternal ancestor.

Such, it will be recalled, was indeed the experience in the development of my new race of white blackberries.

To instill good qualities of fruit into the inferior original berry, it was necessary to cross with the large and well flavored Lawton blackberry.

The immediate result was seemingly to obliterate the white-fruiting tendency altogether.

But a wide experience of similar instances led me to continue the experiment, which for the moment seemed to be carrying me away from my ideal of a white blackberry; and the principle of reversion came to my aid in the next generation and gave me, as will be recalled, a berry that combined the light color of one of its grandparents with the size and flavor of the other.

I have already suggested that it aids the memory, and helps to give tangibility to the facts, to recall the Mendelian phrase which speaks of blackness versus whiteness in such a case as constituting a pair of unit characters; naming blackness as the dominant and whiteness as the recessive feature; and which gives us assurance that a fruit which shows the recessive character of whiteness in the second generation will thereafter breed true, thus affording us evidence of definite progress toward the ideal of our experiment.

Aid From Unit Characters

As the principles that govern these cases are of very wide application, it follows that there is very great advantage from the standpoint of the plant developer, in the discovery of pairs of unit characters and the demonstration of their relation toward each other as regards dominance and recessiveness.

An interesting illustration of this is afforded by the experiments made by Professor R. F. Biffin, of Cambridge University, in the successful attempt to develop a new race of wheat.

Professor Biffin through a series of experiments showed that when beardless ears of wheat are crossed with bearded ones, the beardless condition proves dominant, so that all the offspring are smooth-eared; but that the recessive quality of bearded grain reappears in the second generation.

The same thing held true for various other pairs of unit characters, such as red chaff versus white chaff, red grain versus white grain, hollow stem versus solid stem, and the like.

Professor Biffin was able to make an immediate practical application of his experiments through which he developed a new race of wheat that is proving of great economic importance. It appears that the best races of British wheat have been peculiarly susceptible to the fungous pest known as rust. There are, somehow, certain races

Pears with Blended Heredities

When Mr. Burbank blends the strains of pears from the Orient and Occident, the hybrid offspring show wide variation of form and texture and flavor, particularly in the second and subsequent generations. This picture shows characteristic specimens of such mixed heritage—good material for the development of new varieties.

of wheat that are immune to the pest; but unfortunately these produce a very poor quality of grain.

Professor Biffin found that susceptibility and immunity to rust constitute a pair of unit characters, in which susceptibility is prepotent or dominant.

When he crossed the susceptible grain with the immune one, he therefore produced an entire generation of susceptible grain.

His experiment had seemingly gone backward, quite as in the case of my first generation of white blackberries.

But in the ensuing generation the recessive character of immunity reasserted itself; and, combined with this desired character, in a certain proportion of the progeny, there appeared the other desired quality of a good head of grain of fine quality.

So by the application of this principle of the segregation and recombination of unit characters Professor Biffin produced a new race of wheat in two or three generations, and this new race of wheat breeds true.

We shall see this principle illustrated over and over in connection with the long series of my plant experiments.

In case of the wheat, as in that of my white blackberry, the process was relatively simple because we were dealing only with two pairs of unit characters. Moreover, the case of wheat is further simplified by the fact that this plant is self-fertilized and under conditions of cultivation has become a very fixed race, little subject to variation.

When we deal with races of fruits that tend to vary almost indefinitely, and when further we are concerned with ten or a dozen unit characters, the matter becomes vastly more involved, as we have previously seen illustrated.

But the amateur will do well to begin his experiments with simple cases, dealing with only a single quality, say a particular color of flower, that he may thus learn to distinguish the principles here enunciated. In due course he may go on to apply these principles to more complicated experiments in plant hybridization. But unless he learns at the outset that certain characters that are submerged in the first hybrid generation will inevitably reappear in the second, he will constantly blunder in his interpretation of tentative results.

On the other hand, when he has learned to gauge his second-generation hybrids correctly, he is on the highway to success as a plant experimenter.

Common, French, and Burbank Marigolds

The large double Burbank marigolds have been developed from the small single flowers through selective breeding. By cross-fertilizing different varieties, a tendency to variation is induced, and by preserving for seed purposes only those flowers which vary in the desired direction, any given quality is accentuated, until finally such a metamorphosis as this is brought about. The rapidity of development varies with different plants, but many generations are required to produce such a transformation as that shown in this picture.

PLANT AFFINITIES

CHOOSING THE LINES OF LEAST RESISTANCE

"WHY do not plants hybridize in a state of nature?" a visitor asked me. "You seem to get most of your new varieties by hybridizing old ones. Why does not Nature take a leaf from your note-book and produce new species in the same way?"

And I was able to inform my facetious questioner, much to his surprise, that the method he suggested was one that Nature had practiced from the beginning, and is constantly practicing all about us.

We were standing near the gateway of my Sebastopol place. I pointed out across the road.

"Why, just over by the roadside," I said, "you may see for yourself precisely such an experiment in hybridizing as I have made in the case of thousands of plants. Do you see those tarweeds there? Doubtless you are familiar with them.

[VOLUME III—CHAPTER II]

"There are two common species growing there together. One of them has large showy flowers, the other small and inconspicuous ones. The botanist calls the large flowered species *Madia elegans,* and the other *M. sativa.* The two species do not look much alike, and some botanists even classify them in different genera.

"If you look at all closely you will see that there is a third form of plant, bearing some resemblance to each of them, growing among the others, and I can assure you that this is a natural hybrid between the two.

"If you examine this hybrid, you will find that its branches are less spreading than those of its large-flowered parent, although not upright like those of the other parent; and that the stem is stouter than that of either parent. As to foliage, the hybrid plants have larger and thicker leaves than those of the large flowered tarweed, more closely resembling the other species in this respect, but the ray-flowers are intermediate in size and shape as well as color, the reddish-brown that characterizes the flower of the more conspicuous parent being reduced in the hybrid to a spot just in the top of the tube.

"So here you are probably witnessing the creation of a new species in nature: You, of course, are an evolutionist and therefore are

Hybrid Corn

A second-generation hybrid between the Indian corn and a primitive sub-tropical species called teosinte, which is believed to be the type from which the cultivated corn was developed. Mr. Burbank has made extensive experiments with this interesting primitive corn, some of the results of which are shown in other pictures in this volume.

aware that all species of plants as well as animals have been evolved in past ages by a development from earlier forms, but you very probably supposed that this creative process has now come to a standstill. Let me assure you, then, that this process is going on to-day very actively, in all probability quite as actively as at any time in the past.

"Species of plants in a state of nature are constantly hybridizing, and new species are being developed under our eyes.

"There is nothing anomalous about the case of the tarweeds, although they afford a very interesting illustration of the development of which I speak. The same thing may be observed in the case of certain genera of the mint family. Here in some cases the hybrids thrive almost to the entire exclusion of the parent species. In other cases they gradually disappear, being too unstaple to establish themselves by seed.

"Everything, of course, depends upon the qualities of the hybrid. If it is well adapted to the environment it survives. If better adapted than its parents, it probably runs them out altogether. But, on the other hand, if the hybrid is less well adapted than the parent forms to make its way in the world, it is of course weeded out by natural selection."

In response to a further query, I named for my visitor, among plants that often hybridize in a state of nature, the various species of the genus *Rubus*, including the blackberry, raspberry, the tribe of wild roses and crabapples; the California lilac, the various members of the oak tribe, the willow, the strawberry and the huckleberry; nor are these all—the list might be almost indefinitely extended.

Indeed, it is my firm conviction that hybridizing between natural species is a phenomenon of almost universal occurrence.

I believe that no other equally plausible explanation has been given of the appearance of seeming spontaneous varieties or mutations that furnish the material for the operation of natural selection, and are thus the basis of organic evolution.

It is true that such a suggestion as this would have seemed heretical not very long ago; but vast numbers of experiments in hybridizing different species, and even representatives of different genera, in my orchards and gardens have afforded a mass of evidence that no one can ignore. So to-day it is coming to be recognized more and more generally that the hybridizing of wild species is Nature's conventional method of producing variability, and, as it were, testing out the environment by supplying new forms that come in competition with the ones already developed.

LIMITS OF HYBRIDIZING

But why then, you will perhaps ask, does not the production of new forms between natural species take place so universally as to disturb the entire scheme of organic nature. In point of fact, the zoologist and the botanist are able to describe vast numbers of species, each of which has certain fairly well-defined characteristics and differs in certain definite regards from other forms.

It is true that the more closely the matter is studied the more commonly varieties are found that manifest characteristics intermediate between those of the supposedly fixed species. But even when these are taken into consideration, it still remains true that the word "species" as applied to a vast number of familiar forms of vegetable and animal life, has a pretty definite and tangible meaning.

How is this possible, if the interbreeding of species is a universal phenomenon?

The answer is found in the facts (1) that the hybrid forms produced when species in nature are crossed, for the most part quickly disappear because they are not an improvement, from the standpoint of adaptation to their environment,

Ten Corn Variations

The smallest figure shows the grain of the teosinte, the primitive type of corn. The other figures show a gradation between this primitive form and the perfected field corn, as developed through hybridization. We may suppose that the corn passed through some such stages as these in the course of its evolutionary development.

on the parent forms; and (2) that limits are imposed by the relative lack of affinity of one species for another.

As to the first point, it must be recalled that each existing species has been produced only after long generations of struggling against adverse conditions. Constantly there is a tendency to variation within certain limits even in the case of the most fixed species. Such variations constitute tests of the fitness of the species to live in the environment in which it finds itself. Favorable variations are preserved by natural selection, simply because they have the capacity to outgrow the original form, or outlast it in times of drought or other hardship.

And so every existing wild species proves by the very fact of its existence that it has a large measure of adaptability to the existing environment.

It is always improbable, then, in the nature of the case, that any new intermediate form such as would arise from hybridizing two allied species, will be better adapted to survive than the parent form. Such cases do arise, else we should have no new species, but in general the rule holds. So we may fairly count it exceptional if a hybrid between natural species survives beyond the first or second generation.

The struggle for existence is always keen, and the individual organism that lacks ever so little of equaling its fellows in vitality and responsiveness to its environment must inevitably perish.

Nevertheless, the experiment of producing new forms through the hybridizing of old ones is perpetually being made, and must continue to be made, if existing forms are to remain plastic, ready to take advantage of the changed conditions of environment; ready, that is to say, to evolve in future as they have evolved in the past.

But there are limits beyond which this perpetual experimentation with new nascent species could not advantageously be carried, and so nature puts a sharp limitation upon the extent to which the experiment may be undertaken.

Affinity Founded on Cousinship

And this is done by the simple procedure of making it increasingly difficult for species to interbreed in proportion as the species become divergent in character.

Tarweeds, for example, may interbreed among themselves, and various species of mint may similarly interbreed, but no species of tarweed could hybridize with a species of mint. One member of the rose family may hybridize with another—blackberry with raspberry, let us say, or quince with apple; and in the same way different species of oak may interbreed; but the hybridizing of apple or blackberry with any species of oak is almost unthinkable.

Similarly, in my experiments I have been able to hybridize peach with almond, and almond with plum, and plum with apricot; also apple with quince, and quince with pear. Stone fruit with stone fruit, that is to say, and seed fruit with seed fruit—but never stone fruit with seed fruit.

In a word, the possibility of cross-fertilization between species is conditioned on a certain closeness of relationship, which we speak of as affinity.

This, as the evolutionist teaches us, is a matter of actual genetic relationship. All members of the rose family, for example, have branched from the primal ancestral stem at a period much more recent than that at which the common ancestor of the present-day apple and rose and blackberry branched from the primal stock of, let us say, the oaks.

In the broadest view, there is a cousinship between all species of plants; just as there is relationship between all the twigs of an actual tree. But the species of an existing genus may be likened to twigs on a single branch; other genera representing different branches which may diverge in opposite directions, and only come together at the trunk.

Corn Tassels Bearing Kernels

Among the most interesting of Mr. Burbank's experiments with corn are those in which the tassel of the corn, which in the cultivated plant bears pollen only, has been induced to develop pistillate flowers and seeds. This is a reversion to the ancestral form in which the seeds were borne at the tip of the stalk, as is still the case with most other grasses.

Then, too, there is a time element involved.

Species that are closely similar in appearance are those that have branched from the ancestral stem in relatively recent epochs; species more distinct trace their cousinship through remoter lines; and forms so widely diverse as to be placed in different orders have been separated for still longer periods. And we must suppose that in each generation the new forms have taken on a modicum of new traits, and have tended to fix the divergence of earlier traits through which they attained specific difference.

In due course, then, it comes to pass, that a given form has branched so widely from its cousins that the harmony of purpose, so to speak, that once obtained between them no longer obtains.

The racial memory as to their common ancestry has become blurred, if the phrase be permitted, and each species has become so fixed in its own manner of life that no compromise between them would be possible.

And so we find, in point of fact, that it becomes increasingly difficult to hybridize species that are obviously widely divergent in form of stem and foliage and flower, and that in a vast number of instances any attempt to hybridize these forms is altogether futile.

It must be understood, however, that it is by no means always possible to predicate, from observation of a given pair of more or less distantly related species, whether or not the two would be mutually sterile. Sometimes the experiment results in a surprise, and we are able to produce offspring when the cross seemed altogether improbable.

Such was the case, it will be recalled, with my experiments in hybridizing the dewberry with the pollen of the apple and pear and rose and mountain-ash. Such was the case also with the cross which resulted in producing the sunberry, and with that which developed the plumcot.

In each of these cases, to be sure, the pistil of one plant accepted the pollen of the other, as it were, unwillingly. But persistent effort effected the desired result, and in the three instances last mentioned fertile offspring were produced. Possibly these might not have survived in the state of nature, but under the conditions of artificial selection they provided the foundation for the development of what may fairly be considered new species.

Plant Antagonisms

The characteristics that make it impossible to hybridize two species that have varied beyond certain limits are sometimes physical.

Thus it may chance that the two species have developed the habit of blooming at different times. If the flowers of a given species are altogether out of bloom before the flowers of another species open, it is obvious that, in a state of nature, hybridizing between these species will never occur, however close their affinity. Similarly there are two closely related species of evening primrose that are not hybridized under natural conditions because the flower of one opens only for a brief period at midday and that of the other only during the night.

Again it occasionally happens that the physical structure of the style which carries the pollen tube to the ovules is such as to prevent the carrying out of this essential process. In the case of a large pollen grain and an exceptionally slender style, it is probable that the fructifying substance of the pollen is debarred from finding its way to the ovule.

Such cases are probably exceptional, however, and the usual barrier erected by Nature between species is not so much physical as chemical. That is to say, the antagonism is inherent in the plants themselves.

Allied species are of such chemical constitution that the protoplasm from one mingles readily with protoplasm from the other.

Corn Tassel Growing From the Ear

This reverses the condition shown on page 41. Here also the pollen-bearing tassel and the grain-forming ovules are together, but they are located in the axils of the leaves instead of at the tip of the stalk. This anomaly illustrates the mixing up of hereditary tendencies that may take place when different species are hybridized. The mingling of the strains of the primitive Teosinte and the cultivated corn brings out latent hereditary tendencies.

In the case of more widely divergent species, it may come to pass that the juices of one plant are actually poisonous to another. In such a case it is futile for the pollen grain and pistil to meet, because no fertilizing influence will be transmitted.

Even if the degree of chemical antagonism developed has not reached a stage that makes fertilization wholly impossible, it may be sufficient to prevent the development of a thrifty offspring.

Or, as is quite usual, it may result in the sterility of the hybrid progeny, and thus put a barrier upon farther advance along that line.

If proof were needed that such a chemical antagonism prevents the cross-fertilization of species separated too widely, further evidence may be found in the negative results that attend the attempt to graft a branch of one of these species upon the stock of the other.

Generally speaking, it will be found that species that cannot be cross-fertilized, also cannot be cross-grafted.

In exceptional cases, it is possible to effect the graft where efforts at hybridization have proved futile. Such was the case, for example, with my grafted tomato and potato vine. But in general, the plant that refuses to mate with another plant refuses also to accept its stem as a companion organism when grafted or budded.

However carefully the grafting experiment may be performed in such a case, the uncongeniality between stock and cion is soon made manifest. The surfaces do not unite; or if union takes place there is but slight tendency to grow; or the cion does not thrive, and is presently blighted.

There are all gradations—from actual poisoning in which there is no tendency whatever to unite, to a partial or even temporarily complete union, followed by separation even after years of growth—according to the degree of antagonism.

This chemical antagonism between the tissues of the plants themselves affords the surest evidence of the long periods of time during which the two species have lived under more or less divergent conditions, and have been occupied, each in its own way, in the development of new characteristics. Yet that such intimate differences of constitution should obtain between species that show many outward points of resemblance must always be matter for surprise to the plant lover whose attention is called to it for the first time.

That this intimate record of grades of cousinship should be permanently graven in the protoplasm of the plant itself is one of the most mystifying and thought-compelling of biological revelations.

If any one were to doubt that the intimate chemical structure of plant protoplasm and plant juices may thus be depended on to reveal genetic relationships, and to mark nice shades of distinction between allied forms, evidence from a quite alien field might be cited that would set the matter at rest.

Evidence From the Animal World

The evidence in question is furnished by an extraordinary series of blood tests through which Dr. G. H. F. Nuttall, the American Professor of Biology at Cambridge University, has traced the intimate relationship of large numbers of animals of different orders.

By inoculating rabbits with the blood of different species of birds, reptiles, and mammals, Dr. Nuttall was able to develop an extraordinary serum with which the intimate constitution of the blood of other species of animals could be tested. He thus demonstrated, for example, that lizards and serpents are more closely related than turtles and crocodiles, but that all these reptiles are nearer to one another than they are to birds, and nearer to birds than to mammals.

He showed that the dog carries in every drop of its blood chemical proof of closer relationship

Corn Seventeen
Feet High

Corn was originally a sub-tropical plant, and the primitive teosinte is a plant of tall growth. By hybridization and selection, Mr. Burbank has developed this race of corn, which grows with tropical luxuriance, reaching a height of seventeen feet.

with wolves, and foxes, and jackals of every species than with any member whatever of the cat family. Similarly, all cats—tigers, lions, leopards, along with the domestic tabby—give proof, in the chemical constitution of their blood, of a common origin. And, bringing the comparison still nearer home, the blood of man is more like that of the chimpanzee, the gorilla, and the orang, than it is like that of any other creatures; and the monkey tribes of the Old World are more manlike in the constitution of their blood than are the monkeys of the New World.

Dr. Nuttall's experiments comprised sixteen thousand individual tests, with a total of at least 586 species of mammals, birds, reptiles, batrachians, fishes, and crustaceans, coming from all parts of the globe. The biological implications of his experiments have been commented upon as follows:

"Doubtless some hundreds of thousands of years have elapsed since the direct ancestors of men branched from a common stem with the direct ancestors of the gorilla. There has been no blending of blood in the intervening centuries. Cats have been cats and dogs dogs from geological epochs so remote that we hesitate to guess their span in terms of years. So the intimate chemical qualities that denote man or ape or cat or dog, each in contradistinction to all the others, must have been transmitted unmodified through countless thousands of generations.

"It taxes credulity to believe that such intangible properties could be transmitted unmodified through the blood streams of such myriads of individuals; but the evidence of the test-tubes proves that this has been done.

"What makes the marvel greater is the fact that the bodies of the animals have meantime been so modified as to develop utterly divergent species—for example, the lion, the tiger, the puma, the leopard, and the house cat; different types of dogs, wolves, foxes and their allies. But in each case some intangible quality of the blood remains unchanged to prove the common origin. Blood is indeed thicker than water."

The bearing of these extraordinary experiments upon the case in hand will be obvious.

If animals carry in their veins generation after generation, through untold thousands of years, these intimate chemical conditions, then the same thing may well be supposed to be true of plants. And so the affinity shown between species that can be hybridized, and the antagonism between species that refuse to hybridize, can be explained on the basis of a fundamental intrinsic quality of the protoplasm that is the foundation substance of life.

This gives us a more profound and comprehensive appreciation of the word "affinity" as applied to various species of plants than we could otherwise have.

It also makes it in a measure comprehensible that the traits of remote ancestors should be carried latent in the tissues of the germ-plasm, as we have seen that they are carried, for untold generations.

The Continuity of the Germ-Plasm

This germ-plasm, which is the connecting link between one generation and another, is passed on, according to the prevalent idea, from parent to offspring, generation after generation, subject only to such modifications as may from time to time be imposed through environing influences.

The physical mechanism that underlies this transfer we shall have occasion to examine in another connection when we discuss at some length the theories of heredity. For the moment it is enough to reflect that as the offspring in each successive generation spring from the substance of the parent, the germ-plasm may be thought of as a continuous stream uniting the remotest ancestor of any given strain with the most recent descendant.

A Mosaic Leaf

When a purple-leaved plum is hybridized with a green-leaved plum, the hybrids of the first generation have green leaves, but purple leaves reappear among the varying hybrids of the second generation. Occasionally, however, a cross between purple-leaved and green-leaved varieties, where the varieties lie near the limits of affinity, results in a condition that might be described as a mosaic, the leaves partaking of the characteristics of both ancestral strains. This picture illustrates such a case.

Every tree in the orchard, for example, carries within its tissues a portion of protoplasmic matter that has come down to it through an almost infinite series of growths and divisions in unbroken succession from the first tree that ever developed on the earth—or, for that matter, from a vast series of more primitive organisms that were the progenitors of the first tree.

And while this stream of primordial protoplasm has been changed by an infinitesimal quantity in each successive era, it has retained even to the present the fundamental characteristics that it had from the outset.

That such is the case seems little less than a miracle; that an almost microscopical speck of protoplasm which we term a pollen grain should contain the potentialities of thousands of generations of ancestors, and should be able to transmit them with such force that the seed growing from the ovule fertilized by that pollen grain will inevitably produce, let us say, an apple tree, not a pear tree or a plum, is beyond comprehension.

Yet we know it to be true.

And so the plant hybridizer who consciously merges two different protoplasmic streams when he brings the pollen of one flower to the pistil of another, participates in what must be considered the most wonderful of all experiments.

He brings tokens out of an almost infinite past to blend with the divergent tokens of another ancestral stream no less ancient.

And it is not strange if he feels a certain impulse of elation when he reflects that his conscious efforts have thus brought together ancestral tendencies that have long been separated and that now will appear in new combinations—stimulating such interplay of life-forces as may bring into being plant forms that may be described, without violence to the use of words, as new creations.

—That the intimate record of cousinship, in all its grades, should be permanently graven in the protoplasm of every living thing, is a thought-compelling biological revelation.

A Shirley Poppy—Showing Reproductive Organs

The petals of a flower are designed to attract insects. The essential organs are the pollen-bearing stamens and the pistil joining the ovule at the center of the flower. This picture shows the large number of stamens of the poppy, each with a terminal anther, bearing pollen, growing in a circle about the pistil with its curiously rounded end, called a stigma, designed to receive the pollen. The office of the insect is to transfer pollen from the stamens of one flower to the pistil of another.

PRACTICAL POLLENATION

A SURVEY OF WORKING METHODS

ONCE upon a time—it may have been about the year five million B. C.—a plant imbued with nascent wisdom made a tacit compact with a fellow creature of the world at large that was fraught with strange and fateful meanings for races of beings yet unborn.

The fellow creature in question was at that time probably the most highly developed citizen of the world, although in modern terminology he would be termed "merely an insect." The compact the plant made with him was to the effect that one should manufacture sweet nectar and freely supply it as food; and that the other in return should carry the fructifying pollen grains from flower to flower.

Doubtless no more important compact was ever entered into in the history of animate creation before or since.

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For out of this compact grew the rivalry that stimulated development and made possible the evolution of the whole race of plants that bear beautiful flowers and exhale sweet perfumes. But for this eventful alliance, there would never have developed in the world a conspicuously colored or a scented flower of any kind.

And it requires no argument to show that a world without beautiful and sweet-scented flowers would be a world robbed of a large share of its attractions as an abiding place.

But that is not all. The alliance between insect and flower did not merely suffice to give us things of beauty. It bespoke utility as well. It made possible the bringing together of germ-plasms from plants growing far apart, thus insuring virile and variant strains; and this determined in large measure the amount and direction of the evolution of the highest orders of plants.

For it must be observed that, with rare exceptions, the higher plants are precisely those that long ago entered into this coöperative scheme whereby they trusted their fate absolutely to the insects. They hazarded much—for if anything should lead to the destruction of a few insect races, entire orders of plants would suffer race suicide. But if they risked much, they also profited much; for the cross-pollenizing effected

The Stigma of a Poppy, Greatly Enlarged

The stigma of the flower may be variously modified to facilitate reception of the pollen. This picture shows the curious arrangement in the case of a poppy. The pollen grains deposited on this stigmatic surface send out little tubes that penetrate the stigma and ultimately make their way to the ovule or seed case, carrying the nucleus that unites with the nuclues of the egg cell, thus effecting fertilization. Each egg cell is fertilized by a single pollen nucleus.

by the insects afforded the constant stimulus to variation that underlies all evolution, and enabled the plants that entered into the coalition presently to outstrip their fellows.

Wherever you find a tribe of plants that shows great diversity of form, large numbers of species, and ready adaptability to improvement, you will as a rule find a tribe of so-called "entomophilous," or insect-loving flowers, dependent upon the winged messengers for the consummation of their matings.

Vast responsibilities then were implied in this coalition of the plants and the insects; but the results have justified the hazard.

Plants That Did Not Join the Union

We shall presently see illustrated in detail the curious adaptations of form and color and structure to which the plants of various species were led in their rivalry to secure the good graces of the insects and thus to make sure of perpetuating their species.

Every blossom of the entire orchard, every flower of the garden, and with a few exceptions all of the vegetables under cultivation furnish illustrations in point. But it should be recalled that there are large numbers of plants of a lower order that from the outset refused to enter into the coalition, and that even to this day have declared themselves independent of the plant-insect union.

Plants of this non-union clan are the entire races of lowly mosses and lichens; a goodly number of aquatic forms that maintain the appearance and manner of their remote ancestors; and the familiar tribe of ferns; and some of the trees which depend mainly upon the wind.

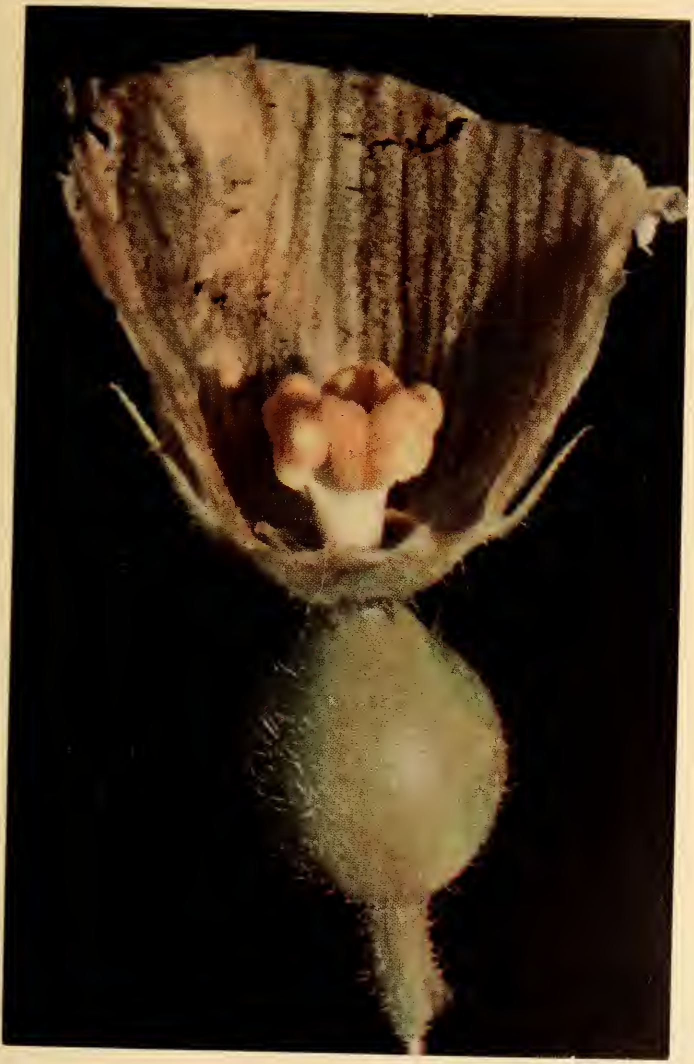
All of these, and a large company of forms less familiar to the amateur, have obstinately retained throughout the ages the primeval habit of propagating their kind not with immobile pollen grains but with the aid of self-moving germ-cells. These motile germ-cells, of microscopic size, find their way through the water—supplied in case of land plants by a film of rain or of dew—from one plant to another, and effect cross-fertilization without calling in the aid of any allies. They do not need to attract insects, and so they have not adopted the system of advertising through the development of large and showy blossoms and nectar cups to which the members of the plant-insect alliance are obliged to resort.

But if the lowly plants thus maintained their independence, they have done so at a very great sacrifice.

They are not more independent than they are unprogressive; and indeed they are unprogressive

Pollen-Bearing Pumpkin Blossom

Many plants bear pollen and ovule on separate blossoms, so that self-fertilization is impossible. They are said to be dioecious. This picture shows a pumpkin blossom with the modified and coalesced stamens at its center bearing a quantity of pollen. The insects in visiting the blossom carry the pollen on their bodies or feet and transfer it to other flowers.



Seed-Bearing Pumpkin Blossom

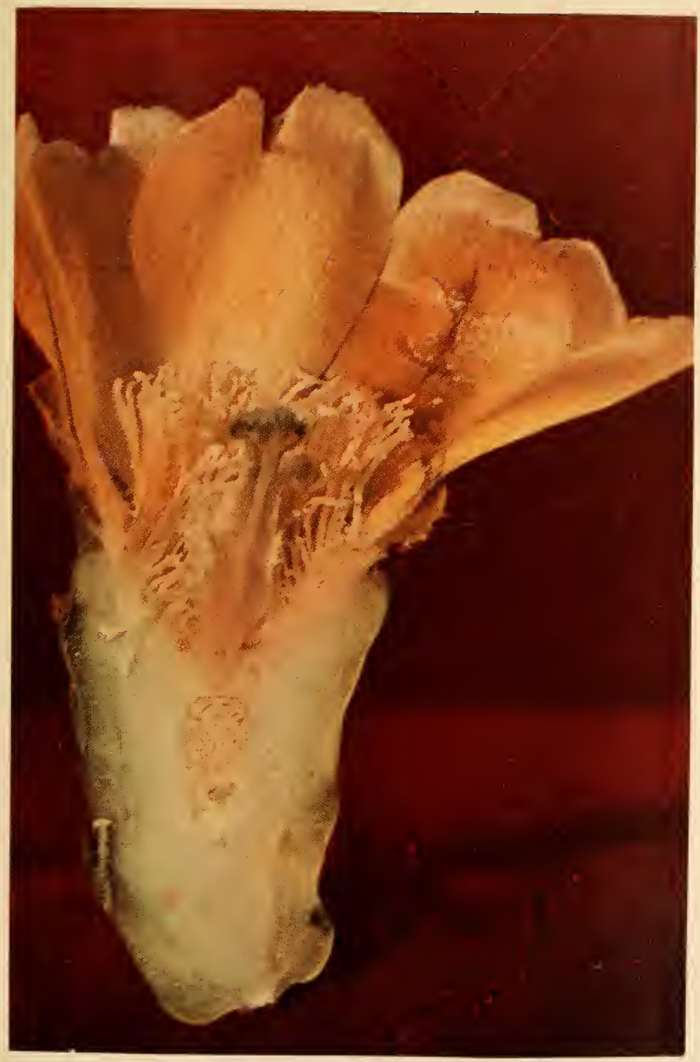
This blossom is the mate of the one shown on the opposite page. The stigma to receive the pollen occupies the same position that is occupied by the pollen-bearer in the other flower. The bulbous growth at the base of the flower is the ovary, or seed case, which, if the flower is fertilized, will develop into a pumpkin.

precisely because of their independence. The method of cross-fertilization that they have adopted does indeed enable some of them to blend the strains of different individual plants; but in every instance the parents must be growing in the immediate vicinity of each other.

Except by the accidental and most unusual transfer of a plant through the agency of a passing animal, there is hardly the remotest chance of effecting cross-fertilization between individual mosses or lichens or ferns growing in widely separated regions.

But we have already seen that it is precisely this blending of traits brought from parents growing under different environing conditions that is chiefly responsible for making plants vary and furnishing the materials for evolutionary progress. So it goes without saying that the plants that are restricted, in the choice of possible mates, to individuals growing under the same conditions to which they themselves are subjected, cannot expect to change rapidly and therefore do not evolve in any such ratio as plants having the other habit.

And in point of fact we find that the plants that retain this primitive custom of fertilization with the aid of motile germ cells, acting quite independently of insect or wind, are plants of a



Cross-Section of a Cactus Blossom

This is what is called a perfect flower—that is to say one that has both stamens and pistil. The stamens are grouped in a circle about the pistil, as in case of the poppy, this being the typical arrangement. The picture shows the seed case or ovary at the base of the pistil. Each ovule must receive the nucleus of a pollen grain or it will not develop. Where the stamens are thus clustered about the pistil, cross-fertilization is usually prevented by the maturing of the two sets of organs at different periods.

low order of development, showing relatively little diversity of form and small capacity for adaptation.

The most conspicuous of them with which the ordinary observer is familiar, namely the ferns, bear a striking resemblance in contour to plants of the remote Carboniferous Era, traces of which have been preserved in the coal beds. And there can be no doubt that this persistence of the primitive form has been largely due to the special method of fertilization which the ferns have retained.

If it be permitted to carry personification one stage farther, we might say that the ancestors of the ferns belonged to a conservative family, jealous of its independence, and unwilling to enter into outside alliances.

And the penalty of conservatism here, as so often in the range of human experience, has been racial stasis.

Plants That Have Left the Union

It would appear, however, that there are certain races of plants that were once members of the plant-insect alliance but which are now no longer in the union.

These apostates include two quite different tribes of plants.

On one hand there are numerous gigantic

trees that no longer depend upon insects for the fertilization of their flowers.

On the other hand there are little cowering plant-waifs that nestle close to the earth and which, in quite a different manner, also assert their independence.

The trees that have thus revoked the treaty of alliance include such familiar forms as the pine, the oak and the walnut.

These trees, and a goodly number of their fellows, long ago declared against further coöperation with the insect, and adopted the method of producing large quantities of pollen and scattering it in the air to be carried by the wind to the pistillate flowers, which in some cases grow on neighboring branches and in other cases on quite different trees.

The method is in one sense wasteful, inasmuch as it involves the production of vast quantities of pollen, only an infinitesimal portion of which will ever come in contact with a receptive pistil. And of course the production of this pollen must draw heavily on the energies of the living substance of the tree.

But on the other hand the tree that thus depends upon the wind rather than upon the insects is under no necessity to develop large and conspicuously painted flowers. Nor need it

Two Gourd Blossoms to be Pollenated

The Gourd belongs to the same family as the pumpkin, and, like that plant, bears the staminate and pistillate flowers separately. This arrangement makes it very easy to effect hybridization. Gourds and other squashes are cross-fertilized so readily that different species must be grown far apart if the strains are to be kept pure.

Pollenating the Gourd Blossoms

To effect fertilization, nothing more is necessary than to pluck a staminate flower, pulling away its corolla, to expose the pollen-bearing surface, and to insert this in the pistillate flower, gently dusting the stigma with pollen. The facility with which this may be effected makes the members of this family very attractive to the amateur experimenter.

produce nectar to feed the insect allies, since these have been renounced. And it may very well chance that the saving of energy thus effected more than counterbalances the waste through excessive pollen production.

At all events the plants that have adopted this system of pollenizing give evidence that their plan is not a bad one in the very fact of their extreme abundance.

Moreover the "wind-loving" or "anemophilous" plants, as the botanist terms them, have not only produced a great variety of species and vast numbers of individuals, making up the bulk of our forests, but the individuals themselves are of such virility of constitution as to attain gigantic size. Indeed a moment's consideration makes it clear that the plants that had depended on the wind rather than on insects for fertilization are quite in a class by themselves in the matter of size, inasmuch as they constitute the bulk of our forest trees.

This relation between size and habit of spreading the pollen broadcast on the winds cannot be altogether accidental.

But whether the trees grew large because they had given up the alliance with the insects, or whether they gave up the alliance because they were growing large, it would be hard to say.

We know that, in the main, insects tend to keep near the surface of the earth, and it may be that the plants that tended to grow very tall were relatively neglected by the insect messengers. But on the other hand, there are insects that haunt the highest trees, and we can hardly doubt that had even the tallest of plants desired to retain the services of insect messengers, races of these would have been developed that would have proved equal to the most exacting demands.

What seems on the whole most probable, then, is that the trees have changed their allegiance from insect messengers to wind because of the very nature of the conditions under which they grew.

By raising their heads high and higher into the air they obviously put themselves more in contact with the wind and thus make it increasingly possible to spread their pollen broadcast across wide stretches of territory.

As a matter of fact we know that the pollen of pine trees in particular may be carried almost in clouds for scores and even hundreds and hundreds of miles.

So there is every opportunity for the cross-fertilization of individual trees growing in widely separated territories; and there is therefore no restriction put upon the possibilities of progress and evolution for these large-growing plants in penalty for their renunciation of the services of insect messengers.

The case of the trees, then, simply illustrates the fact that there may be more than one way to effect a given purpose, and that a change of method may be no barrier to progress, even though the abandoned method still remains an admirable one for a vast coterie of organisms of slightly different habit.

SELF-FERTILIZED PLANTS

But the case of the other company of plants that have back-slidden from the insect alliance is altogether different.

The plants in question do not make up any great conspicuous tribe, comparable to the forest trees, but are a miscellaneous company of lowly vegetables of unrelated families. Familiar examples are the wheat of the fields, peas and beans in our garden, and a certain number of the more obscure species of violets.

The jewel weed, the fennel, the rue, and the nettle, are other somewhat less familiar yet not uncommon tribes of plants whose flowers are habitually self-fertilized.

There can be no question that these plants are the descendants of tribes that were at one time members of the plant-insect union. The fact that

Strawberry Blossom Ready for Pollenating

Some varieties of strawberries bear perfect flowers as illustrated in this specimen, and others have blossoms that bear the pistils separately. It is necessary, in cultivating the strawberry, to bear this in mind, and if a pistillate variety is planted there must be pollen-bearers in the neighboring rows, otherwise there would be no crop of berries. The bees are depended on to effect the transfer of pollen. In the perfect flowers, the stamens and pistils mature at different periods, to guard against self-fertilization.

most of them retain more or less conspicuous flowers proves this beyond question. In the case of the wheat, which might be thought a possible exception, there is the evidence of certain species of wild wheat, growing to this day in Palestine, which have only partially renounced allegiance to the insects, still putting forth flowers that on occasion may be cross-fertilized with their aid or with that of the wind.

Just why these various plants of different families have departed from the custom that has served their fellows so well, would be interesting matter for conjecture.

Perhaps the most plausible suggestion is that the ancestors of the plants that now have closed flowers and thus depend exclusively upon cross-fertilization had fallen on evil days in which there was a dearth of insect messengers in the regions they inhabited.

The story of the starved martins, told in an earlier chapter, furnishes a striking illustration of the fact that insects that ordinarily are abundant may in any given season fail to put in their appearance.

And even if the insects themselves are abundant, the weather conditions, in a given season, may be such as to make it almost impossible for them to carry out their bargain by transferring

Strawberry Plant After Pollenation

This shows Mr. Burbank's usual method of marking a plant that has been hand-pollenized. A record is made of the parent forms, and the seed will be preserved to carry forward the experiment.

pollen from flower to flower. Every orchardist knows that a protracted rainfall just at the time when his apple, pear or plum trees are in bloom, may prevent the bees from visiting the flowers; and in such case, as is only too well known, there will be a partial, or no crop that season.

With trees and other perennial plants it is not matter of absolutely vital importance that there should be a crop of seeds produced each season.

Failing progeny this year, next year or the year after will answer, in the case of a plant which grows on a permanent stalk or from roots outlast the winter.

But the case of the annual plant is altogether different.

Should such a plant fail for a single season to produce seed, its entire race would vanish instantly from the earth.

That thought is rather startling when presented thus tangibly.

Yet its truth is almost axiomatic. As a rule, the entire seed crop of an annual plant in a state of nature, either germinates or decays the ensuing season after its production. And it is absolutely incumbent on the plants that grow from this seed to produce in turn a store of seed that will carry on the racial stock.

So it is not strange that a plant that is thus perennially threatened with destruction should adopt exceptional measures to ensure the fertilization of its flowers.

Very often it may have happened that certain individual flowers that chanced to be self-fertilized were instrumental in saving the life of a species that otherwise would have been exterminated. And as, through the operation of heredity, the offspring of these flowers would tend to reproduce the self-fertilizing habit of their parent, the surviving representatives of the species might thus come to constitute a tribe in which the habit of bearing self-fertilized flowers was the prevailing custom.

And thus it is, perhaps, that the method of reproduction followed by the wheat in our fields and the peas and beans in our gardens may be accounted for.

Yet the fact that certain of these self-fertilized flowers, as for example the violet, retain the custom of putting forth showy flowers even though these for the most part are seedless, shows how powerful is the hold of remoter heredity, and how persistently the plant clings to a custom to which its ancestors owed their racial development. Moreover, it has been observed that the violet, when transplanted to a sunny spot and made accessible to insects, may resume the custom of growing seeds in its conspicuous flowers, whereas hitherto it had produced them only in the small inconspicuous bud-like flowers at its base which never open.

Schemes to Ensure Pollenation

It is curious to observe how insistent is the inherent demand for fertilization of the flower, and how even flowers that openly advertise for the insects may strive to provide for self-fertilization in the event that their call remains unanswered and in vain.

The common barberry *(Berberis vulgaris)* for example, opens and exposes its pollen-bearers only during the bright hours of a cloudless day. But in case an insect fails to visit it, provision is made that will ensure self-fertilization; for in due course the stamens dart forward and sprinkle their pollen over the pistil.

In the case of the fennel flower of France, described elsewhere, which does not open at all, the pistils bend forward when they are ripened, and after taking the pollen from the stamens, straighten up again.

With the rue, the arrangement is curiously complex and machine-like. Of the several stamens, each in turn bestows its pollen on the pistil at their common center. It has been

Balloon Berry Blossom

Such a flower as this is rather troublesome for the pollenizer, as its cluster of stamens must be removed, to make sure that self-fertilization does not occur. This may be effected with a small pair of pincers. The operation is not difficult, but it requires time. Of course care must be taken not to injure the stigma, which is to be fertilized with pollen from another flower.

observed that the stamens advance alternately, numbers one, three, and five in turn; numbers two, four, and six following in succession, as if the entire mechanism were actuated by clock work.

But these and sundry other ingenious mechanisms for self-fertilization after all only evidence the resourcefulness of a plant in its struggle for self-preservation.

It is better that a flower should be self-pollenized than that it should not be pollenized at all. But the process is in no wise comparable, in its value for the race, to the more usual process of cross-fertilization.

The self-fertilized plant develops fixity of race. It lacks the needed stimulus of the blending of different racial strains. It will produce few varieties, thus giving little opportunity for the operation of natural selection.

In a word, such a plant is really marked for ultimate extinction, unless, as in the case of the wheat, man steps in to give it the refuge of artificial selection.

It may well be doubted whether the existing races of cultivated wheat could perpetuate their species, if put upon their own resources in competition with wild plants, for a dozen or two dozen years.

Balloon Berry Bush After Pollenation

Here small paper bags have been tied loosely over the flowers that have been cross-fertilized. Mr. Burbank does not usually find it necessary to resort to this expedient, for if the stigma of a flower is entirely covered with pollen, there is little danger of subsequent contamination with other pollen. To make assurance doubly sure, however, the paper bags may be used, particularly by the amateur who operates on a small scale.

The habit of self-fertilization may preserve for a certain number of generations a plant that would otherwise have been completely exterminated; but at best it marks a stage of degeneration and decline. The plant that follows it is in a sense retracing its steps down the ladder of evolution by which its ancestors have made ascent.

And so it is not surprising to find that the vast majority of the useful plants of orchard and garden have kept up the traditional alliance with the insects to which they owe the multiplicity of their specific forms and the virility of the individual members of their organization.

THE WISEST OF PLANTS

It is flowers of the great brotherhood of insect-lovers, then, that chiefly claim the attention of the plant experimenter, because these are the ones that make up the chief census of orchard and garden.

As a matter of course it is plants of this fraternity that are of interest to the amateur, because, generally speaking, it is these alone that put forth blossoms that please the eye.

Whoever is interested to undertake experiments in plant breeding must then, familiarize himself with the mechanisms by which the plant makes known its appeal to the insect and those

Complete Kit of Pollenizing Tools

This shows all the apparatus required for the most elaborate series of experiments in cross-fertilization. The scapel is used sometimes to cut across unopened blossoms—for example, apple blossoms—in such a way as to remove the pollen-bearing anthers all at once. Where the form of the flower does not permit this, the pincers are used to pluck out the stamens. The watch crystal is used to collect pollen, which is transferred to the stigma of another flower either with the finger tip or with a camel's hair brush. The other implements are required exceptionally to manipulate a flower of peculiar form. The magnifying glasses are needed only with very small flowers. The use of the paper bags is illustrated on page 81. The cardboard labels are to record the experiment.

through which the perpetuation of its kind is effected; the mechanisms, that is to say, of the typical flower.

As we come to study flowers in detail, it will appear that among those dependent upon insect-fertilizers, no less than among the wind-fertilized, there are individuals that bear the essential organs of the flower in separate blossoms. Reference was made to this in the case of our hybridizing experiment with a certain species of dewberry, and we shall see other illustrations of it from time to time.

But the major part of the most familiar cultivated plants, including all the conspicuous fruit trees of our orchards, bear flowers each of which contains within the same blossom both the staminate and the pistillate organs.

Ordinarily it is the function of the bee to carry pollen from one blossom to the pistil of another. But on occasion even these flowers may be self-fertilized. Thus it may be said that the most important, from a human standpoint, among the existing plants have adopted a compromise, in which cross-fertilization is the rule, yet which makes possible self-fertilization in case, under the stress of circumstances, cross-fertilization should fail to take place.

Doubtless on the whole this was the best course of all. The plants that adopted it might be said to be the wisest of their race.

THE TYPICAL FLOWER

What may be regarded as the typical or perfect flower, then, is one that contains both pollen-bearing and pollen-receiving parts, surrounded by the conspicuous insect signal that we term the corolla; and having also a less conspicuous outer shield termed a calyx.

The calyx is the original shield about the flower bud, and its function is over when the flower opens.

The botanist ordinarily speaks of the calyx as a modified leaf. He refers to the petals of the corolla as being also modified leaves or enlarged and beautified modifications of the calyx. He thinks of the stamens and the pistil as modified petals; and he justifies this estimate by showing that under cultivation it is often possible to transform these essential organs into petals.

Thus, for example, are produced such double flowers as the cultivated rose and the chrysanthemum. To the human eye, these are things of beauty but from the standpoint of plant economy they must be regarded as travesties of flowers, since they are far less able and often wholly incapable of producing seed.

But it is perhaps a somewhat more philo-

Pollen-Bearing Grape

The members of the grape family, like the strawberry, differ as to the character of their flowers. Some plants bear perfect blossoms, others are staminate with at most a rudimentary ovary. The plant thus occupies an intermediate position between those plants that all bear perfect flowers and those that always bear the stamens and pistils on separate blossoms. The various arrangements suggest the need of cross-fertilization in the economy of plant life.

sophical view of the flower to consider it as a mechanism developed about the all-essential central organ, the pistil.

This, the female organ of the plant, consists, in the developed form, of a basal structure, the ovary, containing the ovules or embryo seeds, and a more or less protuberant style at the end of which is the stigma that receives the fertilizing pollen.

Considered as to its origin, the pistil is in effect a modified bud. Everyone is aware that individual buds of a plant may have the property of being able to reproduce the entire plant. The pistil is a modified bud each embryo seed of which, when fertilized, has the same potentiality.

By the most wonderful miracle of the organic world, this infinitesimal structure is enabled to epitomize all the possibilities of a future plant, of predetermined size and form and habit.

It differs from the bud from which it is developed chiefly in that it requires to be fertilized by union with a pollen cell, before it is capable of taking on development; and in the further very essential fact that when mature it may be cast off from its original moorings and carried to any distance, thus in a way making amends for the limitations put upon vegetables by their incapacity for locomotion.

The stamens that normally grow in a circle about the central pistil develop at their ends anthers that produce, usually in relatively large quantities, pollen grains of exceedingly minute size. And each pollen grain contains, somewhat as does each ovule, all the hereditary potentialities of the entire plant. The pollen grain cannot, indeed, be made to develop into a plant; but its union with the ovule is essential to the development of that organism, and it is certain that the pollen grain, despite its infinitesimal size, brings to the union factors that represent its parent plant effectively and in full measure.

It would be unbelievable, if we did not know it to be true, that a fleck of matter of scarcely more than microscopic size should contain the potentialities of a mammoth tree, and should predetermine the details of structure of a future tree even to its remotest leaf and to the finest details of its flowers and fruit. But that the pollen grain actually has these potentialities has been demonstrated thousands of times over by the plant experimenter.

Any amateur who wishes to test the matter may do so, to his complete satisfaction, by making the simplest experiment in cross-pollenizing and watching the growth of the hybrid seedlings his work brings forth.

Giant Artichoke in Blossom

The artichoke belongs to the family of Composites, in which numerous blossoms are grouped together to form a head with a single floral envelope. The daisy and the sunflower furnish familiar examples of this arrangement. The artichoke for eating is plucked before the blossoms are mature. If allowed to reach the stage shown in this picture, it is inedible. Mr. Burbank has developed new varieties of artichoke, the heads of which are of gigantic size.

The pollen grain effects union with the ovule by sending out a thread-like filament of protoplasm, like a tiny root, which penetrates the stigmatic surface, passes down along through the style, and carries the nucleus of the pollen grain to the nucleus of an ovule. When the two nuclei come in contact, fertilization has been accomplished.

When pistil and the stamens have been considered, we are through with the really essential mechanisms of the flower.

From the human standpoint, of course, chief interest centers in the corolla with its wide-spreading petals of varied colors. To the plant itself this structure is in a sense essential, inasmuch as it supplies the visible signal that attracts the attention of the insect. But beyond this it has no share in the process of fecundation. We shall have occasion to consider the form and structure of this showy portion of the flower in a multitude of individual cases, and to observe how it may be modified by process of selection, but from the present standpoint it does not call for further consideration.

From the standpoint of the pollenizer, the stamens with their pollen-bearing anthers and the receptive pistil—with or without a stigma at its tip but always having one or more ovules in the egg-case at its base—are the organs that claim exclusive attention.

Hand Pollenizing

The essence of pollenizing is merely the transfer of pollen from the stamen of one flower to the stigmatic surface at the end of the pistil of another.

This is the work that is ordinarily accomplished by the insect. It is all that the plant experimenter accomplishes when he wishes to effect the crossing of different plants of the same species or the wider crossing, commonly called hybridizing, of different species.

There is nothing occult in the practice of the bee or in the imitation of his work as practiced by the hand of the pollenizer.

What is accomplished in each case is the purely mechanical transfer of a certain number of minute pollen grains from one place to another. Beyond that, everything depends on the vital activities of the plant tissues themselves.

We shall have occasion in another chapter to deal somewhat at length with specific methods that are necessary to effect cross-pollenizing in the case of sundry types of flowers that have developed blossoms curiously modified as to form or details of structure. But the general processes of hand pollenizing, as they apply to the chief

Pollen-Bearing Chestnut Blossom

The chestnut bears its pollen and its ovules separately. It depends largely on the wind to transfer the pollen, and hence does not develop a conspicuous floral envelope to attract insects. But the massed blossoms, in spite of their small individual size, are conspicuous, as this picture shows. The pollen is produced in relatively enormous quantities.

Stigmatic Chestnut Blossoms

Hand pollenizing of the chestnut is effected with the greatest facility, nothing more being required than to pluck a pollen-bearing branch, like that shown on the opposite page, and dust it lightly against such a stigmatic branch as this. Mr. Burbank has produced remarkable results by hybridizing chestnuts from Japan with European and American species. Some hybrids are immune to the fungus that destroys the American chestnut.

flowers of the orchard and garden, may be stated in a few words.

The essential thing is to secure a certain quantity of pollen, usually by shaking it from the flower on a watch-crystal or other small receptacle, and to transfer this pollen to the receptive pistil of another flower either with the finger tip—which furnishes in general the most useful piece of apparatus—or with a camel's hair brush.

It is desirable to cover the receptive portion (stigma) of the pistil fully with pollen, partly to ensure complete fertilization, and partly to prevent the vitiation of the experiment through possible subsequent deposits of pollen from another source.

If the flower to be fertilized has stamens of its own, these should be removed before they are fully ripe—which is often a few hours, or a day before the foreign pollen should be applied. This removal of the stamens may usually be done with a pair of small pincers. In case of flowers that have short pistils—the cherry, apple, and other orchard fruits being good examples—the unopened flower bud may be cut around at about the middle, with a thin-bladed knife, the anthers being thus excised at a single stroke. With other flowers the mechanical details vary, of course; but

Corn Self-Pollenated and Crossed With Teosinte

The upper ear is an ordinary ear of corn, presenting no marked peculiarities. The lower ear was developed by pollenizing the corn silk with pollen from the primitive type of corn called teosinte, which is illustrated on earlier pages of the present volume. The influence of the pollen-parent is clearly shown in the modified form of the kernels. With most plants the pollen does not directly effect the fruit, but corn is an exception in this regard.

the process is seldom complicated. It calls for common sense rather than for great ingenuity.

So-called composite flowers, however, require special treatment. The daisy and the sunflower are familiar examples. Here the true flowers are very small and grouped in masses. Individual treatment is usually out of the question. The best method is to wash away the pollen with a carefully directed stream of water from a garden hose, or by spurting water from the mouth; after which the head of the pollenizing flower is rubbed rather vigorously against the one just de-pollenated, thus effecting fertilization *en masse*.

In exceptional cases it may be desirable also to cover the fertilized flower with a paper bag to prevent the visits of insects; but in practicing pollenation on a large scale this may usually be omitted.

If the stigma has been satisfactorily covered with pollen, it will present no exposed surface for the reception of other pollen grains.

Pending the more detailed discussion of the specific methods of pollenizing adapted to particular flowers, I would give an all-compassing rule which, in itself, will serve as a sufficient guide to the experimenter who has clearly in mind the principles involved in the process of cross-pollenation.

Corn Insufficiently Pollenated

Each individual ovule must be fertilized with the nucleus of a pollen grain. The so-called silk of the corn consists of thread-like pistils, each of which leads to an ovule. The pollen, produced in the tassel, sifts through the air in great quantities, but sometimes it fails to reach all the threads of the corn silk. In that case a defective ear is produced as shown in this picture.

The rule is simply this: Seek Nature's plan and follow it.

In other words, take a lesson from the bees, and pollenize the flowers somewhat as they do. Bear in mind the essentials of the process, which are the same for every flower. Study the mechanism of each new flower and adapt your precise method to the needs of the individual case. It does not matter just *how* the pollen reaches the reception stigma, provided it *does* reach it.

A very short course of practice will give you the knack of cross-pollenizing, and enable you to enter on a course of experiments that will lead to surprising, fascinating and perhaps far-reaching results—results which may prove to be of time wide and world wide significance.

—The ferns belong to a conservative family; and the penalty of conservatism, whether in plants or in human beings, has always been racial stasis.

QUANTITY PRODUCTION

ON SEEDLINGS
AND THEIR CARE

THE word "evolution" chances to have nine letters. Suppose that these letters were penciled on nine blocks of wood that are otherwise identical, and these little blocks were put in a bag and mixed together. Suppose then that you were asked to put your hand in the bag and bring forth one block after another, placing them in sequence as you brought them from the bag.

What probability is there, do you think, that your blindfold selection of the blocks would result in bringing them out in such sequence as to spell the word "evolution"?

A mathematician could doubtless figure out the exact probabilities, but you need not be a mathematician to realize that the chances are almost infinitely against you.

Now I think I am right in saying that the plant developer who expects to find a considerable number—let us say nine—of particular qualities of any given flower or fruit or vegetable combined in just the desired proportion in any single seedling selected at random, stands about the same chance of having his expectations gratified that you have of spelling out the word "evolution" correctly with blocks drawn at random.

But it is obvious that your chance of successful drawing of the blocks would increase in proportion as the number of attempts you are permitted to make increases.

So would the plant experimenter's chance of finding several desired qualities of his fruit or flower combined in just the right proportion increase somewhat in proportion to the number of seedlings among which he can select.

Yet I suppose the mathematician would assure us that the number of attempts you must make with the blocks before you could hope, according to the theory of chances, to bring out all the letters in just the right sequence would be so large as to tax your patience beyond endurance and I can testify that the same thing holds true with regard to the experiment of the plant developer. Though he had thousands of seedlings among which to choose he is not likely to find any one in a given fraternity that fully meets his ideal.

Selected Ears of Corn Drying

A view in Mr. Burbank's experiment garden at Santa Rosa. The two lots of corn shown have been selected for the continuance of the remarkable series of experiments in hybridizing the teosinte, and in developing new varieties.

But if in making your experiment of choosing the lettered blocks you were permitted to retain the blocks bearing the letter "E" when you chanced to draw it first; and if then you were permitted to retain the letter "V" when that was first drawn from the remaining group of eight blocks; and so in sequence with "O" and "L" and the rest—it is obvious that each new test would find you with a smaller number of letters from which to select, and hence with an increasing probability of successful selection.

When, finally, there remained only two letters in the bag, your chance of securing the right one in the first draw would obviously be an even one. And when only the final "N" remains, you could make no mistake — your selection of the right letter then becomes a certainty.

Now I make this illustration because I think it has peculiar application to the case of the plant developer. His method is not unlike the method of selection just suggested. As the result of his first hybridizations, he does not dare to hope that he will secure the exact combination of qualities he would like to see aggregated in his ideal fruit or flower. But by having a large number of seedlings from which to select he may reasonably hope to secure one that will present some one at least of the desired qualities in superlative degree.

Selected Corn Seed

Another view in Mr. Burbank's experiment garden at Santa Rosa, showing selected corn seed in various lots after removal from the ear. The picture suggests "quantity production," on which so much of Mr. Burbank's success depends.

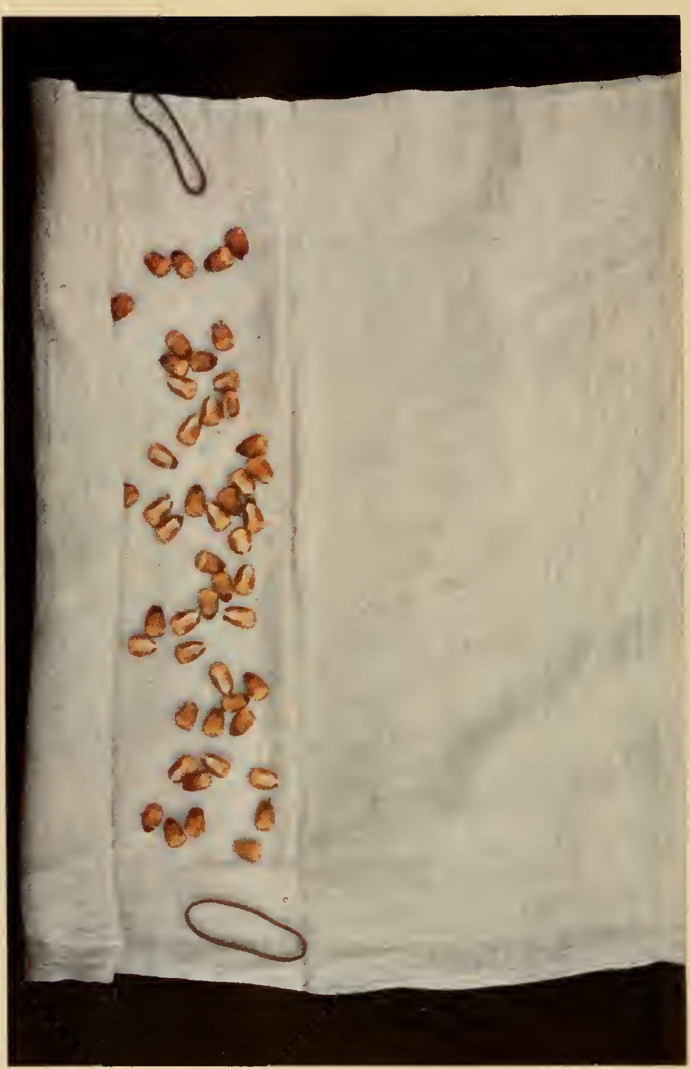
This selected seedling he may nurture and use as part of his equipment for further experiment just as you retained the letter "E" as marking the beginning of your success in spelling the word "evolution."

And as the plant developer continues his experiment with successive hybridizings and successive selections, he will be able in later generations to find individual seedlings that combine successively more and more of the qualities he is seeking. When, finally, he reaches the stage where the parent forms have between them all the desired qualities in superlative degree, he is somewhat in the position that you were in when only two of your lettered blocks remained in the bag. There is at least an even chance that he will find among his seedlings of the next generation one that will approximate his ideal, even though the number from which he selects is far smaller than the earlier groups.

Thus by advancing step by step and using the ground gained as a new starting point the experimenter attains his end with comparative celerity, even though there would have been scarcely more chance of attaining that end with a single experiment than you would have had of spelling out the word "evolution" at a single series.

But it must be fairly remembered that the probability of success is enhanced if at any of the earlier stages of the work you have opportunity to select the best plant among a large group instead of being restricted in choice to a few individuals; just as the chance of securing the block you seek in each successive drawing increases with the number of tests you are permitted.

And in point of fact, this, or something like this, is the actual method in which the experiments of the plant developer are carried out, whenever he is attempting to construct a new fruit or flower or vegetable having a number of specified or clearly imagined qualities. In such a case, the wise experimenter does not hope to secure ideal results with a single hybridization; he seeks to group desired qualities of his flower or fruit together through successive crossings and selections. Keeping one supreme quality in mind and perhaps two or three others in the immediate background, he makes sure of first one and then another of these qualities, adding to them by successive crossings and selections and thus although advancing, as it were by indirection, and at first seeming to advance but slowly he may ultimately work with increasing certainty and approach his goal somewhat rapidly.



Germinating Seeds in Damp Cloth

Seeds of various kinds, arranged in loose rows as here shown, may be rolled in a damp cloth and thus germinated preparatory to planting. This is one of the numerous shortcuts that Mr. Burbank practices. The method is sometimes used merely to test the viability of seeds from different lots.

Seeds Germinated in Damp Cloth

This shows the method illustrated on the opposite page, at a later stage. The four different groups of seeds have been germinated in the same roll of cloth, without mixing, and they are now ready to be transferred to the soil, either in the greenhouse or in the field.

For example, our first cross, say in the case of a prune, may be made between two varieties that both show a fair quality of fruit. Careful attention to the result will guide us in the matter of the next experimental crossing. We soon discover which qualities are prepotent, and which tend to remain latent, and by selecting only individuals that show a tendency to vary in the desired direction, we introduce an element of *direction* into the experiment.

I am accustomed to speak of this as "momentum of variation." We do not always know why a certain plant tends to vary in a given direction, but we may observe the fact, and the wise experimenter is always on the lookout for this tendency, and ready to avail himself of the advantages it offers. Technical workers sometimes give the name "orthogenesis" to this tendency to vary in a certain direction, which I speak of as the plant's "momentum."

Whatever aid we may gain in this way, however, the manner of our advance is often devious.

In fact, it is very likely to be somewhat comparable to the progress of a sailing ship which tacks this way and that, and which at times may seem to be progressing in the wrong direction, yet which in the end forges ahead.

Take by way of illustration the case of our

Pumpkin Seeds Germinated in Wet Newspaper

Sometimes Mr. Burbank employs a piece of newspaper instead of a cloth to germinate seeds, merely wrapping the seeds loosely in the moistened paper. The efficacy of the method is demonstrated in this picture. Seeds thus germinated will make rapid growth when transferred to the soil.

stoneless plum. We discover soon that the stone seed is prepotent or dominant, and stonelessness latent or recessive. So we must be prepared to see the progeny of our first generation of hybrids all produce stony fruit. But a knowledge of the tendency of latent or recessive characters to reappear in successive generations comes to our aid, and we go on with the experiment with full confidence, even though for the moment we seem to be going backward rather than forward.

In due course the second generation of plums appears with a number of stoneless specimens, the latent character having come to the surface. But these lack many of the good qualities that our perfected fruit must have, and in order to breed these qualities into the stock we must make a new cross; and this will involve the breeding in again of the tendency to bear stone fruit.

So in three generations we shall find ourselves, as regards the essential quality of the stony seed, somewhat further back than we were in the beginning.

But, on the other hand, our third generation fruit, even though it has a stony seed, has qualities of flesh that its stoneless ancestor altogether lacked; and in the fourth generation we shall be prepared to find individual seedlings that bear stoneless fruit of greatly improved quality.

In each successive generation, then, we are dealing with better material—getting the chances grouped, if you will.

WINNING AGAINST ODDS

But, in a sense, we are running counter to the trend of heredity, because vastly the great proportion of the ancestors of our plum were bearers of stoned fruits. And so we must continue re-shuffling and dealing over, as it were, and watching results. We may lose in one generation what we gained in the generation before as regards the matter of stonelessness; even while on the whole advancing toward the production of a fruit of desired quality.

But just in proportion as our ideal calls for the combination of numerous good qualities, does the attainment of that ideal become difficult.

Even when, at let us say the fifth or sixth generation, we interbreed individuals that have the desired quality of stonelessness, we shall not at once secure what is desired; because our seedlings combine so many ancestral traits that they will not breed true. Even though they are all stoneless, there will be a great variation as to other qualities, and it is only by dealing with large numbers of seedlings that we can hope to find one or two that will show the desired combination of traits in high degree.

Perhaps the comparison may be thought somewhat whimsical; but I am led to make it because I thought it might serve to suggest the complexities and difficulties that attend a plant-breeding experiment that involves the blending of numerous desired characters.

And the lesson that I wish pre-eminently to inculcate is this: You must make many experiments at plant-breeding before you can hope to secure the combination—the sequence of qualities—that you desire.

The Logic of Quantity Production

Now note the application: Each individual seedling of a hybrid strain represents a unique combination of ancestral traits, and constitutes in itself a new and unique experiment—equivalent to an independent deal of the cards. So the probability of securing what we seek will be somewhat proportionate to the number of seedlings.

This is particularly true in the case of such variable plants as the fruit trees of our orchards. The case is far simpler when we are dealing with plants that vary little in their qualities, or where we are breeding with only a single pair or two pairs of unit qualities in mind—say "hardness" of kernel and immunity to rust, as in Professor Biffin's experiments with wheat; or good flavor and whiteness as in my white blackberry.

The Burbank
"Flats"

Mr. Burbank usually plants seeds in boxes like these, eighteen inches square and four and one-half inches deep, the boards at the bottom being spaced to permit free drainage. He calls such a box a "flat." The boxes should be made of durable wood, such as redwood, cypress, or locust.

But where the varied traits sought to be combined in a Shasta daisy are in question; or the many qualities of a commercial cherry or prune, the case assumes new complexities.

Hence it is that my records tell of tests applied to about half a million seedlings of the daisy; seven and one-half million seedlings of various plums, and the like.

Hence also the constant necessity of what my neighbors speak of as ten-thousand-dollar bonfires in my orchard, when we burn seedlings that have been inspected and found wanting. To burn 65,000 hybrid blackberries in one pile, as I once did after saving perhaps half a dozen individual vines, seems like willful extravagance to the casual observer, but it is an unavoidable incident in the search for perfect fruits.

Such prodigal use of material implies a large measure of experience in the handling of seeds and the growing of seedlings. In point of fact, it might be said that this is the most important part of a plant-breeder's task, so far as the practicalities of experiment are concerned. It is part and parcel of his daily routine.

It is highly desirable, then, that the would-be experimenter should gain a clear understanding of the essentials of method of caring for seeds and cultivating seedlings. So it is my purpose in the

"Flat" With Layer of Gravel

A layer of gravel is put at the bottom of the germinating box to facilitate drainage and aeration, both of which are very essential to the proper growth of the plant roots. Mr. Burbank regards this detail as very important.

succeeding pages of this chapter to give a few practical hints as to various aspects of the subject. Thus summarized, the lessons I have learned in the hard school of experience may enable the reader to avoid some pitfalls and to make certain experimental shortcuts.

KEEPING SEEDS OVER WINTER

To begin at the beginning, let us note that the preservation of seeds over winter calls for careful attention.

All fruit seeds except those of apricots and almonds, when removed from the fruit, are at once placed in slightly moist, coarse sand or fine gravel or in sterilized sawdust.

In warm climates the boxes containing the seeds are then buried on the shady side of a building or tree where they will become neither too dry nor too wet. The object is to keep the kernels as nearly as possible in their original condition.

If tree seeds, especially those of the cherry, the pear, and the plum once became thoroughly dry, it is difficult, and in some cases impossible, to induce them to germinate. An important function of the pulp of these fruits, in the original wild state, was, presumably, to keep the seeds moist until the season for germ motion.

I have elsewhere called attention to the

"Flat" Partly Filled With Dirt

The "flat" is partly filled, on top of the layer of gravel, with specially prepared soil, which is then tamped down with a board, making a flat surface on which the seeds are sown. The soil is a mixture of fifty per cent sand, forty per cent loam, eight per cent powdered moss, and two per cent bone fertilizer.

exceptional difficulty of keeping stoneless plums and prune seeds in condition for growing. Not having the natural protection of the shell, they tend to germinate too early, and of course they are peculiarly subject to the attacks of insects and of fungous diseases. Such seeds may best be placed in cold storage as soon as collected and cleaned, and kept at freezing temperature. Seeds thus cared for will sometimes germinate almost as quickly and readily as beans or corn. They must not be planted too early in the spring, lest their too prompt germination subject them to injury from late frost.

Incidentally, I may note that grafts sent to me from a cold climate have often been observed to start with greater promptness, and grow better than those from our own immediate vicinity where the winters are mild. Cold seems to rest the tissues and prepare them for rapid growth, just as treatment with narcotic drugs has been observed to do in certain interesting experiments that will elsewhere be referred to more at length.

OUT OF DOOR PLANTING

In California, plum seeds are usually planted in January or February, in a little furrow about an inch deep. A furrow may be made accurately and expeditiously with the aid of a triangular bit of board an inch or so wide nailed across another

"Flat" After Seeds Are Sown

The seeds are loosely covered with the prepared soil and powdered moss. A thin sprinkling of gravel on top prevents the seeds from washing about, and retains moisture. It also prevents the spread of fungous growths.

longer piece, so that when drawn along a garden line it makes a narrow furrow of exact width and uniform depth throughout.

Plant the seeds about one-half inch to an inch apart, and cover with a thin layer of soil; then fill the furrow with sawdust. This is an important matter with cherry and plum seeds, especially with the stoneless ones which must be given every inducement to push through the soil. A heavy, compact soil placed over cherry and plum pits prevents a large number from pushing up to the light. For this reason a sawdust covering is preferred, and it also regulates the moisture with exactness, allows for sufficient aeration, and equalizes the temperature. Moreover, the sawdust is distasteful to slugs, thrips, cut-worms, and other insect pests.

Peach, nectarine, and apricot seeds are planted farther apart and a little deeper; quince, pear and apple seeds are planted about the same as plum seeds, both as to distance and depth, or in large lots may be rather thickly sown in drills or furrows six or eight inches wide and eighteen to thirty inches apart.

For growing seedlings of conifers—pines and their allies—cold frames or shallow boxes are used filled with mellow sandy loam; or the seed may be sown broadcast or in rows in cold frames

"Flats" With Sprcuting Seedlings

All manner of seeds are sown in the "flats," and Mr. Burbank has so perfected the method that he usually sprouts ninety-nine seeds in a hundred. The same method is used for the commonest flower and the rarest exotic. "Flats" growing hybrid cactuses are side by side in his greenhouse with those containing orchard fruits, and flowers of many species.

without boxes. The object of the cold frames is to shelter from hot sun and drying winds and in cold climates to prevent freezing.

If the season is short or if warm weather comes on suddenly, it is sometimes desirable to soak seeds in water before planting.

After being in the water several hours they should be drained and set in a warm place where germination can start quickly. In this way growth may sometimes be advanced by a week or more. But such forced germination is not usually necessary or desirable. If carried too far before planting, it endangers the growth. On the other hand, the very early plants often escape cut-worms and other insects by attaining a fair growth before these pests put in an appearance.

Boxes for Seedlings

Valuable plants to be grown in large quantities from rare seeds, may best be started in small boxes or "flats" indoors, under glass or in sheds made of laths or slats so spaced as to allow free entrance to air and sunshine.

Boxes of the right design and construction are far better for this purpose than pots or earthen pans. The boxes or "flats" that I have used for twenty years are made of redwood lumber. Where this cannot be obtained, cypress is nearly as good, but soft pine is not durable and should

Seedlings in the Greenhouse

The "Flats" are here shown at a later stage, when some of the seedlings have been transplanted to give them room, and have attained considerable proportions. Much time is saved by thus developing the seedlings in the greenhouse over winter.

be avoided. Eighteen inches square, outside measure, four and one-half inches deep, inside measure, is a good size.

Two opposite sides are of common board lumber three-quarters or seven-eighths of an inch thick; the other sides, are a little less than half an inch thick. The bottoms are made of redwood "shakes" which are about one-fourth of an inch thick; two or more spaces of an eighth of an inch being left for drainage. Across the bottoms are nailed three strips which add rigidity and strength as well as affording better ventilation and drainage. After all the parts are carefully fitted, the joints are sometimes dipped in linseed oil, before being strongly nailed together. This gives durability and tends to prevent the nails from rusting out.

These redwood boxes may be used for many years if sterilized once a year by being placed for about three or four minutes in boiling water.

A suitable soil is the first requisite in raising seedlings in boxes. The mixture which I have generally found best for use in the early winter for raising seedlings in boxes in the greenhouse, is compounded about as follows: One-half clean, rather coarse, sharp sand; with about forty per cent. of some good pasture or forest soil which generally contains more or less leaf mould. To

Protecting Seedlings from the Birds

A net drawn over the "flats" or propagating beds gives protection from the birds, and is an indispensable auxiliary where rare exotics or new hybrid varieties are being raised.

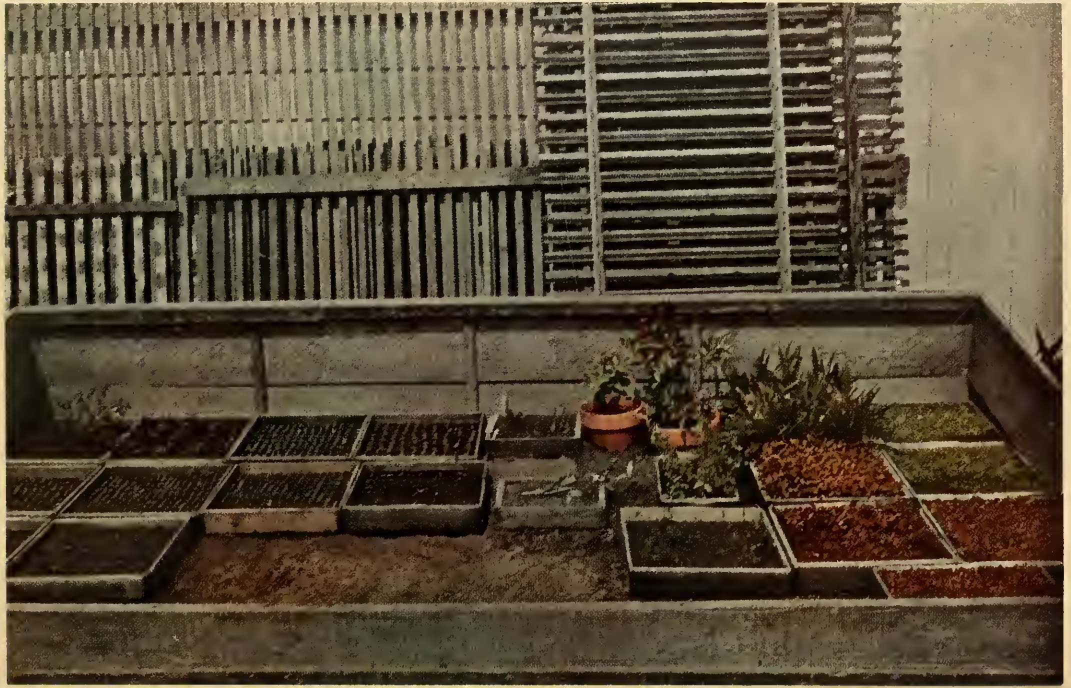
this is often added ten per cent. finely powdered moss or peat. These mixtures, with the addition of about one or two per cent. of fine ground bone meal or superphosphate, make soils in which seeds of almost any kind of plants from any part of the earth will germinate. Seedlings thrive in this soil until they are ready for transplanting.

If seeds of choice plants are to be grown, the soil is sterilized by a thorough scalding to destroy any fungus or insect pests.

Usually we find it suits the plants better if a part of the soil last prepared is left over for use with the new mixture, like yeast for a loaf of bread, and I always prefer to have a little of the old on hand for this purpose.

Common sharp sand, if the right texture can be obtained, is far better for cuttings than the soil just described. The sand found along creek or river banks is generally free from injurious insects or fungous diseases. But for rare cuttings and very choice seeds, this should be rinsed by pouring large quantities of water through it, at the same time stirring or jarring the material.

In filling the boxes, coarse gravel, such as will just pass through a half-inch mesh, or a little smaller, is placed one-quarter to one-half inch deep over the bottom of the box. This ensures perfect drainage and sufficient *aeration,* both of



Mr. Burbank's Only Cold Frame

To accustom seedlings to the outdoor air, Mr. Burbank places the "flats" in boarded enclosures covered with movable frames made of laths, which shield the tender seedlings partially from the wind and sun until they are hardened and ready for the fields.

which are of the utmost importance. The box is then filled, to within about an inch of the top, with the sand or special soil. Make the filling a little shallower for fall planting, when we expect much cool, damp weather, and slow growth, to prevent drowning or "damping off" of the seedlings during the winter; a little deeper for spring planting, to prevent too sudden drying out, and otherwise to regulate the amount of moisture.

This may seem like a matter of small consequence, but such details often determine success or failure.

The Seedling Kindergarten

All ordinary seeds are sown quite thickly in the boxes and covered lightly with the same soil, according to the size of the seed—just a dusting of soil for the finest of seeds, and an eighth to a quarter of an inch for the larger ones.

In testing new varieties, ten or twenty different kinds of seeds may be planted in sections in one box, each marked with a small wooden label, tacked on the upper edge of the box with the name, or the reference-book number, of the seeds. After the seeds are planted, the surface is pressed down with a flat piece of board until it is level, smooth, and solid.

Instead of watering the surface by any sprinkling process from above, the boxes are placed,

Mr. Burbank's Cloth Screens

Very tender seedlings may be additionally guarded with screens made of thin cloth, which give full protection from the wind, and modify the sunlight. These seedlings may then be placed in cold frames, for a further course in hardening, before they are transplanted into the open.

after the seeds are planted, into a square pan containing water sufficient in depth to rise nearly or quite even with the surface of the soil. In a few minutes the water saturates the soil and entire contents of the box, without disturbing the seed, and without packing the soil in the least. The boxes are then removed and tilted to one side so that the superfluous water can slowly drain out.

A thin layer of moss sifted over and under the seeds acts as a non-conducting blanket, equalizing the temperature and retaining moisture.

A layer of gravel above the moss protects the seeds or young plants from being washed about when they are watered from above, as they are usually sprinkled after a few weeks of growth. The thin covering of gravel also wards off fungous diseases which afflict tender seedlings. All this may seem like unnecessary trouble, but it is absolutely necessary if one wishes to attain the best success. No part of the program can be omitted without risk of loss or injury to the seeds.

When the seedlings have two to four leaves it is best to transplant them into another box, whether they are large or small, in order to give them more room in which to develop.

In each box used for raising fruit seedlings we put about sixty-four, or sometimes late in the season as many as one hundred specimens. They

Setting Out Plants From the "Flat"

When the seedlings are sufficiently hardened, if the weather is suitable, they are transplanted into the open garden. The "flats" are taken into the garden, so that the transfer may be made directly and with the least possible damage to the roots of the plant. An ordinary trowel is the best implement for transplanting most seedlings.

are allowed to grow until toward spring when the weather becomes warm, about the time of the blooming of fruit trees, when they are ready to be transplanted to the open fields.

Some of the smallest plants raised in greenhouses, like calceolarias, lobelias, begonias, ferns, etc., may readily be transplanted, even when they can hardly be seen, by lifting them on the end of a moistened quill, pencil, or small knife blade, placing them on the soil which has been previously moistened as before described, then covering with a glass for a few days until the young plantlets can get established.

This is the quickest and best method of transplanting some of the smallest seedlings, and though apparently tedious is often the most speedy and profitable mode.

Going Up a Grade

In transplanting all small seedlings, they are placed in straight rows in the boxes; usually eight rows with eight plants in a row in the eighteen-inch boxes; but, for larger individuals, six rows of six plants; or, on the other hand, ten rows of ten or even twelve rows of twelve in case of the smallest ones.

After standing in the greenhouse for a week or two, the boxes of seedlings are removed, usually to a sheltered place out-of-doors, in order

Making a Trench for Cuttings

Where cuttings are to be planted, a deep trench may best be made by inserting a flat spade and moving the handle back and forth a few times. The same method may be used for transplanting seedlings that have long roots, it being particularly desirable that the roots shall not be disturbed, lest growth be retarded.

that they may continue growth and become hardened through exposure to sunshine and outdoor air. Later, they may be safely transplanted into other boxes, giving them more room for growth, or to the field where they may be planted in long rows about four feet apart, so that they may afterwards be cultivated by horsepower in the usual way.

In general the treatment here described is employed for cactus, berries, lilies, begonias, grasses, potatoes, roses, ferns, or any of the thousands of species of domestic, foreign, arctic, or tropic seeds which are received from collectors.

In transplanting, it is best to have the boxes of plants carried into the field, and with most plants it is best to saturate the soil in the boxes, letting them drain a little before attempting to transplant. Then with a trowel they may be taken up with the dirt surrounding the roots and set out.

After marking the rows with a garden line, a long narrow crevice is cut by inserting a flat spade and moving the handle back and forth a few inches. The plants can be rapidly placed in the crevice thus made. One side of the soil is pressed down with the foot or with a tamper, and packed quite firmly against the roots.

Then more soil is drawn in with a hoe or rake and carefully placed about each plant, after which

Setting Out Cuttings in the Trench

This picture shows Mr. Burbank's method of setting out cuttings in the trench prepared in the way shown on page 133. The soil on one side of the trench should be pressed against the cutting, and firmly packed with the hand, no other implement being required at this stage.

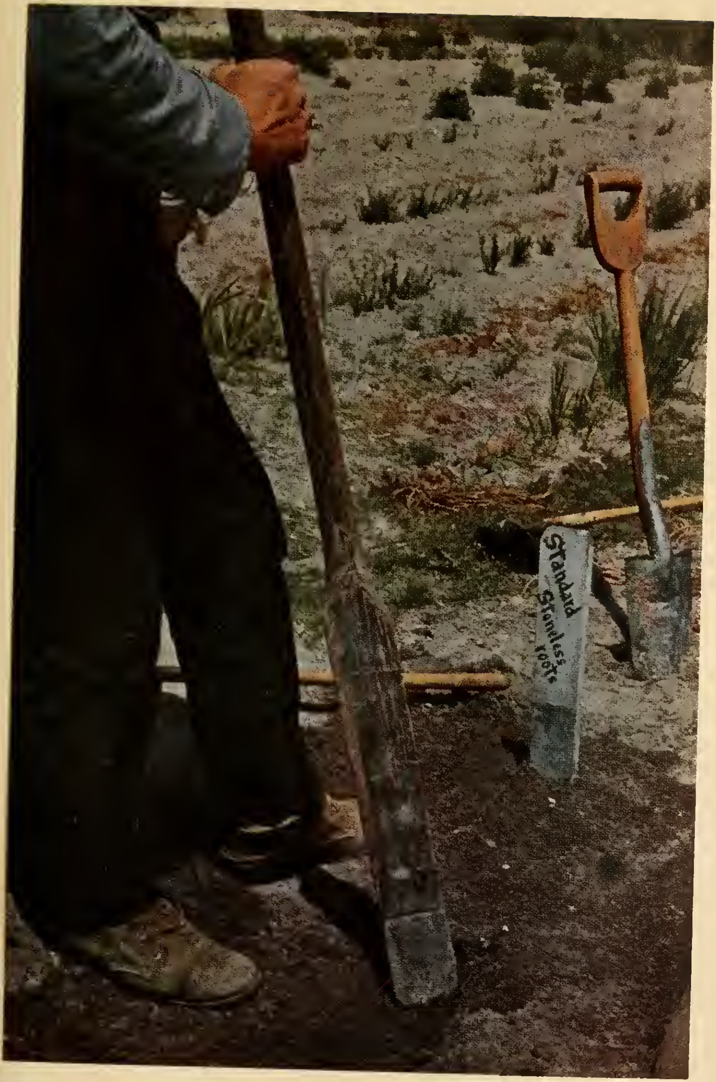
a common garden rake is used in leveling and loosening up the soil along each side of the row, which prevents "baking" and helps to keep the temperature equable and the soil moist. The most tender plants treated in this way are saved almost without exception.

Out in the Open

Nearly all plants should be set out in the field somewhat deeper than they grow in the boxes. When plants have long roots these should be straightened out and placed as deeply as possible in the soil to give them a good start by the time the dry summer weather commences. Otherwise the young plants could not, in some cases, extend their roots fast enough to keep up with the gradually disappearing moisture, and so might die of thirst.

When seedlings are removed from the protection of the glass house to the open air, or in transplanting in the fields, it is best, if possible, to choose a time when there are no severe winds, and when the sun is not too hot and the atmosphere neither too dry nor too chilly.

Generally in California tender plants best withstand moving from the greenhouse to the open air just before or during a warm rain. At such times the atmosphere is similar to that in the greenhouse. Even under the most favorable



Tamping the Dirt Around the Cuttings

The setting out of cuttings is completed by tamping the dirt rather firmly about them, either with the foot or with a tamper like the one here shown. It is well to stir the surface subsequently with an ordinary rake to loosen the soil at the surface, so that it will not "bake." The picture shows also a typical wooden marker, which in this case records that the cuttings are the roots of Standard stoneless plums.

circumstances they must be shielded from winds or bright sunlight to which they are not adapted.

To accustom the tender seedlings to out-door conditions, the flats are placed in square frames about six feet wide and a foot or two high. These are covered with a portable covering made of common laths nailed on narrow strips of board, so placed that the space between the laths is about equal to the width of a single lath.

When the boxes of plants are placed in these frames, it is best to have some slats underneath so they will not rest on the ground; otherwise fungous diseases are often communicated from the earth to the soil in the boxes and to the tender plants.

When the slat covering is kept over the frames for five to twenty days according to the season, the little plants will have adjusted themselves to their new environment so that the slats can be removed.

After a few more days of growth they will probably be strong enough to be removed to the open ground.

Running the Gauntlet

Many tiny seeds, just as they are germinating, may be destroyed in a short time by a cold dry wind, or they may be killed even more quickly by too much moisture and too little air.

Seedling Trees Awaiting Transplantation

When a shipment of seedling trees can not be immediately transplanted, they should be partly buried in pure sand or a very sandy soil. For cuttings, also, sand is better than ordinary soil. Seedlings or cuttings thus guarded may await the convenience of the gardener without injury.

Young seedlings may be killed by a common fungus which causes "damping off." This is very destructive where plants are grown too thickly in the seed boxes especially in a close atmosphere before transplanting. Sometimes a whole box containing thousands of valued seedlings will be destroyed in this way in a few hours, the trouble generally commencing in little spots or patches from which it rapidly spreads in all directions.

The tiny plants may most often be saved after the fungus starts by applying a dusting of sulphur or of coarse, dry sand or gravel. Sometimes if placed in a cool, dry atmosphere so that the excess of moisture is evaporated they may be saved.

The gravel, mentioned as sprinkled over the moss when the seeds are planted, is the first and best preventive of damping off. It covers the soil with a substance on which the fungus cannot readily establish itself, and thus separates the unhealthy from the healthy plants. If good care in general is supplemented by the use of this dry sand or gravel, the fungus has little chance to spread from plant to plant.

Of course, one is obliged to be on the lookout for insect pests, slugs, cut-worms, crickets, aphides, and thrip, which are sometimes very destructive. Slugs, cut-worms, and crickets require instant attention when they first attack the young plants.

The appetites of these pests often increase to greater proportions than can be appeased by the growth of the remaining plants and they must be carefully sought in or under the boxes.

Sometimes slugs may be headed off for a time by sprinkling lime, red pepper, quassia, or tobacco dust in their paths. Thrip and the aphides are best destroyed by fumigating the houses once a week or twice a month with tobacco smoke; the frequency may be regulated according to the abundance and the persistence of the enemy.

All in all, it is a severe gauntlet that the little seedling is called upon to pass. Yet if the methods described in this chapter are carefully followed out, it is possible to grow successfully any seed, from whatever climate or soil or location, that has the least germ of life within it.

These methods have been successfully used with the seeds I am constantly receiving from numerous collectors in Siberia, Brazil, Chili, Argentina, Patagonia, Mexico, Central America, the Philippine Islands, Alaska, British Columbia, North and South Africa, Europe, India, South Sea Islands, Australia, New Zealand, Central and Western China, Japan, and Korea.

By sedulous attention to the details above outlined, the raising of seedlings becomes so certain a procedure that the loss should not exceed one

Protecting Test Corn From the Breezes

To prevent a plant with a tall slender stalk from swaying about too much, a string may be tied about the stalk in the way here shown. This hybrid corn is of a gigantic variety developed by Mr. Burbank, and it grows so rapidly that there is particular danger of injury from the wind.

plant in a hundred. And this, obviously, is a most important consideration, especially with rare foreign seeds or seeds produced by hybridizing experiments that have involved exceptional care and labor. To such priceless stock, any amount of time and labor may be given ungrudgingly. And even in planting common nursery stock one soon learns that a thorough knowledge of the requirements of the plants is essential to success, and that cheap, careless work is always the most expensive in the end.

A perusal of the foregoing pages will perhaps serve, better than almost any other exposition, short of inspection of the work itself, to give the reader an inkling of the enormous amount of mere mechanical labor—in addition to ceaseless watching and patient waiting—required to bring the seedling plant through the time of its tender infancy. When it is further reflected that seedlings must be handled by thousands; and that this care is, after all, only one of many essential stages of each individual series of experiments in plant development, perhaps a fairly clear notion will be gained of the laborious—even though fascinating—character of the task that confronts the person who would develop a new fruit, a flower of modified color, or a plant of altered structure.

Complete Grafting Outfit

The saw and knives and pruning shears are self-explanatory. The iron tool with curved handle lying in the foreground is a wedge to prepare a branch for cleft grafting (see page 163). The utensil at the left is a heater with a basin of grafting-wax and brush for applying it. The tree stump has been cleft-grafted with six cions.

GRAFTING AND BUDDING

SHORTCUTS TO QUICK TESTS

NOWADAYS we hear of some remarkable experiments in the grafting of animal tissues, which strongly appeal to those who have long experimented in the grafting of vegetable tissues.

The experiments made by Dr. Alexis Carrel, of the Rockefeller Institute in New York, are of particular interest. It appears that Dr. Carrel has devised a new method of suturing arteries. With such a process, the plant experimenter of course has no concern, for the juices of plants are not transmitted in any such definite channels as the arteries and veins of animals. But in dealing with animal life the arteries are all essential, and the process devised by Dr. Carrel enabled him to perform grafting experiments such as no physiologist or surgeon had heretofore found feasible.

[VOLUME III—CHAPTER V]

Not only did Dr. Carrel transfer sections of arteries from one cat or dog to another animal of the same species; but he also transplanted successfully even such vital organs as the kidneys.

Moreover, what is more spectacular even if not more important, he actually succeeded in amputating the leg of one dog and grafting it on the amputated stump of the leg of another.

The transplanted limb presently made union with its new stock, as a horticulturist would term it, and the borrowed member became a permanent portion of a new body, just as the cions of my apple trees or plums become component parts of the tree on which they are grafted.

All this, as I said, was so fully in keeping with the familiar experience of the plant experimenter that it had no peculiar interest for me. Perhaps it seemed to me less wonderful than it really is because my conception of the fundamental unity of plant and animal life makes it appear to me inherently plausible that such transplantation of members should take place under proper surgical conditions.

The only difference is that the method of grafting plant tissues one upon another has long been familiar, whereas no one knew just how such grafting could be accomplished in the case of the animal until Dr. Carrel found the way.

But I think what interested me most about Dr. Carrel's experiments was the demonstration his tests made of the limits of successful grafting where the organs or members involved belonged to different species. For, whereas he found that the kidneys and spleen might be transplanted from dog to dog, or from cat to cat, it was quite out of the question to hope for a successful issue if he transferred one of these organs from cat to dog or from dog to cat. Even when the transplanted tissue consisted merely of a piece of artery, it was found that the graft did not take kindly to its new surroundings, unless the animal were of the same species as that from which the artery was taken.

Something inherent in the chemical composition of the tissues themselves makes every fiber of the tissue of a cat, seemingly, more or less antagonistic to the tissues of the dog.

We have already seen how the experiments of Dr. Nuttall, of Cambridge University, demonstrated that the quality of *felineness* or *canineness,* so to speak, penetrates to the last drop of the blood; so it is not surprising to find from this independent source that the same characteristic differences extend to the solid tissues.

And of course I am at once reminded of the similarity of experiences of the grafter of plants.

Here also there are sharp limits fixed to the feasibility of the grafting method. You may transfer the twig of an apple to the corresponding limb of another apple tree, however widely different, with entire facility. You may similarly, although with far less facility, make a graft between twigs of the apple and the pear. In the same way you may combine branches of the different members of the family of stone fruits—plum with apricot, peach with almonds, and the like. But if you attempt to ignore the larger barriers, and strive to graft seed fruit upon stone fruit—apple or pear on plum or peach—your effort will result in failure, just as Dr. Carrel's experiments resulted in failure when he attempted to transpose the organs of cat and dog.

It would be interesting if Dr. Carrel were to extend his experiments so as to test the possibilities of transposing the organs of different species within a family—say from wolf or fox to the dog, or from lynx or leopard to the cat. Here, to judge from our experiments with plants, the probability of success would be far greater.

At all events, we are commonly able to make such grafts as we choose between different species of the same plant genus; and we may reasonably infer that the same thing might be possible in the case of animals.

Cutting Cion for Whip Graft

The whip graft is made by cutting stock and cion on one side only, and splitting each in such a way that the two may be fitted intimately together. The picture shows the exact method of cutting the cion, and the picture on page 151 shows the corresponding preparation of the stock.

It has also been found that in plant life where there has been much crossing either naturally or by intent in the past that most striking *individual* differences appear. Some individual seedlings among any lot of such crossbred plants (all of which may have come from the seeds of a single variety), will thrive when grafted on certain other species or varieties *even better* than on their *own* roots, while other individual varieties refuse to combine or grow under any conditions; for instances, the common French prune thrives better on almond roots than on its own, the golden drop plum will not live when grafted on the peach while some of its nearest relatives, the common French prune and others, grow, thrive and produce fruit abundantly. It thus appears that artificially produced varieties may acquire really specific difference of a profound nature.

The Mutual Influence of Cion and Stock

Leaving the solution of this problem to the physiologist, however, let us turn to the specific task in hand, and consider that very important part of the plant experimenter's task that has to do with the grafting of vegetable tissues.

It is convenient to recall that the trunk or branch upon which a twig is grafted is called the stock, and that the transplanted twig itself is spoken of as the cion. The practical methods of

Cutting Stock for Whip Graft

The stock cut on one side is split with the knife to receive a cion cut as shown on page 149. The picture shows the exact method of procedure. It will be seen that this is a modification of the cleft graft depicted in the frontispiece and on later pages of the present volume. The whip graft is used for small branches, usually not larger than the one here shown.

grafting, as applied to different varieties of plants, will be detailed in a moment. But first I wish to consider very briefly the mutual influence that cion and stock exert upon each other.

That there is an intimate chemical and vital relation between the immediate living surfaces of stock and cion admits of no question. The very fact that we cannot cause plant tissues to make union unless they are of allied species, is in itself sufficient proof of this. Moreover, the fact that the cion must receive its entire supply of water, conveying all nourishment except carbon (which is drawn from the air) through the medium of the tissues of the stock, suggests that there must be a uniformity of chemical composition between the two that might be supposed to amount almost to identity; particularly after the cion has been in place for a term of years, and has grown from a tiny twig to a large limb.

Yet, in point of fact, there is abundant evidence that the cion maintains its original identity of character from first to last. This may be more readily understood when we know that *all plant food is developed within the foliage.* To be sure the roots supply water, the universal solvent and transportation agent of all life, and small quantities of certain minerals and organic substances in solution, but these are not digested

Whip Graft in Place

The cion and stock shown on pages 149 and 151 respectively are here placed together in such a way that the cambium layers of the bark of the cion and stock come in contact. Only this inner layer of the bark is composed of active living cells, and the graft will be a failure if the living tissues of stock and cion are not in contact. It will be seen that only one edge of the cut surface of the cion is in contact with the cambium layer of the stock. But this serves every purpose.

for assimilation as plant food until combined with carbon dioxide which is transformed in the leaf cells under the influence of the active rays of light, first into fruit sugars and by later transformation to cane sugar but oftener to starch, a more stable form of food substance, in which form it is most commonly stored in seeds, bulbs, tubers or enlarged roots or stems, or to wood and less often to various other substances used in the economy of plant life and quite often useful to animal life and to the industrial life of man. These transformations are presented to us in the various food products and the numerous gums, rubber, coloring materials, drugs, oils, and perfumes.

Thus it will be seen that every organic structure on the earth, every plant and animal whether of earth, sea or air, including man himself, is wholly dependent upon the food always first developed in the leaves of the plants.

But to return to our cions—a twig of the Baldwin apple, grafted on a wild crab apple tree, will produce Baldwin apples, and not wild crab apples. Moreover, the Baldwin apples thus grown will be identical in appearance and flavor with those that grow on the tree from which the cion was cut. This seems very mysterious, but the like of it is matter of every day observation in the orchard of the up-to-date fruit-grower.

Whip Graft Waxed

After the cion has been accurately placed, as shown on page 153, the exposed surfaces, including the entire body of the cion, are painted thickly with grafting wax, applied warm with a brush. If the wax is rather hot, it should be applied first about the bark of the stock, and then carried over the cut surface as it cools. The method of applying the wax with a brush, instead of with the fingers as was formerly done, is a great time saver.

Nevertheless, the question has more than once arisen as to whether cion and stock may not exert upon each other an influence of a profoundly modifying character.

That such may be the case, to the extent of producing a poisonous influence, has been observed in the case of grafts between species somewhat distantly related. It has been observed, for example, that some of the English plums unite with the peach, and do fairly well for a time, while others refuse to unite under any circumstances, and still others when budded or grafted on a peach stock seem to poison the peach tree, even causing its death. Yet, on the other hand, the French prune will often grow better on the roots of the almond or the peach than on its own roots.

In each of these cases, it would seem, there must be an influence, in one case harmful, in the other beneficial, transmitted between cion and stock.

It will be observed that such influences as these merely extend to the life or vigor of the plant, and have nothing to do with the question of transferring its inherent characteristics. And it is universally admitted, that, as a rule, the influence of stock on cion, or of cion on stock, is thus limited. A cion of tender race may thrive

Whip Graft Bandaged

The process of grafting illustrated on preceding pages is completed by wrapping the waxed surface with a bandage, to give further protection, and hold the cion more firmly in place until union is effected. It will be seen that stock and cion are cut in such a way that they interlock rather firmly, but additional stability is given by the bandage. It is obviously desirable that the cion should not move while the tissues are uniting.

on the roots of a hardy stock, for the simple reason that these roots have vigorous growth and large capacity for imbibition of nourishment.

But just as you cannot make a dog and cat identical in constitution merely by feeding them the same food, so you cannot cause a grafted cion on your peach or pear or apple tree to conform in shape or constitution to the stock on which it grows merely by giving it the same nourishment that the stock receives—for as explained above all the most important functions of plant life are carried on in the leaves. Thus we may have an explanation of the fact that the graft governs the root almost absolutely as to variety or individuality, while the roots are purveyors for the foliage.

Sap-Hybridism

Nevertheless, I have had at least one experience in the course of years of practice in grafting that seems to demonstrate the possibility of the transfer from cion to stock of qualities that transform in a very tangible degree the essential characteristics of the plant.

I refer to a case in which the twig of a purple-leaved plum that I received from France was grafted on an old Kelsey plum tree which stood just at the corner of the vine-covered cottage on my old place in Santa Rosa.

The graft was made in the season of 1893. I was exceedingly anxious to hybridize this new and interesting importation with some of my plums, so I watched it carefully. But much to my disappointment, no blossom or signs of blossom appeared during the year. So there was no possibility of making such a hybridizing experiment as I desired.

Imagine then my astonishment when from a quantity of seeds gathered from the Kelsey tree, there grew next season, among other seedlings, one with deep purple leaves. This strange seedling proved to be a thoroughly well-balanced cross between the original purple-leaved graft that I had imported and the Kelsey upon which the graft was growing.

There was a most perfect balance in foliage, fruit, and growth so far as I could judge. The tree was light purple in foliage throughout the season. Its fruit was small, nearly globular, and purple in color even when only half grown.

Everything about the appearance of this strange seedling seemed to suggest that it was a cross between the purple-leaved plum I had imported and the Kelsey. There was no other purple-leaved plum within thousands of miles. My cion had not bloomed, and so crossing could not have occurred in the ordinary way.

So I can see no escape from the conclusion that this was a case of so-called sap-hybridism, the very existence of which has been doubted.

The purple-leaved cion had seemingly influenced its host in such a way as to produce what was to all intents and purposes a hybrid progeny.

The new purple-leaved seedling was grafted upon an old tree, and in due course I produced several thousand second and third generation offspring from the original seedling. The fruit is of a characteristic red color, and in flavor it closely resembles the fruit that the original purple-leaved cion subsequently bore. In size the fruit is intermediate between that of the purple-leaved cion and that of the Kelsey.

The descendants of this hybrid stock vary in the second and succeeding generations, just as they might be expected to do had they grown from a hybrid seed produced by pollenation; thus affording additional evidence that we have to do with an actual case of sap-hybridism.

Grafting to Save Space and Time

I record this case thus at length because of its extreme unusualness.

Never in the entire course of my wide experience have I seen another case in which I could trace such definite influence between the grafted cion and its foster parent. And so we may

Grafted Wood

This shows the heart of an old graft, the original location of stock and cion at the center being revealed, surrounded by the growth of new wood. Of course the woody portions of stock and cion do not unite, but the new tissues formed in concentric layers make the grafted branch practically as strong as other branches of the same size.

take it as a safe general rule that a cion, however grafted, will retain the characteristics of its parent stock, and that the tree on which it grows will be fundamentally uninfluenced, so far as the character of its fruit is concerned, by the intruder.

It is not at all with the expectation of influencing the fruit product of either cion or stock that the familiar process of grafting is resorted to. The chief object of grafting, as practiced in my orchard, is to economize space and save time. As to the former point, it will be obvious that where scores or hundreds of twigs from different seedlings are grafted on limbs of a single tree, we are enabled to watch developments among these hundred of specimens, and by uprooting the original seedlings to utilize the ground they occupy for other purposes.

As to time saving, I have discovered that by grafting small cions near the tip of the limbs of the foster parent, instead of near its trunk, the cion comes much earlier to maturity, and bears fruit in the second season instead of waiting until the third or fourth, as it otherwise would do.

So it is that on a single tree in my orchard almost a thousand different seedlings may be tested simultaneously; and by the practice of selection of early-bearing varieties during the past thirty years, I have produced seedlings of a type

Cutting Stock for Cleft Graft

Here the wedge shown among the implements on page 144 is being used to split the stock, preparatory to the insertion of cions. A glance at the Frontispiece or at the picture on page 165 will show the next stage of the operation, when the cions have been inserted.

which almost invariably bear the second year from my grafting. Indeed, so universal is this, that not one unfruited cion in a thousand will be saved for the third year unless it possesses some remarkable quality of growth, or shows peculiarly prominent and rounded buds, associated with the broad foliage that betokens unusual possibilities of future fruit-bearing.

The reader who has followed the accounts of the long series of experiments necessary to develop say an early-bearing cherry or a stoneless plum will appreciate in some measure the value of a system of grafting which shortens by two or three years the interval between successive generations.

It will be readily comprehensible that by the use of these grafting methods I have been able to attain success in development of new varieties of fruits in half the term of years that would otherwise have been required.

General Principles of Grafting

The single principle that underlies all successful grafting, is that the layer of tissue called the cambium layer, lying just beneath the bark of the twig, shall be brought in intimate contact with the corresponding layer of tissue of the stock on which it is grafted. The life-giving sap flows through this thin layer of tissue only. As to the

Cleft Graft Waxed and Unwaxed

At the left, a cion inserted in the cleft, constituting a cleft graft. At the right, a cleft graft completed, all but the bandaging, by the application of the grafting-wax. The manner of cutting the cion for insertion in the cleft is shown on page 189. The cion is cut in wedge shape, one edge of the wedge being thinner than the other.

central woody tissues—the so-called heart of the twig—there will be no union between stock and cion in any case.

But this is of no consequence since the new growth of wood soon covers the trivial wound with which the cambium layer will make ready union under favorable circumstances; and the growth will continue outward, year by year, until ultimately the cion and stock are so firmly joined that they constitute a branch scarcely less strong than the ungrafted branches of the tree.

But unless the living tissues of the cambium layer are accurately joined, no union can take place, and the graft will be a failure.

If this essential principle is borne in mind, the process of grafting becomes a comparatively simple one, and one that may be carried out successfully by amateurs with very little preliminary practice.

A few specific hints as to the details of the method may, however, be of service. So I shall give a brief account of the methods employed in my orchards, where the process of grafting is carried out thousands of times each year.

Grafting may be divided under three headings: (1) Grafting proper, in which a cion or small shoot is inserted into or upon the stock; (2) Inarching, in which the cion is left attached to

Side Graft in Position

The side graft is made by bending a branch and making an oblique incision with a knife. The cion is cut in wedge shape as for a cleft graft, and it is of course inserted in such a way as to bring the cambium layers in contact. The process is completed by waxing and bandaging as with the other forms of grafting.

its parent stock until union with the new stock is completed; (3) Budding, which consists of the insertion of a single bud upon the cambium layer of the stock. There is no fundamental difference between the three processes; they are merely different methods of accomplishing the same purpose.

Grafting may be more or less successfully carried on at any time of the year. But during the spring and early summer months the vital cambium zone is usually at the maximum of activity, forming wood tissue from its inner surface, and bark from its outer surface. At this time of maximum growth, wounds are rapidly healed, and union between a cion and stock is most rapidly secured. Nurserymen and fruit growers take advantage of this fact.

The most satisfactory results almost always follow spring grafting or summer budding. It is necessary, however, that there should be activity enough in the sap movement to form the cellular connection between the stock and the bud before the latter perishes from drying out; sap flow is also necessary to allow the bark to be lifted readily from the cambium for the insertion of buds.

The best success usually follows the grafting of mature, or nearly mature, buds in the case

Side Graft on a Root

This does not differ from the ordinary side graft except that the cion is inserted in an incision made on the root, which is exposed by digging away the earth. The side graft has the advantage of not splitting the stock, and if the incision is made of just the right size, it may be possible to bring the cambium layers of the bark in contact on both edges of the cion.

of trees and shrubs; though young tender buds often thrive nearly as well.

THE MORE COMMON METHODS

The best and quickest way to graft young seedlings is by "side" grafting. This graft is made by taking a piece of the new wood from the tree to be multiplied, about 2½ inches long with well formed buds on it. Slice off both sides of the lower end of the graft in the form of a sloping wedge, the cut on each side being not much over one inch long. Both sides should be alike, but one of the *edges* should be thicker than the other.

The tree to be grafted is bent to one side with the left hand. With the right hand a sloping gash is made downward on one side of the tree just above the ground, and the graft, described above, is pushed down into this cut as far as it will go. The cambium layers of the cion and seedling meet at some point, and a union of the tree is formed. After the cion has been placed, the tree is allowed to spring back to its upright position, and is at once cut off with a pair of pruning shears, about two inches above the graft.

Warm wax is often applied with a small paint brush over the wound to keep out the water, germs, and dry air, though waxing is often omitted with good success if the graft is well covered with earth leaving a single bud above the surface.

The Root Graft Completed

In side grafting to the root, as shown on page 169, it is not necessary to use wax, as the dirt will afford sufficient protection when replaced and tamped about the cion. It may be desirable, however, to cover the exposed end of the cion with wax.

In grafting cions on the branches of trees, as in transforming large trees or whole orchards, the so-called "cleft" graft is usually employed.

In preparing for this, the branch of the stock tree is sawed off at a convenient place, the exact position being determined by the character of the experiment. If we are seeking to make a permanent tree, the graft is implanted upon the limb not more than a foot or two from the trunk. But where it is intended merely to test the cion as to its fruiting possibilities, time being an object, it is placed far out among the smaller branches by what is called the "tongue," or "whip," graft.

In sawing limbs over an inch thick to serve as stocks, care must be exercised that the limb does not split. In order to avoid this, saw part way through from the top, and finish it by sawing from the bottom. Most persons who graft do not trim the stock after it has been cut, but I have found that the cambium layers join much more readily if the top of the stock is trimmed carefully with a knife so that it is smooth all around the edges. Clean incisions heal best with vegetable just as with animal tissues.

In making the "cleft" graft, the stock is split with a grafting tool. The wedge shaped portion of this tool is for the purpose of holding the cleft open until the cions have been inserted. The

Crown or Bark Graft

For this graft the stock is sawed off as if for a cleft graft, but the incision is made, as shown above, to include the bark only, exposing the cambium layer. The cion, cut wedge shape is inserted, and a waxed bandage is applied. The cion here is not at first held quite so securely as in case of a cleft graft, but, on the other hand, the stock is not split, which is an advantage.

cions are then cut and connected with the bark usually one on each side of the cleft. When the tool is removed, the sides of the stock hold the cions tightly so that it is seldom necessary to tie a string or piece of cloth around the graft. It is usually best to put on a piece of cloth, however, after waxing. This insures more uniform results.

Grafting wax, a formula for which will be given presently, is usually applied several inches below the crack which was made for the cleft in which to insert the cions.

In some cases, however, the stock will later crack below the point where the grafting wax was applied, and when this occurs there is great danger of the graft dying. For this reason it is wise to visit the grafts several times at intervals of a week or so and where any open crack is found, additional wax should be applied.

There are various modifications of the cleft graft. One is used for the walnut and fig which it is almost impossible to graft by the common cleft graft.

Modifications are made as follows: Instead of splitting the cleft, triangular grooves are made with a fine-toothed saw on several sides of the stock. The edges of these splits are pared smooth with a sharp knife and the cions which are usually large, after being carefully fitted, are

Bridge Graft

This is allied to "inarching," in which the cion is left upon its original root until union is made, the plant from which the cion is to be taken being planted close to the one that is to serve as the stock. The two are brought together, and the bark sliced from a branch of each so that the cambium layers come in contact. After union, the stock is cut above and the cion below, thus leaving the cion on a new stock.

driven into these slits with a small mallet. Strong cords are then bound around the stock to help keep the grafts in place until they have united with the stock, when they may be cut to give room for further growth.

All cut surfaces should be carefully waxed as in ordinary cleft grafting.

It is well to tie ordinary grocery sacks over the grafts, covering the stock as far down as it has been cut. These are allowed to remain until the buds have made a good start when they may be torn open and finally removed.

In making all grafts, care must be exercised in getting the cuts on cions and stocks smooth, so that the parts may fit closely together. In the cutting of each side, a single bold clear cut is better than whittling and trimming.

The "tongue" or "whip" graft is used in making bench (i. e., indoor) grafts and sometimes in "top grafting" trees. Top grafting consists in placing grafts on the various branches of a tree in order to change it over to the new variety. The tongue graft differs from the cleft graft in that there is a cleft and wedge on both cion and stock. These interlock when closely pressed together as shown in the accompanying picture. This mode of grafting is seldom used except on limbs less than one-half inch in diameter. It is very difficult to

Cutting Stock for Top Graft

A tree may be made over by cutting off its entire top, and grafting cions to form a new head. Mr. Burbank recommends that the cut edges be smoothly trimmed for this and for all other grafts. The additional time and effort required to smooth the cut surfaces with a knife will be amply repaid by the better results attained.

make the proper cut on limbs larger than this. In top grafting large trees, it is often well to graft only on the strongest limbs one season, and on the smaller branches the next. In general practice, however, a whole tree is usually grafted over at the same time.

"Bark" Grafting and "Inarching"

In grafting chestnuts a modified method called "bark" grafting is best. The cion is trimmed very thin and quite a space is allowed for the cambium layer to come into contact with the cambium layer of the stock. A "T" shaped slit is made in the bark of the stock, cutting through to the cambium layer. The flaps about the vertical slit are turned back, the cion inserted, and the lips of the bark closed over it and bound firmly with a piece of cloth or strong twine to give good support. Grafting wax is applied freely.

Such grafts are usually made on a fairly large stock where it would be impracticable to split the stock. As a rule four cions are inserted on one stock, for usually two of these die. If they should all live, two should be cut out, as the grafts do best when there are not more than two on one stock.

"Inarching," as already stated, differs from ordinary grafting in that the cion is left upon its original roots until the union is made.

Top Grafts in Place

In this case a single relatively large cion has been placed at the end of each stock branch, so that the new head will have approximately the form of the original tree. Many orchard fruits do better on foreign roots, and this method of top grafting is a familiar horticultural procedure. In Mr. Burbank's orchards the grafted cions are usually new varieties to be tested.

The plant from which the cion is to be taken is planted close to the plant that is to serve as the stock. The two are brought together and the bark sliced from a branch of each so that the cambium layers come together. This connection is bound and waxed. After union has taken place, the cion is cut off below the union and the stock is cut off above it, thus leaving the cion on a new stock.

This process is only exceptionally used, as it requires too much time and expense, and with most plants is usually no more successful than the simpler methods of grafting.

GRAFTING WAX

Mention has been made of grafting wax, as being very generally used to protect cion and stock during the process of healing and union of tissue. After testing many formulas, I selected the following, and no other has been used in my orchard for many years:

Eight pounds of common resin and one pound of beeswax or paraffine (either will do if no acid or alkali is present, though beeswax is generally preferred) are mixed with one and a half pounds of *raw* linseed oil. Boiled oils often contain chemicals injurious to plant life. If the wax is to be used in cold weather, it is better to use only seven and a half pounds of resin and a half pound

Cutting a Bud

Budding is only a modified form of grafting. One of its advantages is that each bud will become a separate branch, so that a rare variety may be more fully tested. The bud is removed by slicing off about an inch and a half of bark, including the bud, making the incision just deep enough to include a little of the wood.

Cutting the Bark to Receive a Bud

A T-shaped incision is made in the bark of the stock on which the bud is to be grafted, and the edges about the vertical slit are turned back, exposing the cambium layer. The slice of bark with the bud (see page 181) is then slid into this pocket, and the bark of the stock is folded about it and secured with a string.

The Bud Graft Completed

This shows the completion of the process of bud-grafting, preparation for which is shown on the opposite page and on page 181. It is not necessary to use grafting wax, as the string will hold the bark securely in position until union has taken place. The string should then be removed, that it may not constrict the tree.

of beeswax in the mixture, thus giving slightly thinner consistency.

The ingredients are slowly heated together until the resin and wax are melted and all thoroughly combined. This composition when partly cooled is poured into pressed tin pans, to make cakes of convenient size for handling. The mixture sticks to the tin with great persistence; but by turning the pan upside down and pouring boiling water over it for a few seconds the wax can be shaken from the pan.

These cakes are broken into pieces of convenient size, and in use the wax is kept warm in any convenient dish or pan having a short strong handle. The wax may be heated over a small coal oil stove, and when applied to the grafts should be much warmer than can be borne by the hand, but not hot enough to scald the plant tissues. If heated in a double heater, the outside one containing water, the danger of overheating is lessened.

If applied with care with a small paint brush, first around the thick bark of the stock, and later, as the wax on the brush cools, on and about the cuts and open joints, no harm will result. The plan of brushing the hot wax about the graft, instead of applying it by the fingers in the tedious old-fashioned way, saves nine-tenths of one's time,

Bud After a Year's Growth

The bud grafted as shown on page 183 may remain dormant or take on immediate growth according to season. It may develop a branch several feet in length in the course of a single season. The stock should not be altogether cut away above the bud at first, as in that case there may not be sufficient circulation of the sap to stimulate growth. The picture shows a branch grown from a grafted bud, being trained to upright growth.

and does far better work than could ever be done by the old method.

If the wax should prove to be too soft and sticky, as is sometimes the case in very warm weather, melt it over again with more resin added. If too brittle, add a little more linseed oil so as to bring it to the right consistency to spread well, and at the same time "set" well on cooling. It gives the most satisfactory results when about the consistency of ordinary chewing gum.

Properly applied, the wax serves as a valuable protective and germ-excluding dressing, comparable in its function to the aseptic dressing applied by the surgeon to wounds or after operations.

Multiplication by Budding

There is one form of grafting which differs so radically from other methods that it is often thought of and spoken of as if it were a totally different method. This is "budding"; that is to say, the process of transplanting a single bud from one tree to another. This is really only a special case of grafting; it differs from other methods only in that in ordinary grafting the cion usually has several buds instead of a single one. As a practical procedure, therefore, budding has the advantage of supplying several grafts from what by the other method would be only

Bud With Stock Cut Away

The process of bud-grafting illustrated in the preceding pictures is completed by the cutting away of the stock, so that the branch grown from the ungrafted bud will assume upright growth and make a new top on the tree. Of course buds may be grafted on branches of an old tree as well as on the trunk of a sapling, the process being exactly the same in each case.

a single cion. Therefore budding is generally used for the production of nursery stock on a large scale, or for the introduction of rare varieties, grafting material for which is costly or difficult to secure.

The method of budding is closely similar to the method of "bark" grafting, already described, except as to season—which, for budding, is June, July, and August, while the trees are in full leaf. A piece of bark about an inch and a half long, with a well-ripened bud, is sliced from a twig of the variety desired, the incision being just deep enough to include the cambium layer and perhaps a minute portion of wood.

The bark of the stock is slit horizontally and vertically to form a T; the size of the slits being determined by the size of the bud to be inserted. The upper corners of the vertical slit are gently lifted with a knife and turned back to reveal the cambium layer. The bud is pushed under the bark; the flaps of which are brought over it, and securely tied. Waxing is not usually necessary.

In ten to fourteen days, the bud becomes united to the seedling and the binding cord may be loosened or removed.

The bud remains dormant, until the next spring. When the leaves begin to start, the tops of the seedlings are cut down to within two or

Quince Cion Ready for Grafting

It is sometimes advantageous to cut a cion as here shown, including a portion of older wood. This may be grafted on a large branch to make a permanent tree. On the other hand, where it is desired to hasten fruiting, Mr. Burbank grafts small cions on the smaller branches.

three inches of the bud, all buds being at the same time removed except the one inserted the season before. Thus the vigor of the tree is thrown into the new bud, and by fall we usually have well branched trees from 3 to 6 feet high, according to soil and climate, from the single bud which was placed in the seedling the preceding summer.

Sometimes instead of allowing the buds to remain dormant over winter they are placed on the young seedling trees earlier in the season. Fully ripened buds for such transplantation may often be obtained in June or early in July. After the bud is inserted, the tops of the young trees are at once broken over at about half their height, leaving only a piece of bark and a part of the wood to continue circulation. If the whole top is removed the result is failure.

When the weather is moist or where irrigation is practiced, the buds will often start out even before they are fully united with the stock, though there is a great difference in this respect. Some varieties of hybrid Japan plums and even the common French prune often make 3 to 6 feet of growth the same season.

These are called June buds by nurserymen. When well grown they are excellent trees, as they can be transplanted, leaving the whole root system complete, whereas with trees two years old, some of the roots have to be destroyed in transplanting. Another great advantage in the June bud or yearling over the larger two year old trees, especially in California, is that the tops can be cut down low to form heads of any uniform height desired because all the side buds are young and fresh.

Hints as to Heading and Culture

With most fruit and ornamental trees, the stocks are secured by planting seed. These are planted during the winter in California, and during the fall or early spring in the colder Eastern states.

In general practice, seedlings of pears, cherries, apples, etc., of one year's growth are purchased by nurserymen. These are purchased from persons who make a specialty of producing seedling stocks in large quantities. A large portion of these are imported from France, though American seedlings are being more and more used. These young seedlings are lined out in rows for field culture about four feet apart, being planted from six to twelve inches apart in the rows.

During the summer following, usually in July or August for cherries, plums, and peaches, and in September for apples and pears, budding or grafting may be done to best advantage.

If there is a marked difference in rate of growth of cion and stock, or if for any reason the two do not blend to advantage, an ugly swelling often results at the point of union; hence the experienced grower avoids making such combinations. These plant affinities cannot be foretold; they can be determined only by experiment. As already pointed out, the success, vitality, and growth of a graft will very largely depend upon the affinity between cion and stock.

Occasionally species from different genera may be satisfactorily grafted.

For example, some of the pears often thrive even better for a time and produce superior fruit when transferred to a Hawthorn or apple stock. Almond cions thrive well on peach or plum seedlings. Apricot cions grow and thrive well on seedling plum or peach stocks.

Cherry cions do well on seedling stocks of the wild Mazzard cherry of Europe. The Mahaleb cherry is sometimes used when it is desired to have dwarf-growing trees. The peach generally thrives on its own roots only. Apples thrive best on their own roots or on various wild crab apple roots.

Pear cions do well on seedlings of wild or inferior varieties of pears. Most of the seedlings grown in this country are grown from

Cions Showing One, Two, and Three Buds

A cion with a single bud, like that in the center of the picture, will serve the purpose, and may be employed where wood is precious, as in case of a single seedling of a choice variety. Ordinarily, however, a cion is cut to include two or three buds, thus making allowance for the possible failure of one or more buds. Small twigs like these, if grafted near the ends of branches of an old tree will bear fruit in perhaps half the time that would be required if they were left on their own roots.

seeds secured from Europe. Quince stocks are sometimes used for certain varieties of pears, more especially for dwarfing and bringing into early bearing.

Seedlings of the hardiest and most vigorous growing varieties of plums, either European or American, may be used for plum stocks. The myrobalan plum from France is a favorite. The peach is also used for some varieties. Stocks or the seeds from which to grow them can usually be secured from wholesale growers and dealers.

If it is desired to test the qualities of hundreds or thousands of seedling fruits, a knowledge of grafting is of the utmost importance, as several hundred varieties may be readily tested on a single tree.

On the Gold Ridge Farm there are *single acres* on which ripen several thousand distinct varieties of hybrid seedling plums that could not properly be tested one each on a separate tree on less than about *seven hundred acres* of land. Besides, a seedling grafted into a bearing tree usually produces fruit in two or three years, but if the same seedling were planted as usual and allowed to fruit, it might require five, ten, or fifteen years.

There is still another advantage in grafting many seedlings in a single tree; a better opportunity is afforded for *comparative* tests; if scattered over a large orchard, some trees might be in better condition, or have better roots or better soil than others, and thus no accurate comparative test could be made.

In grafting for the purpose of testing seedlings, the weaker-growing seedlings are placed on the strongest-growing branches of the tree, the stronger growers being placed toward the outside and lower down on the tree and on the smaller branches.

When so many varieties are grafted on a single tree, some may be extremely vigorous growers, others only moderately so, and still others will be weak, slow growers. In the winter pruning we always take pains to give the weaker growers plenty of space to develop, while the stronger growers are severely pruned.

It is no small matter to prune properly a tree on which several hundred varieties are being tested. An ordinary pruner might ruin the tree in a few minutes, by leaving the most worthless varieties almost covering the tree, while smaller, slower-growing varieties of great value might be so crowded that they would either die or become stunted and bear no fruit. This later aspect of the process of grafting, then, is one that imperatively demands the attention of the plant-developer himself, or of his most skilful assistants.

Two Burbank Apples

Mr. Burbank has experimented extensively with apples, and has produced a number of fine new varieties. The one here shown has a peculiar richness of color as well as valued qualities of flesh. In some of his experiments Mr. Burbank has introduced strains of the wild crabapple.

LETTING THE BEES DO THEIR WORK

NATURE WILL HELP US ALL SHE CAN

OUT in the desert regions of the southwestern United States there grows a very remarkable plant called the yucca, or Spanish bayonet. Doubtless you have noticed it from the car window, or you may have seen it growing in a garden. Its bristling array of bayonet-like leaves gives it a very individual appearance, and the cluster of creamy white flowers that it puts forth on its tall central stalk gives it added distinction.

But even if you are familiar with the appearance of the plant, you perhaps have never heard the wonderful story of its alliance with a particular species of insect, upon which alliance the lives of both plant and insect absolutely depend.

The story is one of the most curious ones in the entire range of plant and animal life. Cases of so-called "symbiosis," in which an insect and a plant are mutually modified for mutual aid, are common enough in nature. But so extreme a case as that of the yucca and the insect that is its inseparable associate is seldom duplicated.

The insect in question is a little yellowish white moth, so unfamiliar that it probably has no colloquial name, but known to the entomologist as the *Pronuba yuccasella.* If you were to watch closely you might see these moths visiting the flowers of the yucca in the twilight. You would require exceptional opportunities for observation if you were to discover precisely what takes place during this visit. But entomologists have kept watch to good purpose, and the terms of the extraordinary coalition between the yucca and the pronuba moth are now an open secret.

It appears that the female moth that visits the yucca blossoms has developed a long ovipositor with which she can pierce the tissues of the ovary of the plant and so lay her eggs within it. Her prime object in visiting the yucca flower is thus to deposit her eggs. In due course the eggs hatch and the growing seeds of the yucca will furnish them a supply of food. So there is nothing very remarkable about this part of the procedure.

The surprise comes when we learn of certain maneuvers preliminary to the deposit of the eggs. If you could watch the little moth on her visit to the first flower, you would see her begin at once industriously to gather the adhesive pollen grains with the aid of a curious pair of tentacles growing about her mouth; tentacles unlike those of any other moth.

As the pollen grains are gathered they are rolled into a small pellet, and when this is of a satisfactory size, the moth leaves the flower and flies to another.

But here instead of continuing her task of pollen-gathering, the insect makes her way to the center of the flower and, piercing the basis of the pistil with her ovipositor, lays her eggs among the embryo seeds of the ovary. Then she crawls carefully up the style and, poising at the tip, pushes the little ball of pollen down into the cavity of the stigma.

By this seemingly preconceived and carefully perfected plan, then, the little moth has obviously done precisely the thing necessary to insure fertilization of the flower in which her eggs are deposited, with pollen from another flower.

No plant experimenter, whatever his skill, could have done the thing better.

Cross-fertilization is assured; the ovules among which the eggs of the moth were deposited are sure to develop, giving an abundant supply of food for the larvæ when in due course they are hatched. The little grubs will grow and thrive, and presently will eat their way out of the ovary and fall to the ground, where they will bury themselves for a season; coming forth as adult moths in the succeeding summer, just at the time when the yucca is flowering.

SERVICE FOR SERVICE

At first glance it is not obvious how the yucca profits by this curious arrangement.

But observation shows that the progeny of the moth seldom or never consume all the yucca seeds that are so conveniently stored about them. After they have eaten their fill and have sought a new shelter, enough yucca seeds remain to insure perpetuation of the species. The progeny of the moth have indeed taken toll of part of the crop of yucca seeds in recompense for the services performed by their mother.

But, on the other hand, had not the moth paid its visit, the flower would by no chance have been fertilized at all.

Here, then, is a case in which there is absolute mutual dependence between a particular species of insect and a particular species of plant. In the desert regions it inhabits, the moth could find no other place to deposit her eggs where food would be assured her offspring; and in the burning desert air, the stigma of the yucca, if not placed deep within the tissues, could hardly endure exposure and still perform its function. The arrangement between stamens and pistil of the yucca is such that no other insect is likely to pollenize it, even were there other insects at hand.

All in all, as I said, this is one of the most curious and thought-provoking instances in all nature of mutual dependence between an animate creature and a plant.

One can scarcely leave the yucca and its strange visitor without inquiring how so extraordinary a coalition could have been brought about. Unfortunately no very precise answer can be supplied. We can only assume that the complex and intricate relationship now manifested is the final result of a long series of slight adaptations through which insect and plant were mutually specialized in such a way as to conform to each other's needs.

It is impossible to conceive that any sudden mutation of form on the part of the plant or of habit on the part of the insect could have led to so complicated an alliance.

The change must have been very slow and gradual. First, we may suppose a condition in which the ancestors of the yucca were sometimes visited by the ancestors of the moth, but were not dependent on them for any very complicated method of pollenation. Then successive ages in which the moth gradually developed its special pair of pollen-gathering jaws, while the plant correspondingly shortened its pistil and became more and more dependent upon the peculiar process of fertilization to which the moth was becoming adapted.

To any one who has not thought long and carefully, with the examination of many examples, along the lines of the evolution of organic forms through natural selection, as explained by Darwin, all this will probably seem rather vague and unsatisfactory. And, indeed, it must be admitted that among all the extraordinary cases of adaptation through which insects and plants have come to be mutually helpful, this is at least as difficult to understand as any other.

The seeming intelligence of the act of gathering and depositing the ball of pollen is emphasized by the fact that this pollen is never of *direct* use to the progeny of the moth, yet is vitally important to them *indirectly* because it fertilizes the seed embryos of the plant that are to serve them as food. At first glance, then, one can scarcely escape the thought that the moth must have had some such comprehension of the plant's needs as that which leads the human plant-experimenter to cross-pollenize his flowers.

One might even be excused a momentary half-

Wild and Improved Dandelions

Mr. Burbank often experiments with our common wild flowers, being always on the lookout for varieties that are susceptible of improvement. His success in developing the familiar dandelion is shown in this picture. The improvement was made by selective breeding. Mr. Burbank thinks that it may be possible to improve the stalk and leaves of the dandelion until it becomes an acceptable garden vegetable.

conviction that the insect must be endowed with intelligence almost of the human order.

PLANT INTELLIGENCE

Such a thought is dispelled, however, when we reflect on the seeming intelligence of plants themselves and the apparently well-reasoned schemes by which certain flowers ensure the taking of effective toll of the insects attracted by their nectar.

Even in the case of the yucca, it will be observed that the plant was not quite a passive partner in the arrangement through which the perpetuation of its kind was assured. The pistil of the flower had gradually been depressed below the pollen-bearing anthers, in full confidence that the moth would carry out its share of the mutual compact. And when we reflect that this conformation of stamens and pistil was doubtless modified from an earlier arrangement less advantageous to the plant, we are confronted with evidence of a seemingly intelligent capacity to adapt its structure to its needs on the part of the plant that to some extent matches the apparent intelligence of the insect.

Similar evidence of seeming design on the part of flowers in the arrangement for guarding against self-pollenation meets us on every side.

Consider, for example, the way in which the lilies project the receptive stigmas far beyond the stamens; or the way in which the amaryllis, the carnation, the balloon-flower, the geranium, and numerous others effect the same purpose by careful provision that the stamens and pistils of any given flower shall not come to maturity at the same time.

Then there are plants like the sage, the stamens of which seem to lie in wait for the visitor; being observed to bend quickly over, under stimulus of contact, and rub their pollen on either side of the insect's back. Again there is the milk-weed *(Asclepias cornuta)*, which stores its pollen in tiers of hand-bags connected with a strap that entangles the feet of the bees—and which, in its over eagerness to make sure of the transfer of its precious wares, sometimes defeats its own purpose by so overloading the insect that it cannot fly away.

There are water plants, too, that adopt methods to secure cross-fertilization that are ingenious and wonderful almost beyond belief.

Thus the little water plant called *Villarsia nymphoides* sends out its flowers from its submerged haunts as little detached balloons that float to the surface of the water and then burst open to offer their pollen to the insect messengers.

And the eel grass *(Vallesneria spiralis)*, by an even more wonderful arrangement, projects its pistillate flower up to the surface of the water on a long spiral stem grown solely for that purpose; while its staminate flower strains at the short stalk on which it is tethered until it breaks away and rises detached to the surface. The pistillate flower, once pollen has been brought to it by the insects from its floating mate, is drawn again beneath the water by the recoiling stem, never to reappear.

In the pre-evolutionary days, such instances as these were cited as giving incontrovertible evidence of design in nature.

But no one nowadays regards them in that light, if we use the word in the old teleological sense. Since Darwin taught us the way, we are able to explain these marvelous adaptations; but as evidences of the operation of the great principle of natural selection they are no less wonderful.

And most remarkable of all, as viewed from the present standpoint, are the orchids, the extraordinary pollenizing devices of which were first made generally known through the studies of Darwin. A familiar illustration of the methods adopted by this curious tribe is furnished by the species known as *Orchis mascula,* which bears its pollen in small bundles at the end of a slender stalk, at the other end of which is a disc covered with a sticky secretion. An insect cannot secure nectar from the flower without carrying away at least one of these pollen stalks.

But the most remarkable part of the operation is that, so soon as the insect withdraws from the flower, the pollen stalk attached horn-like to its head, bends over and curls itself into precisely the position that will inevitably cause it to strike the pistil of the next orchid that the insect visits.

Another species of orchid, known as *Orchis pyramidalis,* grows two pollen bundles held together by a sort of collar, with which it decorates its insect visitor, clasping it, for example, about the proboscis of a butterfly. Here as in the other case the pollen-carriers adjust themselves in precisely the right position for the deposit of their important burden; and in this case the arrangement is such that a portion of the fructifying powder is deposited on each of the two pistils with which this species is equipped.

The Senses of Insects

It is needless to multiply instances of the wonderful adaptations of form through which the various species of plants have made sure that the insects for which nectar is provided shall carry out their part of the bargain.

Some flowers have long tubes which only the coiled proboscis of a moth or the slender bill of a humming-bird can fathom. These are sure to provide pollen-carriers of a bulky character which only humming-birds or large insects like the moth could transport. Mechanisms may even be provided to exclude from the nectar chamber bees and other small insects that could be of no service to the flower.

But such cases, while in the aggregate numerous, are on the whole very exceptional. In general the plants with which the horticulturist deals, and particularly the plants of the temperate zone, have contented themselves with a much more simple arrangement, whereby the pollen-bearers are so arranged that any small insect that visits the flower is sure to go away laden with pollen.

In particular, provision has been made by the vast majority of flowers of the orchard and garden to attract a single species of insect, the bee.

This familiar insect, the one member of its vast tribe that is directly helpful to man as a producer of food, is the indispensable coadjutor of the most important varieties of cultivated plants. Bees of one species or another are the universal distributors of pollen in orchard and garden. The beautiful flowers that the apple and plum and cherry put forth, and the perfumes they exhale, are primarily designed as advertisements for the bee and the bee alone.

Verbena Bed

This view in Mr. Burbank's experiment garden at Santa Rosa gives an impression of quantity-production as applied to a familiar flower. Mr. Burbank will inspect carefully each blossom in this bed, and will select the few specimens that show a tendency to vary in a desired direction. By such selection, he has developed, among others, a valuable race of scented verbenas.

Whoever realizes this truth will not be likely to doubt that the bee, in common with other insects, has good olfactory organs and an eye for the discernment of color. Yet there have been entomologists, even in recent times, who have questioned whether insects really have the sense of smell, and, others who have challenged their color sense.

As to the latter point, whoever has taken the trouble to observe the maneuverings of an individual bee in the flower garden, and has seen it pass from one red flower to another, confining its visits exclusively to blossoms of one hue, will have gained sufficient evidence that the bee is by no means color blind.

As to the sense of smell, if further evidence than that supplied by every-day observation of the visits of insects to perfumed flowers were required, it is furnished by an interesting and remarkable experiment made by Professor Jacques Loeb, formerly of California University, now of the Rockefeller Institute in New York.

Professor Loeb placed a female butterfly in a cigar box. Closing the box he suspended it in mid-air between the ceiling and floor of a room, and opened the window.

"At first," says Professor Loeb, "no butterfly of this species was visible far or near. In less than an hour a male butterfly of the same species appeared on the street. When it reached the high window its flight was retarded and it came gradually toward the window. It flew into the room and went up to the cigar box upon which it perched. During the afternoon two other males of the same species came to the box."

A commentator observed that the experiment makes it unequivocally clear that insects possess an olfactory sense of almost inconceivable delicacy. But the question as to what is the real character of the stimulus that produces the sense of smell, is one of the mysteries of science.

"A substance like musk," he says, "may give out a characteristic odor continuously for an indefinite period, while the substance itself appears to lose no weight. If particles of the odoriferous substance are really thrown off, these particles must be almost infinitely tenuous. If, on the other hand, the stimulus is due to the giving out of waves or vibrations comparable to the waves of light or of sound, the nature and other characteristics of these manifestations of energy are absolutely unknown."

Another experimenter has shown that ants will follow a trail that has been made by other ants bearing honey or sugar. The inference seems obvious that the ants are following a very delicate trail by the sense of smell. But perhaps it is well, considering the unrevealed nature of the stimulus associated with odors, to adopt Professor Loeb's cautious phrasing and speak of the sense through which insects are guided to odoriferous objects as "chemical irritability."

The fact that a bee is able to travel in a straight line backward and forward between its distant hive and the flower bed or the apple tree from which it is harvesting, even though the distance be a matter of miles, suggests the possession of organs of sense of a far more delicate character than our olfactory nerves.

It is hardly probable that vision is an important aid in these long-distance flights; for Professor Loeb's experiments have led him to infer that the dioptric apparatus of insects is very inferior to the human eye. Moreover the flowers would scarcely find it necessary to put out expansive corollas and deck themselves in gaudy colors if their signals were meant for creatures having very acute vision.

In point of fact, the complex multiple eye of the insect, devoid of any such adaptive apparatus for focusing as the lens of the mammalian eye, does not suggest acuteness of vision, but rather a more or less vague appreciation of large masses of color.

The recent experiments of Dr. Charles A. Turner, of the St. Louis Academy of Science, have, indeed, demonstrated that bees can distinguish between color patterns as well as between different colors. But, although the tests of the naturalist Plateau, which seemed to show that insects are attracted solely by odor, are thus controverted, it doubtless remains true that the sense of smell—or some equivalent sense of a kind as yet unanalyzed—is the chief guide in bringing insects from a distance to the vicinity of flower bed or fruit tree.

Professor Loeb declares that the "chemical irritability" of the insect, as excited by odoriferous objects, is immeasurably superior to the sense of smell of human beings, and possibly even finer than that of the best bloodhound. Observation of the honey-gatherer making his "bee line" from hive to orchard and back again prepares us to accept this statement at its full valuation.

There must even arise a question as to whether the insect's equipment of "chemical irritability," or whatever it may be called, does not amount to the possession of a sixth sense.

Aiding the Bee

We have instanced over and over the vital importance of the process of cross-fertilization which the bee accomplishes for the flower.

It may be of interest to cite a few familiar illustrative instances of devices adopted by certain familiar flowers to make the services of the bee surer and more effective. Inasmuch as the bee has no conscious share in the plant's solicitude to effect cross-fertilization, it has been found expedient on the part of many flowers to adjust the arrangement of stamens and pistils in such a way that the visiting insect shall surely receive a modicum of pollen, yet cannot rub this pollen against the stigma of the same flower.

Some illustrations of what might be called extreme measures to prevent such inadvertent self-fertilization, were given earlier in the present chapter. Let us note a few additional instances, with reference in particular to flowers that are largely pollenated by the bee.

A simple and effective method of guarding against self-pollenation we have seen illustrated in the common geranium *(Pelargonium)*.

When the geranium flower first opens, a little cluster of anthers may be seen on the tip of the erect filament in the center of the bright, showy flower. At this stage the undeveloped stigma lies closely folded up and wholly unreceptive among the stamens. But soon after the pollen has been shed or gathered, the anthers drop off; then the stigma spreads out its five receptive lobes from the tips of the connecting filaments, and is ready to receive pollen from another flower.

In the snap-dragon flower, and in many other

Wild Flowering Peach, and Improved Variety

Nearly all wild forms of plant life are susceptible of improvement comparable to that shown in the above illustration. Mr. Burbank is always on the lookout for variation among individuals of a species. Wherever such variation occurs it may be accentuated by selective breeding. As a rule further variation is stimulated by hybridizing experiments. In making such an experiment, Mr. Burbank usually has in mind many qualities. In such a case as the above, for example, not only size and color of blossom, but profusion and certainty of bearing would be among the characters carefully watched.

related plants, the anthers lie along the roof of the corolla tube, where they are brushed by insects that pass down the tube in search of nectar. The stigma holds a similar position, but is farther out toward the mouth of the tube. The stigma is a very interesting structure; it is composed of two flattened lips, which respond to the slightest touch.

When a bee, after visits to other flowers, enters the tube, the hair-like appendages on its back brush against the lower lip of the stigma, and the irritation causes the lips to close tightly together, coming thus in contact with and scraping the pollen-dusted back of the bee.

Whether or not the receptive lips have secured any pollen, they remain closed for four or five minutes, so there is no danger that they will encounter the bee as it leaves the flower laden with a fresh supply of pollen from the companion anthers. But a few minutes later the stigma lobes open again, like a trap set for the next visitor.

Human ingenuity could not well devise a mechanism better adapted than this to secure cross-pollenation and ensure against the possibility of self-fertilization.

The foxglove *(Digitalis)* also has stamens and pistils lying along the roof of the corolla tube. Its device to prevent self-fertilization is the less ingenious but equally effective one of ripening the stigma only after the pollen has been discharged—an expedient which, as we have seen, is very commonly resorted to by other species of plants, including the lilies.

The Spanish broom *(Spartium junceum)* is a typical butterfly-like flower, that, in common with others of the same family, has developed a peculiar mechanism to bring about cross-pollenation. The two lower petals are joined together into a keel-shaped structure that connects the stamens and pistils. The other three petals are more enlarged, and are spread to make a more effective advertisement, challenging the attention of insects. The visiting bee naturally alights upon the projecting keel. The weight of its body presses this downward and the stamens and pistils, by a spring-like action, are thrust out against the body of the insect, scattering the pollen freely.

Thus the stigma may become covered with pollen that the bee has received from some other flower while the anthers supply a new coat of pollen for future distribution.

Still a different arrangement is that of the common iris. Here the anthers lie in a fold of the large petal-like branches of the style. The stigmatic surface is confined to a little crescent-shaped patch near the tip of the style-branches, and is protected by a thin, sack-like shield. The

Two Burbank Peaches

Mr. Burbank has done a large amount of work with the peach, one of his recent introductions being the excellent new variety named the Opulent. He has hybridized the peach with the nectarine and with the almond. A smooth-skinned peach that bears an edible almond seed at its center is among his interesting developments.

structure of the flower is such that an insect as it passes down the petals on its way to the nectary, brushes against the anthers, and dusts off the pollen. As the insect passes out, the stigma-shield protects the stigmatic surface completely.

But as the insect visits another flower, its pollen-covered back comes in contact with the edge of the stigmatic shield and the pollen is scraped off against the receptive surface.

These, then, are familiar illustrations of the really wonderful adaptations through which it comes to pass that the bees carry out their part of the ancestral compact that ensures the plant such interchange of pollen as is essential to racial progress. Perhaps the most alluring feature of the entire coalition is that the bee performs its all-important function unwittingly in the course of the quest of sweets that appeal to its appetite. There is no compulsion in the matter; the plant depends upon the more powerful influence of persuasion.

And to add to the satisfactoriness of the entire arrangement, from a human standpoint, it must be recalled that the efforts of the industrious insect, which thus make possible the work of the plant experimenter, result at the same time in storing the nectar gathered from the flowers to form one of the most delectable of foods.

Patagonian Squash

The members of the squash tribe are readily fertilized, as illustrated in earlier pictures of this volume, but the hybrids tend to show extreme variation, and they are very difficult to fix. Mr. Burbank has shown, however, that it is not impossible to fix new varieties by careful selective breeding. The squash here shown was developed from seed sent from South America. It has almost the solidity and weight of a cannon ball.

FIXING GOOD TRAITS

HOW TO HOLD A RESULT
ONCE ACHIEVED

IT IS traditional that you cannot teach an old dog new tricks. The maxim applies with full force to old plants. You may bend the twig and make a permanent twist in the future tree; but the hardened stock of the matured branch will return persistently if bent, and will break rather than change its form.

Now there is something like the same difference in flexibility between young and old races of plants. Here is a variety of plant that has been developed in the orchard or garden, under man's influence, in the course of the past few generations. It tends to vary, and its progeny may be made to adapt themselves to different conditions; by selection, they may be developed into divers and sundry new races.

But yonder palm tree has no such propensity to vary. Its ancestors have remained substantially unchanged, true to their racial type, generation after generation, for untold centuries. It represents an old, fixed, conservative stock. No one knows how to make it change, except within the narrowest of limits.

There is a very essential time element, then, that is instrumental in determining the fixity or variability of a race of plants. A plant that has been bred true to a given type for long periods of time, as is the case with the generality of wild plants, will breed substantially true from seed, and as a rule will maintain its racial type even if transplanted to new surroundings.

But, on the other hand, the generality of cultivated plants are of mixed ancestry. Man has attempted within recent generations, to change them and adapt them to his needs. He has constantly been hybridizing them, or placing them under conditions that resulted in their hybridization through the visits of bees; and he has selected and cultivated the individual specimens that tended to vary, and thus has fostered the habit of variability rather than that of fixity of character.

In the case of most orchard fruits, as we have had occasion to observe more than once, so many strains are blended that propagation from seeds is quite out of the question; unless, indeed, it be desired to secure seedlings of varying qualities in the interests of experimentation, or in the attempt to develop still other varieties.

One might plant a thousand acres with seeds of the Baldwin apple, without perhaps producing a single plant that would precisely duplicate the qualities of the fruit from which the seeds were taken. And the same thing is true in greater or less measure of the majority not merely of orchard fruits but of cultivated plants in general.

The notable exceptions are annual plants that are habitually grown from seed, such as melons and peas in the garden, and the great tribe of cereals represented by wheat, oats, rye, and barley. The reason why all of these breed true from seed is that they are necessarily propagated in this way alone, and it has been essential that fixed races should be developed.

Mankind depends largely upon the cereals for food, and his existence would be altogether precarious could he not have reasonable assurance that when he sows grain of a certain quality, he will secure a crop of grain of similar quality.

The fixity of character of the cereals and various other plants, including peas, and beans, is enhanced and assured by the fact that the flowers of these plants are habitually self-fertilized. If you examine a head of wheat at the right stage, you will find that you must pull open the little bracts in which the flowers are encased, in order to make the stamens and pistils visible. Under ordinary circumstances, insects cannot find access to them. The wind has no influence over them. Their normal habit is to fertilize the pistil of each individual flower with pollen from the stamens that grow within the same closed receptacle.

This is inbreeding of the closest and most intimate character, and there is obviously no ordinary opportunity to introduce the element of variability which, as we have seen illustrated over and over, cross-fertilization brings.

So the essential qualities that make wheat valuable have been aggregated in a few fixed combinations, and the resulting varieties of wheat, differing not very widely from one another, are never crossed, unless by artificial means to meet the special needs of the plant developer.

They remain fixed because they are of pure lineage.

Mixed Ancestry and Inbreeding

The case of the wheat is typical. Its development furnishes an illustration of the method through which many specialized races of animals and plants under domestication have been developed. Indeed, it might almost be said that the one rule that has actuated the developer of special races has been to apply the principle of inbreeding. When an individual appeared in a herd or flock that showed certain peculiarities that the owner thought desirable, the natural and obvious way of perpetuating these was to breed from that individual; and then persistently, for a time, to inbreed the progeny in order to accentuate the desired trait.

The result has often been all that could be expected. Take, for instance, the case of the trotting-horse.

It is, I believe, a matter of record that practically the entire stock of trotters, as developed in America in the past hundred years, descended from a single ancestor, the celebrated "Messenger." This individual horse chanced through some accidental mixture of ancestral strains to combine in its organization the particular qualities of nerve and muscle that adapted it for rapid progress by trotting instead of by the more natural method of running.

And as regards this quality or combination of qualities, the horse proved amazingly prepotent.

Its descendants soon constituted a race of trotters. Pedigrees were kept; the best individuals of the new race were selected as breeders; closely related animals were mated; and the characteristics that make for speed at the trotting gait were in a few generations so fixed that a new race of horse was produced.

The principle thus illustrated applies with equal force to the breeding of plants. Indeed, it is possible here to hold even more rigidly to the idea of inbreeding, inasmuch as the individual flowers may be self-fertilized. We have just seen this illustrated in the case of the wheat and allied cereals.

There is no question whatever that any given characteristic of a plant, once it appears, can be accentuated and fixed, first in individuals, and finally indelibly in the heredity of the descendants of the plant by systematic inbreeding.

But, unfortunately, there are complications in the case of most experiments that the originator of new plants is called upon to undertake, that robs the method of its simplicity. The complications arise from the fact that the would-be originator of new races of fruit or flowers is usually seeking to develop not merely a single quality, but a number of qualities. And this alters the case fundamentally.

In the case of the trotting-horse, the one all-essential quality desired is speed.

The capacity to trot a full mile at high speed does, indeed, imply the possession of stamina and courage, as well as capacity for rapid action of the legs. These are qualities that are necessarily linked with the capacity for the right kind of muscular action.

But beyond this there are very few qualities upon which the breeder must insist. It does not greatly matter whether the speedy animal is small or large; its color is mostly a matter of entire indifference; and it is taken as a matter of course that the record-breaking animal will be nervous in temperament, tender as a hothouse plant, and requiring such care and attention as would be only wasted upon a more plebeian animal.

In a word, the breeder of trotting-horses fixes attention principally on the single quality of speed.

But it is rare indeed that the would-be developer of a new plant can thus fix attention upon any single quality to the disregard of other qualities. On the contrary, as a rule, the plant experimenter, while he may have in mind one most important quality, must consider at the same time six or eight or ten or a dozen other qualities that are only a degree less essential. We have seen this illustrated again and again, and we shall have occasion to recall some of the specific characters involved in the course of the present discussion.

In reality, the task of the experimenter who would develop a new and really valuable variety of plum or cherry or apple or spineless cactus, is to be compared not with the task of breeding trotting-horses as they are, but rather to the task that would confront the breeder were he to attempt to develop a race of trotting-horses which should retain the capacity to trot a mile in less than two minutes, yet at the same time should be big and powerful enough to serve on occasion as draught horses; should be always of some predetermined color, say bright bay; and should be as hardy and require as little attention as the toughest broncho.

It requires no great amount of imagination to see that the task of breeding race horses would be quite different from what it is, were the specifications such as these.

Yet I repeat that the qualities that the plant experimenter usually seeks to combine in his new variety of flower or fruit are at least as varied and as difficult to fix in combination as the qualities just suggested for the supposititious new breed of race horses.

The Shasta on the Witness Stand

Let us by way of illustration recall the case of the Shasta daisy which, the reader will remember, was developed by the union of three different

Rose Cuttings—Developed by Selective Breeding

A new variety of rose—developed by selective breeding—may be propagated by merely cutting the branches into sections, and planting them in the way illustrated on page 135. It is of course necessary to have at least one bud, and preferably two or three, on each cutting. Mr. Burbank has developed some very remarkable new varieties of roses, including one that received a gold medal at the St. Louis International Exposition in 1904.

species of flowers, coming respectively from Europe, America, and Japan.

It will be further recalled, that the ideal daisy that I had in mind for years before it became an actuality, showed in superlative degree a considerable variety of qualities that were not found in combination in any one of its ancestors. Indeed, the Shasta daisy, as ultimately developed, reveals a number of very conspicuous and important qualities that are not shown at all in any one of its known progenitors.

To make the illustration specific, we may cite, among the qualities that are assembled in the finished product, the following: (1) extreme size, (2) dazzling whiteness, (3) broad rays, (4) double rays, (5) gracefully drooping rays, (6) keeping quality of flower, (7) smooth stem, (8) early and persistent blooming, (9) hardiness, (10) constant bearing.

The perfected Shasta daisy manifests these qualities in supreme degree. As regards each and every one of them, it surpasses any of the parental forms from which it sprang; indeed, as to some of them, such as double and drooping rays, it shows an entire departure from all of its observed ancestors, harking back to the remoter forms of past ages.

But to assemble these qualities in a single flower required about fifteen years of persistent effort, and the handling of probably not less than half a million individual seedlings.

Generation after generation the plants were cross-pollenized and selected over and over, always with an eye not merely to a single quality, but to the ensemble of qualities.

And always we were confronted with the difficulty that in reaching out to bring in some new quality, we were disturbing the balance of qualities already attained, and endangering the entire structure.

When, for example, the final cross was made with the Japanese daisy, to secure if possible the element of whiteness shown pre-eminently by that flower, and add it to our mosaic, we, of necessity, brought in also from the Japanese parent, along with the quality of whiteness, such undesired qualities as crude, ungraceful stems and flowers.

It was necessary to select and interbreed, and select again, for successive generations from among a multitude of the progeny of this cross, before a plant was finally secured that presented the desirable combination of qualities, retaining the whiteness of the Japanese parent, but rejecting its undesired characteristics of leaf and stem, and departing utterly from that particular parent in point of size.

But, although an individual was at last found that did combine all the desired qualities, the very fact that this individual had been built up by putting together *this* quality brought from one parent and *that* quality from another, with the rejection of antagonistic qualities in each case, makes it inevitable that the perfected Shasta should contain latent in its system a whole coterie of tendencies which are fighting for recognition, and which will make themselves felt in subsequent generations.

Hence it is that when seeds are gathered from the perfected Shasta they will not give us a crop of flowers like their parent. On the contrary, they will show the utmost diversity of form and size and color, making tangible thus the persistent force of the hereditary tendencies that had been transmitted from divers ancestors, but which were submerged or made latent, simply because they were momentarily subordinated to opposing qualities, in the case of the perfect Shasta.

The Shasta daisy, then, while individually almost a perfect embodiment of the ideal at which I aimed, is when reproduced, from seed, anything but a fixed type. Had it not been possible to propagate the plant by division and then by an unending series of successive divisions to produce an indefinite number of individuals, each precisely like the original because they were in a sense a part of it, my entire series of experiments in developing the new daisy would have been unavailing except for still further selection. But as the case stands, it was possible rapidly to develop an entire race of Shasta daisies by root-division, and thanks to this method the descendants, or, to speak somewhat more accurately, the *sisters* of the original Shasta daisy have become an enormously populous race, scattered to the remotest parts of the earth.

Several other types of Shastas have been developed by new breeding experiments from the original stock, but to this day the race of Shasta daisies must be propagated from the root, and not grown from seed, unless one desires a conglomerate progeny, departing in many ways from the form and quality of the immediate ancestor.

Fixing a Type

In all this, it must be recalled, the Shasta daisy does not differ from a large number of long-established cultivated plants that are everywhere recognized as being "fixed" races.

One does not produce apples or pears or cherries or plums or blackberries or potatoes or sugar cane or horse radish, to say nothing of roses, ornamental shrubs and a great number of flowering plants, from seed.

Wild Grapes

There are a good many species of wild grapes, and Mr. Burbank has utilized several of these in his experiments. His chief work with this species has been done, however, with the common European cultivated grape, which has developed a large number of varieties through being selected for various purposes during past centuries. In particular some of his most important new varieties are descended from a "bud sport,"—that is, a variation that appeared "spontaneously" in a branch growing on an ordinary grape vine.

They are propagated by grafting or budding, or by rooting the stem or dividing the roots or planting the tuber. And the reason in each case is the same. The perfected variety originated from a single individual that combined a large number of desirable qualities, and the entire company of individual representatives of that variety, though they be numbered in millions, are not really descendants, but offshoots, of the original individual.

Each cion or bud from a given tree will produce fruit precisely like that from the tree from which it is taken, because it is itself a part of the tree. And however widely new cions and buds from the first cion may be disseminated, they carry the same traits, because, rightly considered, they are a part of the same individual organism. The Seckel pear tree that grows in your dooryard is, from the standpoint of heredity, a tree of the same generation with untold thousands of other Seckel pear trees that have grown here and there across the hemispheres for more than a hundred years—or since the first one appeared in the orchard of the Pennsylvanian whose name they bear.

Were it not for the contradiction of terms, one might say that all Seckel pear trees constitute a single tree.

All these Seckel pear trees are essentially alike; they bear fruit that may vary in size and lusciousness with varying conditions, but that is everywhere essentially identical in flavor and in the characteristic qualities of texture and color. But if you plant the seeds of one of these pears you do not secure Seckel pears, unless by the merest chance, among the progeny. You secure instead, representatives of a galaxy of ancestors, no one of them individually just like the Seckel, although *collectively* they represent all the qualities of that fruit, plus almost numberless undesirable qualities.

PAIRS OF QUALITIES

The fact that our most familiar and best prized fruits and flowers show this lack of fixity, suggests that the inherent difficulties in the way of fixing the type of these plants so that they will breed true from seed are very great. Otherwise some one would long ago have remedied the defect, for the advantages of being able to grow these useful plants from seed are obvious.

Nevertheless it should not be assumed that the task of fixing the type of a newly developed race of fruit or flowers is of necessity a hopeless one.

The truth is that it would be possible to fix the type of almost any variety of plant, provided time enough and patience enough were devoted to the task, and the experiment were conducted on a wide enough scale. Indeed, nothing more would be necessary than to continue for an additional number of generations the same line of experimentation through which the new varieties were produced; attending carefully at all stages to the analysis of the different qualities that prove to be mutually antagonistic.

To this end, the new terminology which endeavors to analyze the qualities of a given plant into complementary pairs of unit characters may prove very helpful, particularly to the inexperienced investigator.

Such an analysis has always been made, tacitly at any rate, by the successful plant experimenter. No one can think of the development of an *early*-fruiting cherry or prune without having in mind the quality of *late*-fruiting. To speak of a prune with *high* sugar content implies one with *low* sugar content.

In a word, the desired quality of fruit or flower at which one aims is always balanced against the opposing quality—sweet fruit against sour, hardiness against tenderness, resistance to disease against susceptibility to disease, profuse bearing against scant bearing, thorny brier against smooth brier, black fruit against white fruit, and so on down the list.

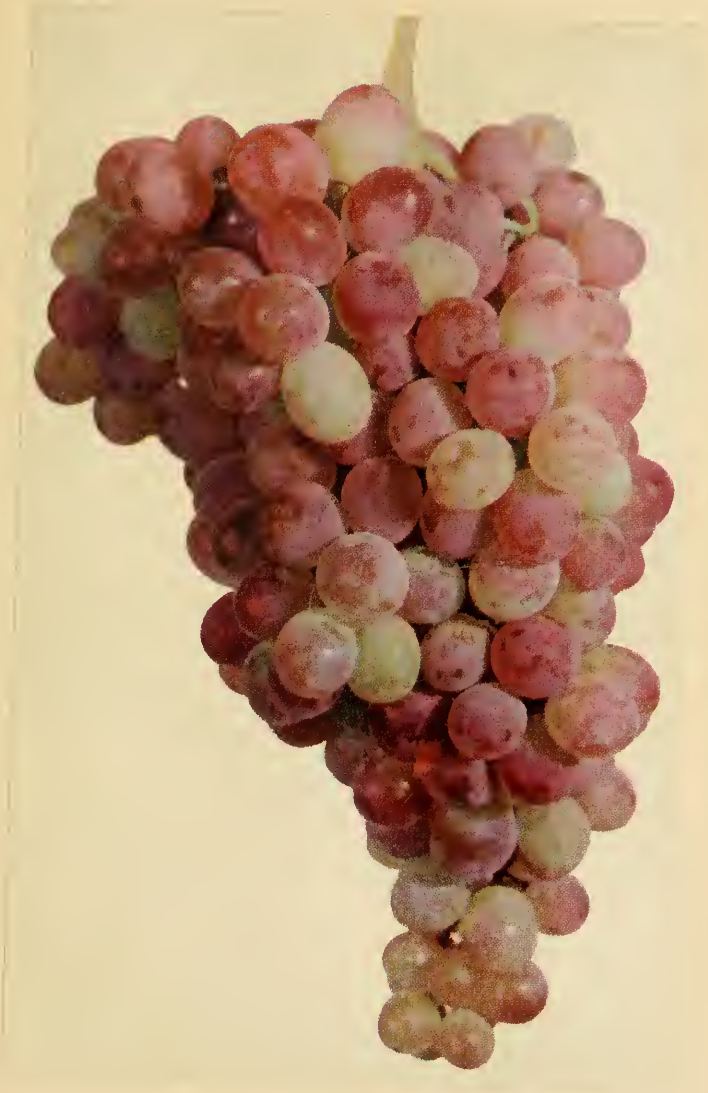
It is only by constantly bearing these divergent pairs of qualities in mind that any experimenter can hope to advance toward the production of an ideal fruit or flower or vine. And it has always been so.

OLD WINE IN NEW BOTTLES

But there can be no question that the new terminology, as used by present day biologists, serves to give precision to the ideas of the plant experimenter, and enables him to analyze the results of his experiments in more precise terms than have hitherto been available.

It will be convenient, therefore, and probably helpful to the reader, in making precise reference to some of the experiments in plant breeding already detailed, with special reference to the possibility of fixing the type of new races, if we discuss the matter in the new terminology.

It will at once appear that when a plant developer attempts to fix a certain type, he is fundamentally changing his point of view. Hitherto he has been concerned to make plants vary, in order that he might seize on new forms, and use them as material for developing the type at which he aims. And his success in developing a new race is largely dependent upon the extent to which he has been able to induce the plants with which he experiments to vary.



Seedless Grapes

This shows one of Mr. Burbank's choicest varieties of new seedless grapes. They have been developed by selection, and are of delicious quality, with an added attractiveness due to the entire absence of seeds. Of course a fruit thus developed must be propagated by cuttings, and is not susceptible of further improvement, unless there should be a reversion to the seed-bearing condition.

So now, when he attempts to restore fixity to something that he has purposely made unstable, he is at once confronted with the danger of undoing much that he has accomplished. The measure of success that he can hope to attain will depend very largely upon the particular kind of unit characters that he has combined in the product that he now wishes to make stable.

We have seen that, as between the opposing members of any pair of unit characters, it is usually discovered that one has prepotency or dominancy over the other. When blackberries of normal color, for example, are crossed with the white blackberry, the progeny are all black, because this color is the dominant member, and white the recessive or negative member of the pair of unit characters. But we saw also that the recessive trait will reappear in the succeeding generation, and that when it does reappear, it will, within certain limits, thereafter breed true.

So, when in the second generation we again produce a white blackberry, we have a type which is fixed as regards the particular character of whiteness. In other words, our white blackberry, even though both its parents, and one grandparent, were black, may be considered a berry of pure white strain. From the moment of its appearance it is a fixed type as to color.

But, unfortunately, it is not sufficient that the white blackberry should breed true as regards the quality of whiteness alone. There are other qualities of size and flavor that are equally essential. And these, it would appear, include sundry other pairs of unit characters—sweetness versus sourness, large size versus small size, profuse bearing versus scant bearing, and the like—that are represented in our berry by mixed factors.

In the Mendelian view, it will be recalled, there are always two factors representing any pair of unit characters.

In the case of our white blackberry, in the Mendelian view, both factors for the unit character blackness-versus-whiteness are of the white order; or in the technical phrase, the berry is "homozygous" for that pair of factors.

But as regards, let us say, the factor for the unit character bigness-versus-smallness the case is different; for this character may chance to be represented by one factor of each type. In other words, resorting again to the technical language, the berry may be "heterozygous" as regards that character.

In this particular generation, the quality of bigness prevails, because bigness is dominant to smallness. But the factor for smallness must have a hearing in the next generation.

Until we can produce a white blackberry that is "homozygous" for size-factors as well as for color-factors, we shall not obtain a fruit that will breed true to size as well as color.

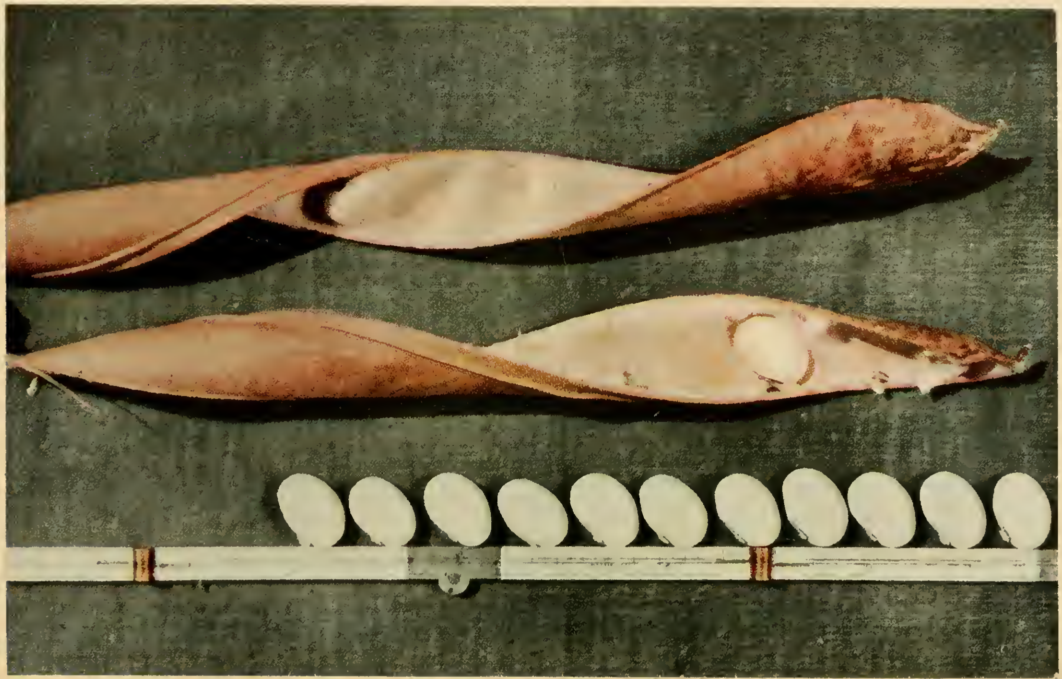
A similar analysis might be applied to the various other pairs of unit characters that are represented in any given fruit or flower. And the essential principle, stated in Mendelian terms, to be aimed at by the experimenter who would fix a newly developed type of plant so that it will breed true from seed, must be to render the plant "homozygous" for the factors of each pair of unit characters involved. If that can be done, the plant will breed true; if that cannot be done, the plant will not breed true.

In the olden phrasing, this would be spoken of as "line" breeding—a method long familiar to every breeder of plants or animals.

Fixing a Type in the Second Generation

In actual practice, where only two or three unit characters are involved, it may be possible to produce a new type that breeds true, or is fixed, in the second generation. In such a case the time element may be ignored.

Take, by way of illustration, Professor Castle's guinea pigs, to which reference has more than once been made. Suppose we have as parent stock a black guinea pig with a smooth coat, and



New Chilian Beans

Mr. Burbank for many years had a trusted collector in Chili, from whom he received numerous interesting new plants. This bean has been developed by selective breeding until it produces large seeds of extraordinary uniformity of size and shape. Hybridizing this bean with cultivated varieties will probably produce interesting variations.

a white guinea pig with a rough coat. Now we have already seen that blackness is dominant to whiteness as regards the coat of the guinea pig, and we must further understand that roughness of coat is known to be dominant to smoothness.

We must expect, then (according to Professor Castle), that when a cross is made, the guinea pigs of the first filial generation will, unlike either parent, be black in color and rough as to coat.

But, in the succeeding generation, the black, rough-coated guinea pigs being interbred, there will be a certain number of offspring that combine the dominant characters of blackness and roughness of coat, and will breed true to these; a certain number will be black and rough-coated, but will bear the latent characters of smoothness and whiteness of coat which will reappear in their progeny; and, finally, there will appear individuals combining the two recessive traits of whiteness and smoothness of coat.

These white, smooth-coated individuals are obviously different from their parents, and different also from either of their grandparents. They constitute a new race, sprung into being in a single generation, and a race that will necessarily breed true as to the character of smooth coat and white coat, because they are "homozygous" as to the factors for both these recessive characters.

Their progeny cannot be black because their germ-plasm contains no hereditary factor for blackness; nor can their progeny be rough-coated, because their germ-plasm contains no hereditary factors for rough-coatedness.

Yet side by side with this new fixed race of smooth-coated white guinea pigs, there are, as we have seen, twins of the same fraternity that instead of being white and smooth in color, are black and rough. And these also constitute a new race that will breed true because they contain, as regards the unit character for color and for condition of hair, only the dominant factors of blackness and roughness. They also are "homozygotes," but they are of the opposite type—dominants instead of recessives.

Meantime, we must not overlook the other members of the fraternity, twin brethren of these new races, which are individually black and rough, but which are "heterozygotes" as regards the unit characters under consideration, and hence will show progeny of variously mixed characteristics as to roughness or smoothness of coat, and as to black or white color.

This illustration, perhaps, gives as tangible an impression as can well be gained, of the complexities that confront the experimenter when he attempts to fix a new type of animal or plant.

Even where only two unit characters are involved, the progeny of the second generation, as we have just seen, may break up into numerous races, some fixed and others variable. And, as we have previously pointed out, the complications thus introduced increase at a startling ratio when more characters are under consideration.

Moreover, the matter is rendered increasingly difficult for the plant experimenter by the fact that he must often wait, particularly in the case of orchard fruits, for a term of years before he can know the result of any single breeding experiment. To sort out the pure types from the mixed ones of any given generation under these circumstances becomes a matter of enormous complexity.

It could be done, by inbreeding representatives of the new type and carefully selecting the progeny for a series of generations.

But in the end, all that would have been accomplished, in the case say of a Shasta daisy or of a stoneless plum or a sugar prune, would be the production of seed that could be used to disseminate the new variety. And in most cases we are justified in feeling that this would represent an undue expenditure of time and energy for a comparatively insignificant result.

For, as the case stands, even though the new form will not breed true from seed, it may be propagated indefinitely from roots or from the grafting of cions; so that in practice the failure to breed true from seed has little significance.

Probably it is the fact of the relative unimportance that our cultivated plants should breed true from seed that chiefly explains the failure of plant breeders in the past to fix the type of the best known fruits and vegetables and flowers.

The same reasoning obviously applies to the newly developed varieties. While so much work remains to be done in the way of developing new types of fruit and flower, the most practiced experimenters will probably feel that they have not time and energy to spare for the fixing of the new races already developed.

We shall have occasion to call attention to various exceptions to this rule in the course of our subsequent studies; particularly with reference to certain annual plants. Here by "line" breeding for a few generations we may fix the new traits almost as firmly as the old traits are fixed in wild species. Again we shall learn in due course of new hybrid fruits like the sunberry, the primus berry, and the phenomenal berry that are fixed as to their chief properties from the very first hybrid generation. But as regards most of the new forms of fruit and flower that we have hitherto described, the rule holds with full force.

Label on Tree Graft

This illustrates Mr. Burbank's method of labeling a graft, in order to keep track of his experiments. The label is of wood, and the inscription is made with paint or pencil. The wire attaching the label should of course be loosely applied to avoid restricting the plant.

RECORDING THE EXPERIMENTS

EASY WAYS TO KEEP TRACK OF PROGRESS

EVERY ONE has heard the story of the distinguished professor who devoted his entire life to the study of a particular species of mite, and who, on his deathbed, regretted that he had not confined his attention to the study of the respiratory organs of this insect, instead of trying to comprehend its entire structure.

This specialist, like many another, felt that he had wasted his energy by attempting to cover too wide a field. He felt that his ten volumes or so on the anatomy of the mite could give but superficial treatment of a great subject.

Whoever sympathizes with the attitude of mind revealed by this doubtless apocryphal yet truly symbolic tale, will have scant patience with my method of plant experimentation. For, far from confining attention to a single species, or even to a single genus or order, I have extended my observations to almost every form of plant, testing species by thousands, and individual specimens by hundreds of thousands or millions, in my experimental gardens; and only by exception has complete record been kept of all details of any given series of experiments, beyond the more or less fallacious records of memory.

Yet I have had the good fortune to produce, I suppose, more forms of plant life that could justifiably be called new, than have been produced by any other single experimenter in our time. Had I stopped to make meticulous record of each experiment, I doubt if I should now know more than I do about even my less important products, and I surely should have been able to produce only a fraction of those that I have produced.

Methods and Results

Yet it must not be supposed that I have altogether refrained from graphic recording of the progress of my tests. The fact is quite otherwise. I have kept in the aggregate a vast body of records, and have had them always at hand, under my eye from day to day, telling of the essentials of my hybridizing and other experiments.

My "plan books" have been a constant aid to memory, and guide to further effort.

My record books have set down in black and

Label on Greenhouse "Flat"

In working on a large scale, time-saving is imperative. Mr. Burbank finds this simple method of labeling his "flats" to serve an excellent purpose. The label is easily replaced, or the penciled inscription may be erased, and a new one substituted, when the "flat" is used for another experiment.

white the unequivocal evidence of progress—or of failure to progress. Few salient facts as to the precise parentage of important hybrids and the exact methods by which variation has been brought about have failed to find explicit record, notwithstanding the omission of multitudes of details that to some observers might have seemed worthy of transcription.

And if I have adopted in the field shortcut methods of recording selection, these have not lacked precision and accuracy, notwithstanding their time-saving character.

In point of fact, all along the line I have endeavored to strike a happy medium between the waste of time that would result from the keeping of unduly elaborate records, and the waste of effort that would necessarily result if no records at all were kept.

The reader who would clearly comprehend the nature of the compromise must bear in mind that I have, as a rule, had a practical object in view in conducting my experiments. It is true, as Professor Bailey has courteously said, that I constantly make experiments with plants for the mere love of the work. It is true also that my tests include hundreds of species from which I expect no very definite return. Yet it is further true that the main body of my experiments have been concerned with flowers or fruits that seem to offer opportunities for practical improvement.

I have usually been seeking, in the experiments to which most time has been given, to modify the plant in such a way as to make it a more beautiful and desirable garden ornament, or to modify a vegetable or fruit in such a way as to make it a more valuable food product.

Such being the case, it will be understood that, with regard to large series of experiments, I have been concerned with results rather than with methods. As to the latter, it often happens that numberless experiments might be described in substantially the same terms. Once the principles of hybridization and selection have been clearly mastered, they may be applied to almost every variety of plant life. There are differences in the detail, but the broad outline is the same for each.

Essentials Versus Non-Essentials

It would then be but a waste of time to record over and over details as to these broader outlines of plant experimentation. Where anything of interest has appeared, any point as to which a plant shows differences from its fellows, this has become a matter for recording.

Moreover, it has been my universal custom to make record of the first hybridizing or crossing

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~~New Seedling Peaches Jan 10th 1891~~

Home Gravenstein Tree

Nov 10th 1891

Seedling

American Queen Plum. Exquisite flavor ripe July 25th
seedling of Robinson. two weeks earlier 2 or 3 times larger

Diagram of Tree Grafts

This is a leaf from Mr. Burbank's plan book. It is a sort of shorthand or diagramatical record that condenses a large amount of information into small space, leaving room for additional records should they be called for. Such a page seems cryptic to the casual observer, but to Mr. Burbank himself it is full of meaning.

through which any particular series of experiments is inaugurated. The parentage of the Shasta daisy, the white blackberry, the stoneless plum, the sugar prune, the plumcot, the thornless blackberry, the spineless cactus—these are matters of clearest and most unequivocal record. The results of the first crossing, through which matters of prepotency and of latency are determined, and through which the plant is given the impulse to variation, are also explicitly shown.

But when, particularly in case of a fruit having complex characters, the experiment passes to stages of the third and fourth generations, involving tens of thousands or hundreds of thousands of seedlings, it is no longer possible to make detailed and explicit record, with exact count of the different combinations and variations developed, for two very explicit and sufficient reasons.

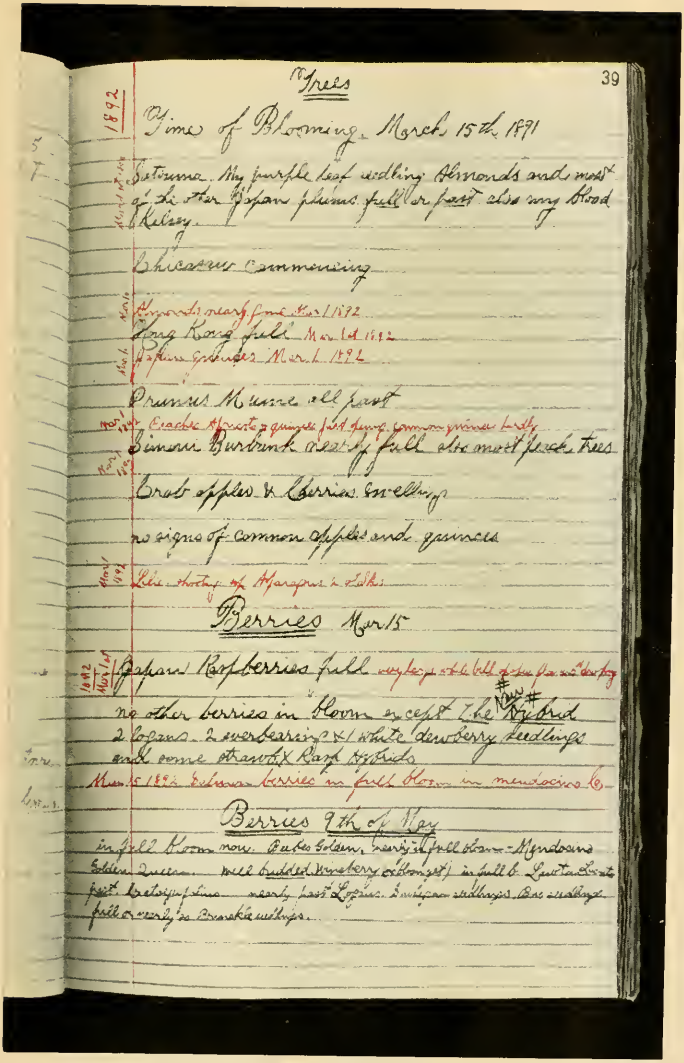
One reason is that the numbers of seedlings involved are so great that it would be physically impossible for any one carrying on hundreds of different series of tests at the same time to make numerical count in accordance with the statistical method adopted by workers who are experimenting on a limited scale.

The second reason is that even if such a count, showing the exact number or percentage of seedlings with different combinations of traits, were attempted, it would be unavailing unless vast companies of seedlings were preserved for the term of years necessary to bring them to fruitage.

When one is concerned solely with numbers, or with such tangible qualities as color of hair in the case of Professor Castle's guinea pigs, or color of feather with Professor Davenport's fowls, it is an easy matter to check results, because the creatures under investigation manifest the qualities that are being tested from the moment of birth, or develop them at a very early age.

But with plants the case is obviously different. Whereas we may judge something as to the character of fruit that a seedling will ultimately bear from observation of the seedling itself, yet for purposes of scientific record such predictions would be considered as worse than worthless. To know what percentage of seedlings of a given generation have really progressed toward the ideal of a sugar prune that will ripen August 1st instead of September 1st, let us say, it would be necessary to let all the seedlings grow for several years, or at the very least to wait two or three years for the grafted cions from each seedling to come to fruitage.

The practical experimenter, seeking results, cannot possibly work in this way when he works on a large scale.



Trees

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1892

Time of Blooming March 15th 1891

Satsuma My purple leaf seedling Almonds and most of the other Japan plums full or past also my Blood Kelsey.

Chicasaw commencing

Almonds nearly gone Mar 1 1892
Hong Kong full Mar 1st 1892
Japan [illegible] Mar 1 1892

Prunus Mume all past

Peaches Apricots & quinces just opening common quinces hardly
Simoni Burbank nearly full also most peach trees

Crab apples & Cherries swelling

no signs of common apples and quinces

Lilac showing of Asparagus [illegible]

Berries Mar 15

Japan Raspberries full [illegible]

no other berries in bloom except the New Hybrid
2 Logans 2 everbearing & 1 white dewberry seedlings
and some Straw & Rasp Hybrids

Mar 15 1892 Salmon berries in full bloom in Mendocino Co.

Berries 9th of May

in full bloom now. Rubus Golden, nearly all full bloom — Mendocino Golden Queen. well budded Wineberry (not bloom yet) in full b. [illegible] just [illegible] nearly past Logans. [illegible] seedlings [illegible] seedlings full or nearly so [illegible] seedlings.

Record of Blooming

Facsimile of another page from Mr. Burbank's record books. This one has to do with the time of blooming of various fruit bearers,—a matter of great importance, because blossom-time is correlative with the time of fruiting, which often has important bearing on the value of a new fruit. It is a little surprising to learn that varieties that bloom early ripen their fruit relatively late, and vice versa.

He must be content to select from among thousands of seedlings the one or five or ten or fifty that appear to him most promising. To these he must pin his faith, and all the rest must be destroyed to make room for other plants.

Otherwise he would require not twenty odd acres, which make up the total area of my experimental farm, but hundreds or even thousands of acres.

And to keep track of the multitudinous seedlings would require the aid not of the half dozen or so assistants whose coöperation makes my experiments possible, but of a small army of equally industrious workers.

Systematic Work Imperative

But, having thus outlined the limitations that necessarily attend work conducted on a large and comprehensive scale, let me now proceed to elaborate somewhat the other side of the story.

Let me outline the various practical methods of recording experiments that have been developed in the course of my years of experience. Let me in particular point out some of the shortcuts that have made it possible for me to record the essentials, and even in important cases the details, of progress, with a minimum expenditure of time and labor.

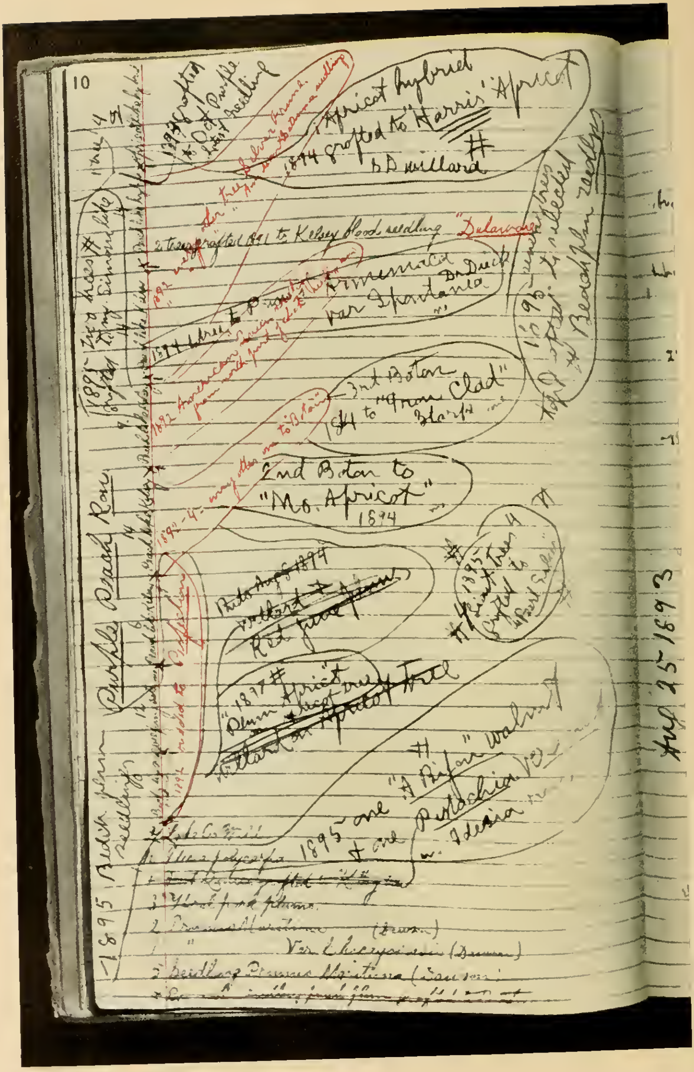
Among the essentials that cannot be overlooked by any systematic and successful experimenter are the following:

A general plan of the ground occupied by all the experiments must be made, and there must be clear record of each plant, shrub, or tree planted. It is important also to record the time when each one was grafted or budded; the date of all experiments in crossing any particular tree or plant; observations as to any anomalies of development; and finally, as a matter of course, the results obtained.

As to these things, the memory, no matter how tenacious, must prove more or less untrustworthy. It is only the black and white record that can be depended upon. But plans may be outlined so simply that all these essentials may be recorded at the expense of very little time or labor.

It is not much trouble, for example, to keep a plan book at hand, each page of which is devoted to a certain planting, its location on the grounds, and all other matters that are worthy of record. It will facilitate matters in such a book to have the records of planting arranged somewhat in the order in which the plantings have occurred during the season.

If these records are made on large sheets of paper so plotted as to show the location of the various beds of plants, this will be an added



Grafting Record

Yet another page of Mr. Burbank's record books, this one dealing with grafting. It will be seen that the records of different years are associated, and it will be obvious that the records were intended for Mr. Burbank's own eye, to supplement the records of memory. When thousands of experiments are being performed simultaneously, it is imperative that the recording should be done with the least possible loss of time.

convenience, as it will enable any particular lot of plants to be located, even if through some inadvertence the label stakes, which are an absolute necessity, have been removed or lost by careless workmen.

Often when planting in the field, letters or numbers are used on the stakes, corresponding with similar letters or numbers in the record book.

LABEL STAKES AND LABELS

As to the label stakes themselves, the ones that I habitually use for general field culture are about 20 inches long, 2 inches wide, and ¾ of an inch in thickness. They are smoothly planed and painted about half way down on both sides with common white lead paint.

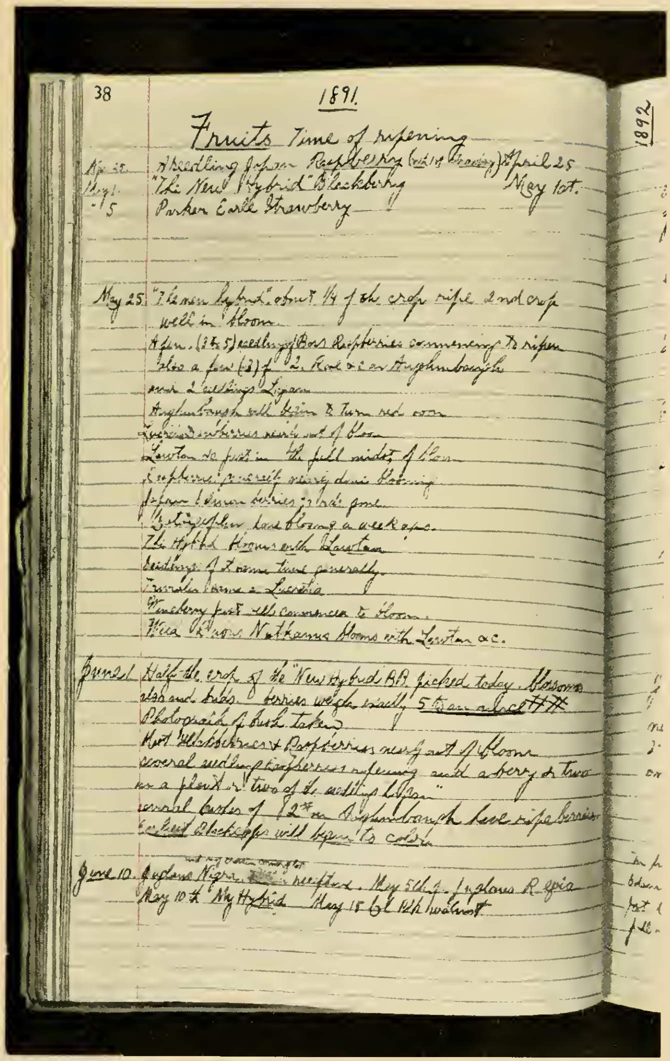
One coat of paint is far better than two, for if a pencil is used the lightly painted surface takes the lead to advantage, and by bearing down heavily with the pencil, indentations are made in the wood that will resist the weather more effectually and thus give greater permanence to the record.

It is desirable to make the label stakes of soft, smooth redwood or other durable wood. In the East the locust is an excellent substitute. It is advantageous to dip the end of the stake in carbolic acid or in a solution of sulphate of copper to prevent decay. These stakes may be used over and over again for many years, being planed off as the occasion requires and repainted.

Many thousands of these label stakes are used each season on my experimental grounds. For smaller beds I use a stake usually 1 inch wide, from ⅛ to ¼ of an inch thick, and from 10 to 14 inches in length. These smaller plant stakes may be purchased of dealers, and are prepared for use in the same way as the larger ones.

For use on trees a special label is employed, to make records of budding, grafting, and variation. This label is usually 5 or 6 inches long, and from 3-16 to ¼ of an inch thick. It is notched at one end and attached to the branch of a tree with a piece of pliable galvanized iron wire. The wire should be loose enough to avoid any danger of strangling the branch.

The labels are painted with white lead. They sometimes remain upon the trees for five, ten or even fifteen years. To inscribe these permanent labels, I use a thick black paint, composed of a mixture of lamp black, linseed oil, and a little turpentine, applying the mixture with a small camel's hair brush. The names of varieties, the parentage, and other important matters are thus recorded. Then, while the paint is still wet, some fine dry sand is sifted over the label so as to protect the paint from the weather.



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1891.

Fruits Time of ripening

Ap. 25 Seedling Japan Raspberry [illegible] April 25
May 1. "The New Hybrid" Blackberry May 1st.
" 5 Parker Earle Strawberry "

May 25 "The new hybrid" about 1/4 of the crop ripe 2nd crop well in bloom

June 21 Half the crop of the "New Hybrid BB" picked today. Blossoms [illegible]
Photograph of bush taken

June 10. Juglans Nigra [illegible] May 5th. Juglans Regia
May 10th [illegible] Hybrid May 15 [illegible] walnut

1892

Ripening Record

This may be regarded as a companion record to the one shown on page 257. It records the highly important matter of the time of ripening of various fruits. This particular page shows among other things that a seedling Japan raspberry ripened April 25th, and a new hybrid blackberry May 1st. Some of Mr. Burbank's finest new fruits, including the Burbank cherry and the Sugar prune are made doubly valuable by the fact that they ripen several weeks earlier than similar fruits of other varieties. Mr. Burbank is constantly encouraging fruits, by selective breeding, to modify or lengthen their season of fruiting.

In addition to the labels and stakes I have just described, a small cardboard label of light weight is needed for making record of the hybridizing experiments. The common cardboard shipping tag about 1½ inches by 3 inches in size with a reinforced eyelet hole, is generally used on plants with tender stems; and where the wind is likely to disturb larger labels, half or two-thirds of the cardboard may be cut off, leaving barely space to inscribe the record.

Where these tags are used in extensive pollenations of many varieties on a single tree, it is not always necessary to write the record, for the same object may be accomplished by cutting off one corner of the card to indicate a certain variety of pollen, and a second corner to indicate another variety; additional varieties being represented by series of notches. Or the same end may be attained by punching holes in the card with a pocket steel punch. This plan saves much time, and the record is more permanent than if it were made with pencil. A large number of tags may be prepared at once with punch or scissors.

Tags of this character are less likely to have their records erased by wasps and hornets, which often partially destroy labels when securing material for their paper homes.

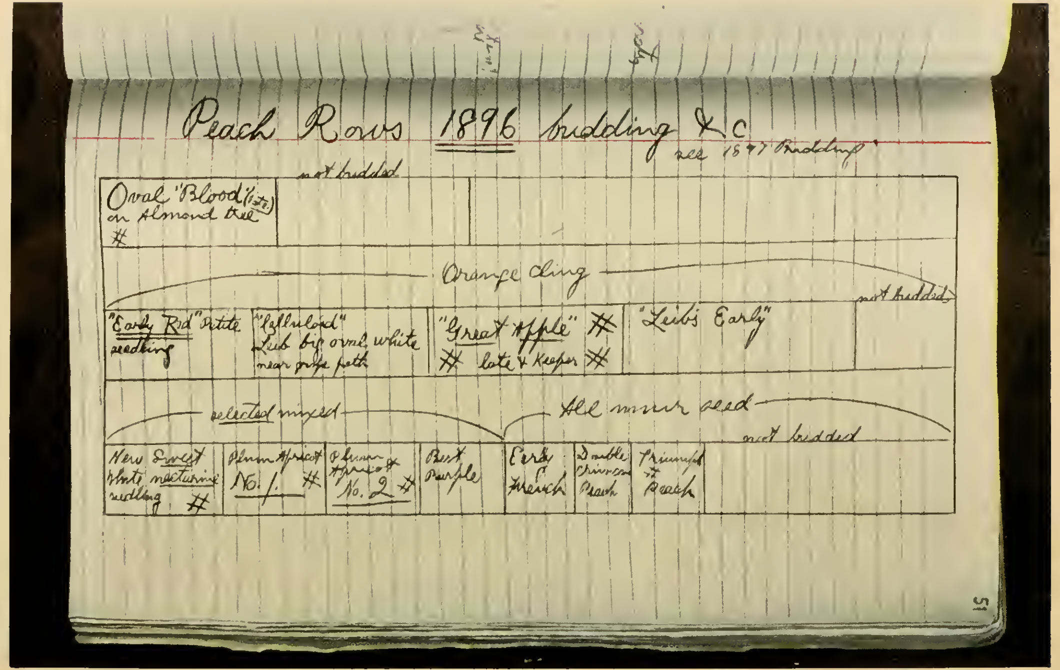
Conspicuous tags such as these are also of aid later in the season when the seed is to be gathered; because they make known at a glance the facts as to parentage, and make it possible to keep separate the seeds of different varieties. The labels are tied to the plants with common twine, as wire or other hard substances would be likely to injure the tender stems when the wind moves the tags about.

When numerous varieties of plants are grown in a single bed, we often nail a common tree label opposite each row on the board that borders the bed, instead of using a stake, as there is less danger of the label being displaced. It will be advantageous to place this label at the side of the bed away from that from which the prevailing winds and storms come. In this section of California the summer winds and winter storms come from the South, East, and Southwest, and in conjunction with the hot sunshine, they are very destructive to paint. So it is advantageous to face the labels toward the North.

All of these are matters of minor detail, yet not without their importance.

Recording Results

In making selection of individual plants that are to be preserved, or from which seed is to be gathered, the most convenient, and at the same time the most accurate method is the simple one



Peach Rows 1896 budding &c

see 1897 budding

not budded

Oval 'Blood' (1 tr.)
on Almond tree
#

Orange cling

not budded

"Early Red" petite
seedling

"Celluloid"
Leib big oval white
near grape path

"Great Apple" #
late & keeper

"Leib's Early"

selected mixed

All minor seed

not budded

New Sweet
White nectarine
seedling #

Plum Apricot
No. 1. #

Plum Apricot #
No. 2 #

Best
Purple

Early C
French

Double
Crimson
Peach

Triumph
x
Peach

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Budding Records

It has sometimes been supposed that Mr. Burbank depends entirely on his memory, and makes very few written records of his experiments. This facsimile page, taken in connection with the others that have just been shown, will serve to dispel that erroneous notion. It will be seen that records are kept of the essentials of each different type of experiment, including not only methods, but results. In point of fact, although Mr. Burbank adopts many shortcuts, his records of essentials are surprisingly comprehensive and complete, considering the enormous range of his experiments.

of tying a small strip of cloth about the stem of the plant.

Visitors to my gardens are sure to notice that each bed of flowers has a half dozen or so plants that are thus decorated. In some cases two or three strings may be attached to a single plant, indicating degrees of excellence. Selection having been made in this way, the plants may be allowed to ripen their seeds, and in due course the workmen may gather them without further direction, placing them in labeled boxes to be stored for the winter.

As regards new fruits, there is particular need of great accuracy, and here it is impossible to avoid a good deal of detail. It will not do at all, in dealing with a valuable addition to the list of fruits, to leave anything to memory as to its season of ripening, size and form, color, flavor, aroma, size of core or stone, length of stem, or any other essential quality.

An exact record must be kept of these items, and for this purpose a book with removable unruled leaves is the most satisfactory.

The fruit should be cut in half with a sharp knife. The incised surface may then be placed directly on the paper, and the outline of the fruit traced with pencil. The specimen may similarly be outlined in cross-section. This preserves a

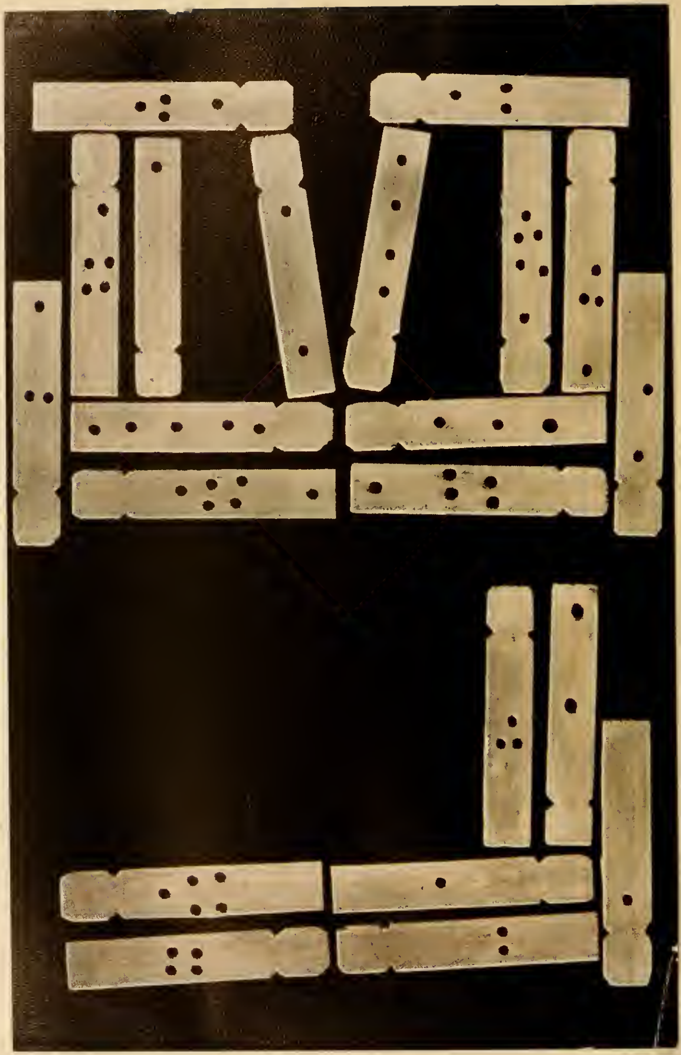
Stakes to Mark Divisions of a Verbena Bed

Here penciled records are kept in the field, on stakes from which Mr. Burbank can tell at a glance the antecedents of the particular varieties of plants he is dealing with. Here there are seeds of many varieties sown in a single bed, but the label-stakes serve as an immediate guide to all of them.

graphic record of the exact size and form of the fruit. The main character of the inside of each fruit may be indicated, and by adding the date of ripening, the time of its earliest and medium ripening, the number of days it will remain in good condition upon the tree, its keeping quality when packed for shipment, and its susceptibility to the ravages of insect pests and fungoid disease, we have on a single sheet a fairly complete and very valuable record, together with a graphic representative of the size and form of the fruit itself.

Record will be made in the same way in successive seasons of fruit from the same tree, with additional record of the appearance of any new characters or qualities. Comparison of the records will show whether the fruit on the young trees has increased in size, improved in quality, or varied in time of ripening from year to year. Not unfrequently the record of the third year shows a very considerable increase of good qualities over the first.

After a record has been kept for four or five seasons, a fair estimate may be made of the general value of this particular fruit. If in addition we know the characteristics of the parent forms—whether the ancestors were hardy or tender, and the like—we are now in position to form a clear judgment as to the probable value of the fruit.



Punched Labels

These labels are important time-savers. Each set of holes represents a specific plant or a different type of experiment, the key to the labels being found in the record books. The upper left hand label here shown might indicate, for example, that the branch on which it is tied bears blossoms of the Sugar prune (one hole at base of label), fertilized by pollen of the Conquest stoneless prune (three holes at center of label). Such labels as this are loosely attached to the stem of the plant that has been pollenized or grafted. They are permanent, and they minimize mistakes.

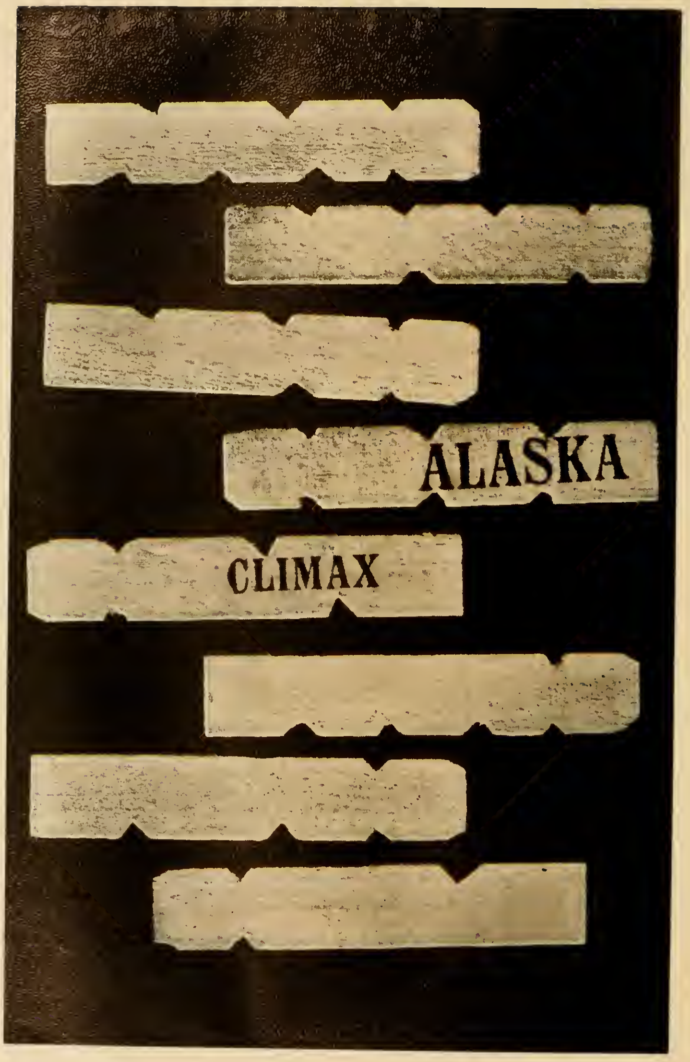
Such a record as this is essential to actual progress. It is important, if for no other reason, to prevent the experimenter from deceiving himself. It is very easy to imagine that a certain product that has caused one much trouble is better than some other; or that a fruit of a given tree is larger than some rival variety. But the record book enables one to put the matter to a precise and definite test; it makes self-deception impossible; and it affords an invaluable guide to further experimentation.

There are thousands of graphic records such as these on the shelves of my library.

I would not think of attempting to conduct an intricate series of experiments looking to the development of a new fruit without the aid of these plan books.

When the experiment is finally completed, a series of these loose leaves, properly collated, furnishes a complete record of the various hybridizings and selections—resulting sometimes in better and sometimes in worse fruits—through which success has finally been achieved. These records are in themselves sufficient answer to any one who imagines that the plant experimenter works haphazard, merely because he does not always adopt a biometric method.

After all, from the standpoint of the consumer



Notched Labels

This is another type of short-hand label similar in its use and interpretation to the ones shown on page 270. Each series of notches tells a different story, and the key to their interpretation is found in the record books. Two notches, for example, might represent the Alaska daisy and three notches the variety named Westralia. The top label above would then record the hybridizing of these two varieties. (The small notches for the string are not counted.) Mr. Burbank finds this method of keeping track of experiments highly satisfactory.

who makes up the main bulk of the population, and whose tastes and needs are the criterion by which the plant experimenter's results will be judged, it is the final product rather than the precise method by which it is attained that is important. But the ideal at which the plant experimenter aims would probably never have been realized had he not given himself the aid of some such system of quick and accurate records as my plan books present.

—Once the principles of hybridization and selection have been clearly mastered, they may be applied to almost every variety of plant life. There are differences in detail, but the broad outline is the same for each.

Variation in Corn Seed

Mr. Burbank finds material for most of his experiments in variations as to one quality or another that appear among plants of the same species. It may or may not be necessary to accentuate variation by hybridizing experiments. The range of variation that may be shown in the seed of a single species is illustrated in this lot of kernels of corn, which show surprising diversity in shape, size, and color. Numberless new varieties could be developed through selective breeding from such a lot of seed as this.

FINAL SELECTION

THE MOST IMPORTANT TASK OF ALL

IN FARMING districts of the Mississippi Valley they have a curious custom in selling cattle at auction. They drive a herd of cows together and the auctioneer asks his audience to bid for first choice, no individual animal being specified.

The highest bidder makes his choice, and the cow he selects is taken from the herd.

Then the auctioneer starts over, receiving bids for "first choice" among the remaining animals. This process is repeated again and again until all the exceptional animals have been selected.

A curious result of the method is that it very commonly happens that different bidders have their eyes on different animals. Farmer A, who bid highest at the outset, did not have in mind the animal for which farmer B was bidding. And so it often happens that after six or eight selections have been made a cow still remains that was regarded by some of the bidders as the very best one of the entire herd.

A man who bid unsuccessfully again and again may thus, in some cases, finally have his choice precisely as if he had made the highest bid at the outset.

The obvious explanation both of the method and of its somewhat anomalous results is found in the fact that individuals differ in their judgment as to what constitute the superior qualities of a cow. Each bidder has noted an animal that particularly appeals to him, and each is backing his own judgment in making selection. The result is a process of elimination that may or may not select from the herd the best animals at the very outset.

"But what have cows and their selection to do with the development of new varieties of plants?" you ask.

Nothing direct and obvious to be sure. But it has often occurred to me that the process of selection at the Iowa auctions is closely comparable to that which is employed by the plant experimenter in the course of his every-day work. In lieu of a herd of cattle, he deals with a group of seedlings. But his task is precisely like that of the auction bidder in that he must select from among scores of plants of the same kind, and often of closely

Chilian Beans

This lot of beans affords another striking instance of the wide range of variation among the seeds of individual plants of the same species. It may be assumed that these widely divergent seeds represent various heredities. Each plant is, in point of fact, a mosaic of characteristics inherited from many lines of ancestry. In Mr. Burbank's phrase, heredity is the sum of past environments. A curious and important feature of the matter is that the different racial strains may be segregated, as illustrated in this lot of beans.

similar appearance, the one that seems to him the choice of the entire lot; and then in succession the second and third and fourth best, until he has chosen possibly six or eight individuals out of a group of hundreds or thousands.

These six or eight individuals will be preserved for use in further experiments. They are the ones with which the attempt to improve the variety to which they belong will be carried out.

And the ultimate success of the entire experiment in plant breeding will very largely be determined by the perspicacity with which the selection of these few individuals was made. Nor can we doubt that it must often happen, in the case of the seedlings as in that of the cattle, that after the final selection has been made there remain, unknown to the experimenter and in contravention of his judgment, better plants among those rejected than any one that he has chosen.

It could not be otherwise when we consider the large numbers involved, the variety of plant characteristics, and the great diversity of traits represented in a single generation of hybridized seedlings. Yet, on the other hand, experience should enable the experimenter to choose with a relative degree of certainty, and it is possible to acquire a degree of skill, based on careful observation of the minute details of plant structure, that will give full assurance of a capacity to select with at least a large measure of success.

A Half Hour in the Orchard

It is usually a surprise to any visitor who comes to my orchard at a time when I am making selections among seedlings of many kinds to observe my method.

Many people have expressed astonishment when they have seen me walk rapidly along a row of plum trees saying: "Kill this one, and that one, and that; save this one, and that one yonder"; indicating the choice between plants to be saved and those to be destroyed so rapidly that the men following me can scarcely tie strings to the selected ones as fast as they are chosen.

In this way I may test from five to ten thousand young trees as I walk along the row, scarcely pausing for more than what seems the most casual glance. But my eye takes in the important thing. I know just what I am looking for. And if my judgment in the matter had not proved in the main good, the output from my orchard would have been quite different from what it has been.

I may recall by way of illustration an experience in which my selective judgment was put to a practical test—no different a test, to be sure, from thousands that I myself have made, but having added interest because it was made by another.

It chanced that a well known judge, who is also a horticultural enthusiast, who had been very much interested in my work, was visiting me at a time when I was sorting out plum trees from among a lot of several thousand seedlings about a foot high. I had a man carrying them away as fast as selected. They were thrown in three piles, the first containing those I had declared to be the best ones for continuing the test; the second pile containing those I thought possibly worth trying; and the third pile those that seemed to me no good at all.

The judge watched me for a few minutes and then said: "You are picking them altogether too fast. You cannot possibly tell like that which are good and which are not."

I replied: "Wait and see, or test the matter for yourself if you wish."

"Very well," said my visitor, "I will do so."

And therewith he selected a few seedlings from each of the piles and took them home with him to graft on trees of his own.

Of course it was necessary to wait two or three years for results. But when the time came, the judge very cheerfully admitted that I had been quite right all along the line. The cions from my discarded pile bore fruit that was almost worthless; those from the intermediate pile gave

Pear Seedlings

These plants illustrate the difference between seedlings from the same lot of seed, raised under exactly the same conditions. The plant in the middle is of relatively dwarfed growth, and Mr. Burbank's experience shows that the difference of growth manifested at this early stage would be maintained throughout the life of the plants. This gives a clew to the selection of seedlings at a very early stage.

fairly good fruit; and from the pile of my first choice seedlings he secured a fruit of such quality that he named it the Klondike, declaring that it gave him more good plums than he had ever had before from a similar tree.

I cite the incident as showing the possibility of gauging fruiting qualities of a seedling at a time when the plant itself is a mere sapling a few inches in height. The capacity to make such selection has sometimes been spoken of as intuition; but it is really a matter of observation and practice. One learns through long experience to judge what characteristics of the seedlings are suggestive of possibilities of fruit-bearing.

And after all this is no more than judging the man of the future by observation of the child of to-day.

The Correlation of Parts

If we were to state the matter a little more technically we might say that such selective judgment as I have just illustrated is based on a knowledge of the correlation between the different parts or members of a plant's organization.

It was first prominently brought out, I believe, by the French naturalist Cuvier something over a hundred years ago that there is always a correlation between the different structures of a given animal, to accord with its habits of life.

For instance the teeth and claws of a cat are associated with its carnivorous habits and are linked with a certain structure of legs and muscles adapting the creature to spring forward with great celerity upon its prey.

A somewhat different structure of body and limb is associated with the talonless feet of the dog tribe which are adapted to rapid running for prolonged periods rather than to sudden leaping and clutching.

It was by careful study of the correlation of parts, of which these are only crude and familiar examples, that Cuvier was enabled to gain an insight into the characteristics of fossil animals of which only small fragments of skeletons were preserved in the rocks. The science of comparative anatomy was the outgrowth of his observations.

Now it is at once obvious to anyone who studies plants attentively that their structure also shows a corresponding and no less invariable correlation of parts. The more conspicuous illustrations of this are obvious to the most casual observer—various adaptations of form of tree and shrub and vine to their natural surroundings are so patent that they cannot escape attention.

But of course the plant experimenter must deal with correlations of a very delicate order. He

Mr. Burbank Selecting Cactus Seedlings

The selection of cactus seedlings, in the course of his experiments leading to the development of the Spineless Cactus, was one of the most arduous tasks that Mr. Burbank ever performed. His hands were never free from prickles for months together, and the pain he suffered was almost intolerable. But ultimate success compensated for the disagreeable experience.

is called upon to make nice distinctions between individual seedlings of the same variety. All will have the same general formation of stem and leaf. He must look, then, for details of variation that would altogether escape the notice of the untrained observer. But that such differences exist, and that they are signs that to the practiced eye are of the utmost importance, any successful plant experimenter can testify.

It would obviously be futile to attempt a detailed description of the nice shades of distinction between various seedlings of the same race upon which the plant experimenter depends in forming his selective judgments. That, clearly, must be matter for practical observation. It can be learned nowhere but in the field. But perhaps two or three illustrations may be given that will at least serve in a general way to suggest what manner of traits are taken into consideration when the plant experimenter is choosing the individuals with which he is to continue his experiment.

A Few Practical Hints

In selecting raspberry or blackberry plants for color of fruit, for example, there is almost always a correlation of the plant and fruit that will foretell the future crop.

I have observed in thousands of instances that vines that have purple spines and canes will in future produce berries that are dark purple or dark red in color. Pinkish leaves, on the other hand, foretell fruit of light pink or red color; plants with yellowish vines and foliage may be expected to produce berries of a yellowish color. Very pale foliage and canes usually indicate that the crop will be of a whitish or amber color.

A knowledge of this correlation between vine and fruit was of great service to me in my later experiments for the development of the race of white blackberries. It enabled me to select for transplantation and particular care vines that would produce the type of berry I was seeking. It was not necessary to await the time of fruiting in order to gauge progress.

The correlation of characters between the vine and the fruit of the grape is not always quite so clearly established, yet it is often observable. Grape tentacles may give clear indication of the size and flavor of the future bunches of fruit. Long before a grape vine has come to the age of fruiting, the taste of the tendrils may give a fair idea of the flavor of the grapes it will ultimately bear.

Moreover the seedling vines that produce bushy stems that are small and much branched, and have small leaves, will almost invariably produce meager clusters of small fruit of poor quality. So the wise experimenter will root out such vines without letting them come to maturity.

Among plums and peaches the correlation of characters is exceedingly valuable.

The case of the plum seedlings already cited suggests the possibility of pre-judgment of fruit from observation of small seedlings. There are a good many characters of leaf and twig that are almost too intangible for description, like the changing expressions of the human face, or like delicately graded colors, yet which to the practiced eye are full of meaning.

Color of Foliage a Guide

A broad general distinction that is fairly obvious to any observer is found in the color of the foliage. It may be expected that a plum or peach seedling having foliage of a reddish purple color will produce fruit dark-colored not only in skin but in flesh. And of course the selection made from any given lot of seedlings will depend largely upon the particular qualities that one desires to develop.

But, as repeatedly pointed out, in practical work one is usually looking for a combination of qualities; and, by the same token, one usually inspects his seedlings for the combination of characteristics of stem and leaf and color. He

Strawberry Bed
Before Selection

Here Mr. Burbank raises a profusion of seedlings, as is his custom, to give opportunity for the development of new varieties. Ultimately he makes careful inspection, and selects the individuals that are best fitted to carry forward the experiment.

seldom has his choice determined by a single characteristic, obvious or otherwise.

SELECTING FOR A SINGLE CHARACTER

Yet there are cases where an experimenter is working with a single plant-characteristic in view, as, for example, when I successfully attempted to develop scented callas and dahlias and verbenas.

Here, obviously, the task of selection is comparatively simple. We are dealing in each case with a flower that has certain desired qualities of color that are firmly fixed in its heredity. The one conspicuous point of variation among thousands of specimens is the presence or absence of a pleasing aroma.

It is necessary, then, merely to select the individual plants that have the most pleasing perfume and to use these only for carrying on the experiment. By making such selection generation after generation, choosing always the sweet-scented and rejecting the others, it proves possible to accentuate and fix the quality of perfume-production without altering the other characteristics of the respective flowers in question.

Again the quality sought may be a particular color of blossom, and it may be desirable to pay attention to this only, practically disregarding all other qualities. Such, for example, was the case with my experiments with the crimson

Eschscholtzia, commonly known as the California poppy.

The blossoms of the plant from which my new type of poppy was developed, had a narrow strip of crimson on the inner side of one petal.

This was an anomaly that appeared "spontaneously." Doubtless it was due to some crossing of ancestral strains that brought out a latent character that had long been suppressed. But as to this we can only surmise. The simple fact of the matter was that a blossom did appear that had this narrow strip of crimson on one petal. I seized on this individual blossom as offering material for an experiment in color variation.

Seeds from this plant produced the next year several plants that had a trifle more crimson on their blossoms.

The following year there was still further improvement, as plants appeared that showed a much larger invasion of the flower petals by the crimson coloring. And by selecting year after year blossoms that showed this increasing tendency to adopt the new color, I produced presently a plant that bore blossoms of a beautiful uniform clear crimson. No trace of the original color remained.

This furnishes a very good illustration of selection for color where the material consisted

A Standard Strawberry

These are strawberries picked from the bed shown on page 288, as having qualities of leaf and blossom and fruit (the latter not yet ripened) that would serve as standards in selecting plants for preservation. The result of the selection is shown on page 294.

of a small strip of an unusual color appearing on blossoms otherwise of a fixed hue.

But the same method of selection may sometimes be applied to the improvement of the shade of color, or even to the development of a new color, from a flower that shows only a faint departure in shade from the normal. And the same principle of selection, followed out in precisely the same manner, applies to the development of flowers or fruits of varying size, of larger or smaller stem, abundance of blossom, profusion of leaf or flower or fruit, and the like.

It is equally possible to alter the proportions of the chemical constituents of a plant in certain instances.

The case of my sugar prunes, which were developed to have a sugar content of more than 23 per cent. as against the 15 per cent. of their ancestral type, will be recalled. In a similar way the sugar beet has by mere selection been developed until the races now cultivated contain several times the proportion of sugar of the ancestral beets even of twenty years ago.

An interesting experiment in causing the progeny of a certain plant to vary in opposite directions through selection, has been made at the Illinois Agricultural Station. Here the quality under consideration was the protein content—that is to say the amount of nitrogeneous matter—in the kernels of a given variety of corn.

The specimen with which the experiment started showed on analysis 10.92 per cent. of protein. Selection was made, among the ears of corn grown from this seed, of the individual specimens having the highest protein content on one hand, and those having the lowest protein content on the other.

By continuing this double selection for ten generations, two races of corn were developed, one of which produced seed having an average protein content of 14.26 per cent., while the other, grown in the same field, showed a decrease to 8.64 per cent.

This experiment illustrates the possibility of selecting out and fixing new races varying widely as to a single important quality of grain among the descendants of a parent plant of relatively fixed strain. In point of fact no plant is so fixed that its individual members do not show variation; none so fixed that it does not supply material with which the experimenter may work in producing new varieties.

Another illustration of the same thing was given by an allied series of experiments at the Illinois Station at which selection was made with reference to the height of the ear on the corn

Strawberry Bed After Selection

This is the strawberry bed shown on page 288, after selection has been made according to the standards illustrated on page 291, and the unsuitable plants weeded out. The fruit that grows on the comparatively few selected vines will be carefully preserved to carry forward the experiment. The blossoms may be hybridized with other varieties to secure variation, or it may be necessary only to select the best among the seedlings, without further experiments in cross-fertilizing. This typical experiment illustrates the survival of the fittest under conditions of artificial selection.

stalk. Seed from the same cob was planted in two fields and grown always under closely similar conditions.

But in one field selection was made for breeding purposes from stalks having the ears higher from the ground than the average; and in the other field from ears that were lower than the average. At the end of five years the two fields were so widely diversified that the average height of the ear from the ground in one of them was less than three feet (33.2 inches), whereas in the other field the average height of the ears was fully six feet (72.4 inches).

One could not well ask a more striking illustration than this of the possibility of developing new races, differing as to some conspicuous character, by simple selection from a given stock.

The case of my winter rhubarb, which came to have a relatively gigantic stalk, will be recalled as of similar import; although in that case the experiment was complicated by having to bear in mind various other qualities in addition to mere size of stalk. My giant corn and the corn with the rainbow-striped leaves are other examples.

Some Alarming Figures

But, as repeatedly pointed out, the experiment usually is complicated by the necessity for considering more qualities than one whenever selection is made with an eye to the production of a commercially valuable variety of flower or fruit or vegetable, and not merely for the purpose of scientific record.

We have seen this illustrated again and again; and we have seen also how great are the complications which result when we are called upon to make a selection that will give us not merely one quality—merely size or a given color or sugar content—but a combination of six or eight or ten qualities, all presented in superlative measure.

We have seen that the chance of securing any given combination of qualities decreases at a startling geometrical ratio in proportion as the number of qualities increase.

The precise formula, as calculated by the biometricians, runs something like this. In case a single pair of qualities is in question—say high protein content versus low protein content in corn—the chances are, if the two strains are crossed, that there will appear in the second generation of their progeny one offspring in four that closely resembles each parent.

But when we are considering two qualities—say protein content and height of ear on the stalk—in combination, the chance that there will be an individual of the offspring like each parent in the progeny of the second generation, is only one in 16.

And when three qualities are in question the ratio jumps to one in 64; with four qualities it advances to one in 256; with five qualities, to one in 1026. When eight qualities are in question, the chance of producing one offspring showing precisely the combination of qualities of each parent is only one in 98,496.

And when we deal with ten qualities we encounter the altogether disconcerting ratio of one to 1,575,936!

All of which makes it very clear that the wise plant experimenter does not depend upon mere chance to give him the combination of desired qualities in the production of a new form of flower or fruit. He must make his selection, in any given generation, with reference to one or two pre-eminently desirable qualities, and must be content to accept for the moment such other qualities, however undesirable, as are associated with the desired ones.

Multiple Selection

For example, in developing a stoneless plum, my earliest selections were made with an eye to stonelessness alone.

Then as I gradually developed a race of plums in which I was certain of finding a fairly large

Inferior Plum Seedling

This seedling should be compared with the ones shown on pages 300 and 302. It will be seen that the one here shown is only about ten inches high, and that it branches irregularly, and has a curved stalk, forecasting a tree of small size and poor formation. The leaves also are small in size and of inferior quality.

proportion of individuals growing stoneless fruit, I could select among these the ones that combined with stonelessness the largest proportion of other good qualities, such as size and color and flavor and abundant bearing.

When presently I had, through selection, developed a somewhat fixed strain that combined the qualities of stonelessness with fair size and good flavor, I could then select among the many individuals showing these qualities the particular ones that showed them in fullest measure; and at the same time I could now have in mind one or two other qualities—say color of fruit and keeping quality—and be guided in my selection by a consideration of these traits in addition to the others that had already been fairly fixed.

Thus the matter of selection, even when many qualities are to be combined in the ultimate product, is not quite so hopelessly complex as the calculations of the biometricians might lead one to suppose. Yet it is assuredly complex enough to test the patience and the ingenuity of the experimenter to the last degree.

So the amateur who enters this fascinating field will do well to begin with simple cases, paying heed to a single quality of any flower or fruit with which he experiments; endeavoring to advance along one line till he acquires skill

Fairly Good Plum Seedlings

These seedlings are intermediate in quality between the one shown on page 298 and that on page 302. They are about eighteen inches tall, and the better one is of upright growth with large well-formed leaves. But it has a rather scant equipment of branches.

enough through practice to attempt more complex experiments.

Let him, for example, increase the perfume of some familiar garden plant, or develop a race having large blossoms, or one having peculiar brilliancy of color.

Any flower bed will show him, among different specimens of the same species, enough of variation to furnish material for his first selection. And he is almost sure to find encouragement through discovery, among the plants grown from this seed, of some that will show the particular quality he has in mind in a more pronounced degree than did the parent plant.

So here he will have material for further selection, and step by step he can progress in successive seasons, often more rapidly than he had dared to hope, toward the production of the new variety at which he aims.

Of course the time will presently come when the amateur who thus begins with what may be called the alphabet of plant experimentation, will wish to advance to more complicated projects. He will wish to urge his plants along a little more rapidly on the path of variation by means of hybridization.

But even here, as will be obvious on a moment's reflection, the experimenter is still dealing with

Perfect Plum Seedling

This seedling contrasts markedly with the one on page 298 and considerably with those on page 300. It is nearly two feet tall; its stalk is relatively thick, and absolutely perpendicular; it has a fine spread of symmetrically arranged branches; and its leaves (shown in smaller scale than the others because of the larger size of the tree) are of perfect shape and of fine color and texture. This seedling may be depended on to make a tree far superior to those shown in the other illustrations. Mr. Burbank confidently selects this seedling as the future bearer of valuable fruit.

selection. For of course he will not make his hybridizing tests at random, but will select for his parent stock individuals that manifest in pronounced degree the qualities that he wishes to combine in his projected new race.

So when we pass from the stage of simple selection of "spontaneous" variations, to the stage of inducing variations along given lines by cross-breeding, we are not abandoning selection but are only dealing with selection in its more complicated aspects.

Rightly understood, then, it is not too much to say that the entire task of the plant developer is a matter of selection. First, he may select varieties as nature presents them to him. Second, he may through selective breeding improve these varieties. Next he selects among these and makes combinations for further variations; and then he is ready for a new series of selections. So from first to last it is only the same story presented in different aspects.

How important a part does selection play in the life about us! Whether it be in animal or human life, whether it be the selection of materials for a nest, an appropriate club or stone to lay low an enemy, the selection of materials for a dynamo or a pyramid, or of words to convey certain thoughts, aspirations or emotions; but selection alone from among all the materials supplied by nature no matter how skillfully carried out can never produce the artist's ideal in pigments or marble, the architect's vision of a great structure for the shelter of thousands—universal standards of excellence—unless their production is accomplished by means other than metrical and statistical!

The beginning is selection and the end is selection.

[End of Volume III]

LIST OF DIRECT COLOR PHOTOGRAPH PRINTS IN VOLUME III

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Artichoke

Balloon Berry

Bean

Budding

Cactus

Chestnut

Corn

Dandelion

Germination

Gourd

Grafting

Grape

Hybridization

Labels and Records

Marigold

Peach

Pear

Plum

Pollenizing

Poppy

Pumpkin

Rose

Seedlings

Squash

Strawberry

Transplanting

Variation

Verbena